Reef Habitats in the Middle Atlantic Bight: Abundance, Distribution, Associated Biological Communities, and Fishery Resource Use

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Introduction

Spatial distribution and perhaps the abundance of fishery resources are influenced by physical and other habitat factors. The identification of significant marine habitats and strong or critical associations between living marine resources (LMR's) and these habitats can lead to a better understanding of how environmental influences affect LMR's and fisheries and support their management (NMFS, 1999a).

The Middle Atlantic Bight (the area of the U.S. east coast and continental shelf between Cape Cod, Mass., and Cape Hatteras, N.C.) hereafter referred to as the Bight, is characterized as being a homogeneous habitat of relatively flat topography, composed of soft sediments, mostly sands, but grading to silt-clay in deeper areas (Stumf and Biggs, 1988; Poppe et al., 1994). Except for relic sand and gravel ridges, exposed Holocene to Pleistocene clay or sandstone in some areas (Allen et al., 1969; Wigley and Theroux, 1981; Stumf and Biggs, 1988; Poppe et al., 1994; NOAA National Data Center-NGDC, 1999), and glacially exposed rock along the southern New England coast, this habitat characterization of the Bight was basically true until European colonization.

Within the last two centuries there has been an increase in hard bottom or reef ("reef" is used hereafter to refer to this multi-dimensional, hard-substrate, structural habitat) habitats in the Bight, which is not commonly recognized by marine geologists and resource managers, e.g. shipwrecks, lost cargos, disposed solid materials, shoreline jetties and groins, submerged pipelines, cables, artificial reefs, and similar objects or material placed in the marine environment by the human population. Some of these human additions are considered objectionable "litter" (Galgani et al., 2000), but larger objects can function as seabed structures that develop and support diverse and special biological communities, even if they can be patchy in distribution. These communities differ significantly from those of the surrounding well surveyed, soft sediment seabed of the Bight.

The expansion of this habitat type in the Bight by man's addition of solid material has probably had an effect on LMR distributions and fisheries (such as American lobster, *Homarus americanus*; cod, *Gadus morhua*; red hake, *Urophycis chuss*; ocean pout, *Macrozoarces americanus*; scup, *Stenotomus chrysops*; black sea bass, *Centropristis striata*; and tautog, *Tautoga onitis*) and possible effect on other resources, but these effects are not well known nor well understood. In fact, reef habitats in general seem underappreciated by northeastern U.S. habitat managers or researchers. For example, no type of reef habitat is even listed as a fishery habitat in recent reviews of northeast fish habitat, except for boulders (Langton et al., 1995; Auster and Langton, 1999), and they are not considered as demersal fish nursery habitat in the Bight (Steves et al., 2000). In the waters south of Cape Hatteras, reef habitats are recognized as important to fisheries and some of the species found in the Middle Atlantic Bight are also part of those fisheries (Miller and Richards, 1979; Parker and Mays, 1998).

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ABSTRACT—One particular habitat type in the Middle Atlantic Bight is not well recognized among fishery scientists and managers, although it is well known and used by recreational and commercial fisheries. This habitat consists of a variety of hard-surface, elevated relief "reef" or reef-like environments that are widely distributed across the predominantly flat or undulating, sandy areas of the Bight and include both natural rocky areas and man-made structures, e.g. shipwrecks and artificial reefs. Although there are natural rock and shellfish reefs in southern New England coastal waters and estuaries throughout the Bight, most reef habitats in the region appear to be man-made, mostly wrecks and "obstructions," and man-made reef habitat modification/creation may be increasing. Very little effort has been devoted to the study of this habitat's distribution, abundance, use by living marine resources and associated biological communities (except on estuarine oyster reefs), and fishery value or management. This poorly studied and surveyed habitat can provide fish refuge from trawls and can be a factor in studies of the distribution and abundance of a variety of reef-associated fishery resources. This review provides a preliminary summary of information found on relative distribution and abundance of reef habitat in the Bight, the living marine resources and biological communities that commonly use it, threats to this habitat and its biological resources, and the value or potential value of artificial reefs to fishery or habitat managers. The purpose of the review is to initiate an awareness among resource managers about this habitat, its role in resource management, and the need for research.

Although hard bottom habitats off southern New England were explored briefly by naturalist dredge in the latter half of the nineteenth century (Verrill, 1872), submarine canyon and tilefish habitats were examined by submarine (Valentine et al., 1980), and some attention was given to biological fouling (Redfield and Ketchum, 1952), little other work has been done to examine this habitat type in the Bight. Reef habitats in the Bight, although not as wide in occurrence and coverage as the glacially scoured, rocky areas of the Gulf of Maine (Oldale et al., 1973), or the fossil coral rock and live coral patch reefs south of Cape Hatteras (Menzies et al., 1966), may have become common enough to warrant consideration of their role in fishery management in the Bight. Although not as common or as spectacular as in the tropics, reef-like habitats (especially shipwrecks) also support recreational diving in the Bight, and many divers harvest reef fish resources by spear (fish) or hand (lobsters). This recreational diving generates economic benefits to nearby businesses through sales and services.

The introduction of manufactured materials as reef habitat, by both accidental and intentional depositions, is expanding in the Bight. These habitats and their associated biological communities need the ecosystem/community-level attention given similar reef habitats in the adjacent Gulf of Maine and South Atlantic Bight areas (e.g. McCarthy et al., 1979; Hulbert et al., 1982; Wenner et al., 1983; Chester et al., 1984; Sedberry and Van Dolah, 1984; Witman, 1985; Witman and Sebens, 1988; Kirby-Smith, 1989). Man-made or artificial reef habitats are also often suggested as replacement habitats for losses of other habitats, especially in estuaries where in-kind mitigation opportunities are often absent (Sheehy and Vic, 1992; Foster et al., 1994). They are also used to create new habitat, e.g. artificial reefs to enhance fishing or surrounding artificial islands (Williams and Duane, 1975; Seaman and Sprague, 1991), or are segregated as special fishery management areas or reserves (GMFMC, 1999). Because of these varied roles involving fishery and habitat management, there is need to begin to better understand the community dynamics and fishery value of this habitat type in the Bight.

This paper summarizes available information in four parts:

1) A characterization and preliminary assessment of the abundance and distribution of reef habitats in the Bight;
2) Known or probable fishery resource associations with reef habitats, several species of which are currently considered “overfished” (NMFS, 1999b), including some endangered marine species;
3) What is known of the biological communities that are associated with various estuarine, coastal, and continental shelf reef habitats; and
4) Discusses status and trends in reef habitats, threats to these habitats, some uses of man-made reefs to manage marine resources, and informational or research needs.

This summary is intended to create an awareness of this habitat in the Bight and serve the information needs of habitat and fishery resource managers.

The Middle Atlantic Bight Reefs

The Bight generally is defined to include estuarine and continental shelf waters and seabed between Cape Cod, Mass., and Cape Hatteras, N.C. It is a broad indentation in the coast line between these boundaries with inflections at the mouth of Chesapeake Bay and New York harbor (Fig. 1). Its nonreef benthic environment and associated communities have been reported by Wigley and Theroux (1981) and Theroux and Wigley (1998), and were reviewed by Pacheco (1988), and are characterized as being composed of sediments that range from clay to gravel, with sand being the dominant sediment (Fig. 1). But within this soft sediment matrix, unnoted natural and man-made reef habitats occur in estuaries, along the coast, across the continental shelf, and in deeper waters. A review of these reef habitats and biological associations follows, which includes references to species, such as aquatic birds, that interact with reef-associated fishes.

Characteristics of Reef Habitats in the Bight

A reef habitat can be composed of natural materials (such as rocks used for shoreline rip rap jetties), sometimes placed by man, or composed of manufactured materials (such as sunken vessels). Some biogenic micro-structures, e.g. coralline algae; anemone, polychaete, or amphipod tubes; or cobble or dead or fossil molluscan shell patches, have some reduced characteristics of a reef habitat. These can support smaller organisms or life stages; Auster et al. (1995) discusses this use of microhabitat. After a period of submersion and epifaunal colonization, most reef habitats have a similar appearance and function, but there can be subtle differences between natural and man-made reef habitats; the characteristics of each type are reviewed separately. The basic source of information on the distribution of reef habitats is NOAA’s NOS Hydrographic Surveys Division Automated Wreck and Obstruction Information System (AWOIS, 1997), although this database only includes structures or reefs that might be of concern to navigation, and many small “reefs” or “snags” are not included in the database. This database is augmented by a summary of artificial reef construction from sources involved in various state artificial reef programs, and a survey of relevant literature. The very abundant and widely distributed shellfish reefs, submerged pipelines, and intertidal man-made structures, e.g. jetties and bulkheads, are only generally considered. No effort is made in this review to estimate the total spatial seabed coverage of all types of reef habitats in the Bight. Some of the targets listed on the maps that seem to be inland are actually within rivers.

Natural reefs

Natural reef habitats in the Bight are found in some areas consisting of biogenic or rock material. Biogenic reefs are created by living stone coral, *Astrangia poculata*, certain shellfishes (eastern oyster, *Crassostrea virginica*, and blue mussel, *Mytilus edulis*), and polychaete worms, such as *Sabellaria vulgaris*. These reef-building organisms have been called "physical ecosystem engineers" by Jones et al. (1997) because they add structural complexity (or micro habitats) to environments, which in turn attracts and supports other organisms. Nonbiogenic natural reef habitats are exposed rock outcrops or random boulders left by retreating glaciers or rafted from icebergs, about 12,000 years before present (YBP), or erosion of sediment-covered rock or deltaic deposits of rock, cobble, and gravel along former river channels across a retreating shoreline since the last glacial period. There are reports of submerged ridges of aragonitic sandstones, thought to be relict beach deposits, mid-shelf off Delaware (Allen et al. 1969). Some natural "reefs" can be ephemeral, such as tree trunks that are washed down rivers, become water logged, and sink to the bottom to provide temporary habitat until wood-borers gradually degrade them. Collections of dead molluscan shells, such as surf clam, *Spisula solidissima*; and whelks, *Busycon* sp.; and exposed semi-fossil oyster shell can serve as micro-reef habitats.

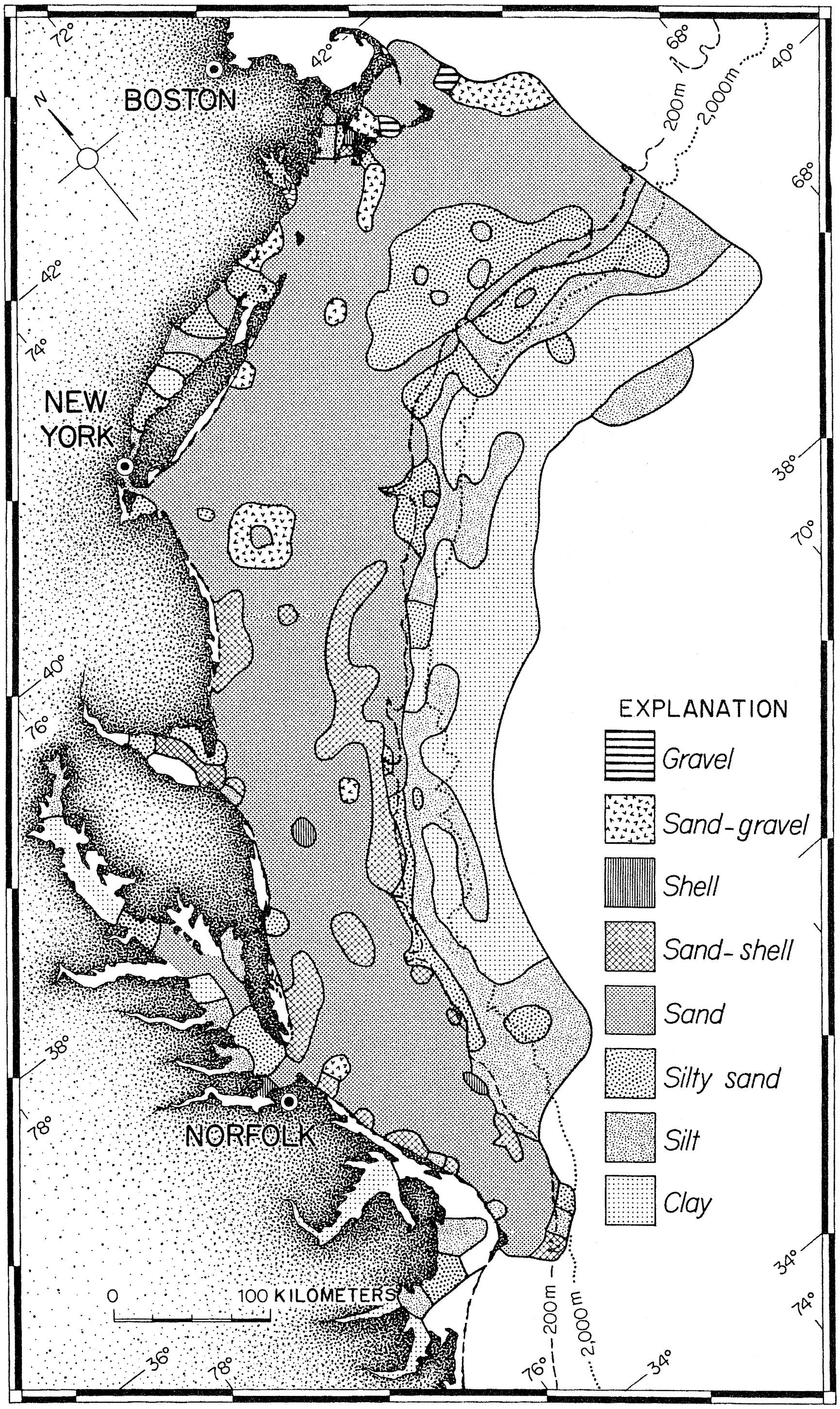


Figure 1.—The underlying dominant sediments types and distributions in the Middle Atlantic Bight (from Wigley and Theroux, 1981).

Shellfish reef habitats (primarily oyster and blue mussels) are primarily known to occur in polyhaline estuaries and coastal areas in the Bight, but mussels occur offshore, too. Oyster beds and reefs are found in Chesapeake Bay and its tributaries, Delaware Bay, the Hudson-Raritan Estuary, in coastal areas of Long Island Sound and Southern New England, including bays on Martha's Vineyard (Ford, 1997; MacKenzie, 1997a, b). Oyster beds were more extensive in distribution and abundance in the nineteenth century than currently, and were enhanced in many areas in the 19th and early 20th century by transplanting cultch and spat.

Blue mussel beds are attached to hard surfaces in more marine and cooler coastal waters, (e.g. Steimle and Stone, 1973; Langton et al., 1995; MacKenzie, 1997a). They can also be found adjacent to larger reef structures after being sloughed off by strong currents or storm surges and there they continue to grow and serve as satellite, low-relief reef habitats. Life spans of a decade or less, predation, and harvesting make the presence and size of these beds somewhat dynamic, and they are not usually mapped as reef structures.

Rocky reefs and associated fauna are mostly found in New York Harbor, Long Island Sound, and along the Southern New England coast, and outcrops of glauconitic marl (a soft sedimentary rock) occur off northern New Jersey (the Shrewsbury Rocks and Elberon Grounds). The AWOIS (1997) database represents a rough estimate of reef habitats, including natural rock. For example, there is evidence of aragonitic fossilized sandstone ridges reported off Delaware at about 80 m depth (Allen et al., 1969) that do seem to be in the AWOIS database, and there are "rocky" areas defined by AWOIS at the mouths of Delaware and Chesapeake Bays (Fig. 2) that are not natural, but are protective rip rap. Some natural reef habitat is also known from areas of the outer continental shelf and within submarine canyons where other outcrops of sandstone and clay occur; the exposed clay in this area is further enhanced as fishery habitat by the burrowing activities of tilefish, *Lopholatilus chamaeleonticeps*, and crustaceans, such as American lobster (Cooper et al., 1987; Steimle et al., 1999f), and by soft coral colonization. These deeper reef-like habitats are not included in the AWOIS database nor on Figure 2.

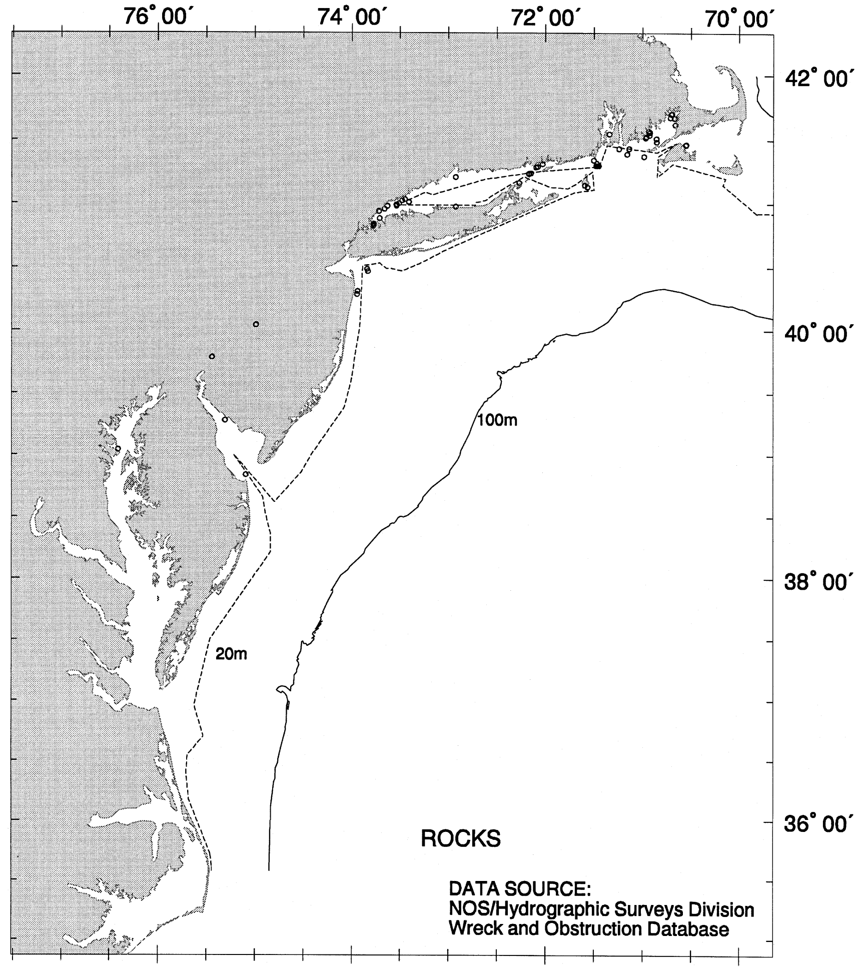


Figure 2.—Distribution of submerged rocky reef areas (○) in the Middle Atlantic Bight, based on NOAA NOS's AWOIS (1997). The targets that appear inland are in the AWOIS database for rivers.

There are anecdotal reports by commercial fishermen of cobbles and loose rock patches associated with gravelly areas in coastal areas, these could represent river deltaic deposits during periods of lower sea levels; but some could be ballast stones from old wooden shipwrecks. Off coastal Delaware and south these rocky patch are also associated with "live bottom," i.e. the rocks are colonized by sea whips, stone coral, and other biogenic structural enhancers (see below).

Man-made reefs

Although native Americans used brush and stone weirs to trap fish in estuaries and rivers, which might be considered a form of artificial habitat which sheltered some fish as well as aggregating them for collection, most man-made contributions to Bight reef habitat have occurred since European colonization in the seventeenth century. As settlers developed the shoreline, they added objects or structures that functioned as reefs to estuaries, coasts, and the shelf by building piers, docks, bulkheads, and leaving wooden shipwrecks. These structures had habitat value similar to submerged trees washed down river into estuarine waters by storms, and in some ways they mitigated the loss of other structured, vegetated habitats (coastal marshes and eel grass beds) that were covered or degraded by shoreline development, although the hard structures did not fully mitigate lost primary productivity. In approximately the last century and a half, metal vessels have gradually replaced large wooden vessels and created more enduring sunken structures. Mid-depth to surface "reef-like" habitat is also created by epifauna colonizing the system of coastal navigation aids, such as buoys and their anchor chains and the submerged supports of light towers; there are presently no oil or gas rigs in the Bight which would add to this type of habitat. Human activities have introduced rocks, as protective structures (jetties, groins, breakwaters, and ice blockers) along or within most coastal areas or bays, or as former waste material as off the mouth of New York Harbor, i.e. the Subway Rocks, which are material removed while constructing the New York City subway system.

Shipwrecks constitute one of the most abundant types of man-made reef habitat in the Bight. A summary plot of wrecks from the AWOIS (1997) database suggest that they are most common near the mouths of major estuaries or ports (Fig. 3), as might be expected from the volume of shipping traffic in and out of these ports. However, many smaller or older, partially degraded or buried wrecks are not in the database or shown on these charts, and their distribution is likely to be similar to the plotted shipwrecks. Many of the shipwrecks on the outer continental shelf are products of WW II submarine attacks. As shipwrecks degrade, their structural complexity changes and this affects their habitat value for fishery resources.

Another type of "reef" habitat noted on NOS charts and in the AWOIS (1997) database, is "Obstructions." These are objects on the seabed of unknown composition, and many are probably small or degraded shipwrecks, lost anchors or deck cargo, a few airplane wrecks, and similar objects. The most notable of these are summarized on Figure 4, and, like shipwrecks, the plot focuses on larger targets of potential concern to navigation.

In the last half century or so, fishermen and fishery managers have recognized the value of "reef" and wreck habitats to fisheries, and they have been constructing artificial reefs in coastal waters. The use of artificial reefs for fishery enhancement has continued to expand, although they are a relatively small part of the plotted man-made or overall reef habitat available in the Bight (Fig. 5), in comparison with wrecks and obstructions (Fig. 3, 4). Areas where artificial reefs have been constructed are noted by an older term, "fish havens," on NOS navigation charts but are not included in the AWOIS (1997) database. Artificial reefs placed on the seabed specifically for fishery enhancement tend to be found in coastal and estuarine waters (Fig. 5) and serve primarily the recreational fishery. They have been built and developed in the Bight since the 1920's or 1930's, and especially since the 1960's. Initially they were developed with a variety of recycled materials, ranging from Christmas trees stuck in concrete bases, wooden beer cases half filled with concrete, rubber automobile tires, to the recent use of de-

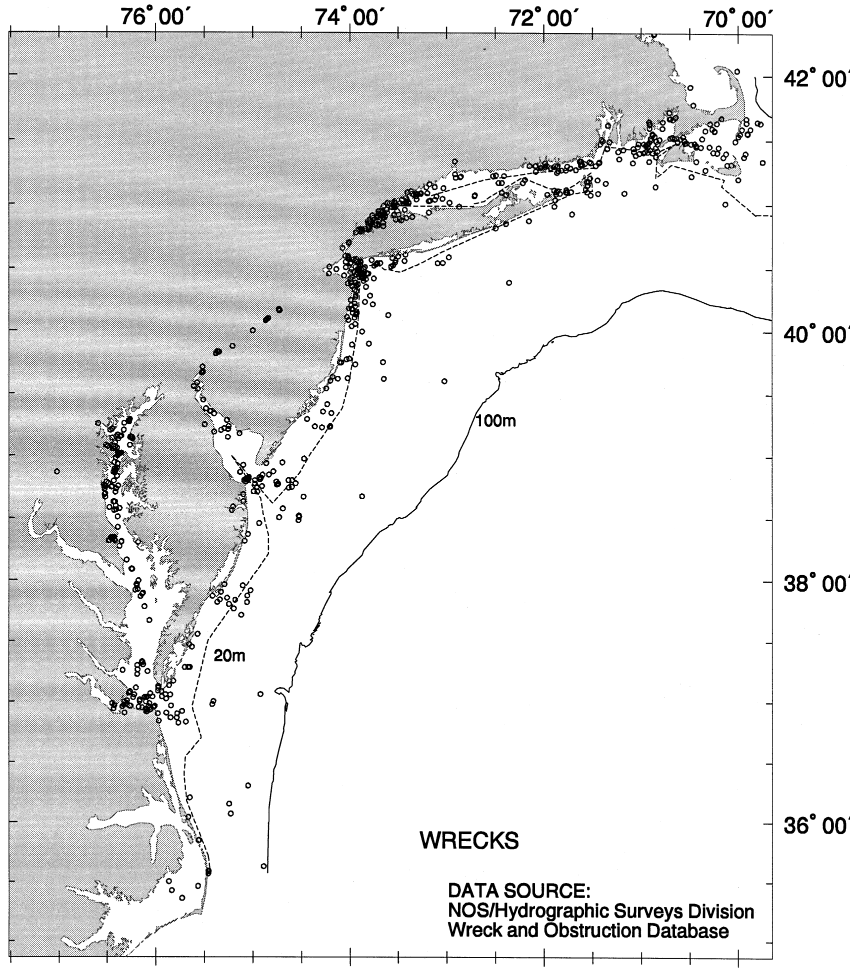


Figure 3.—Distribution of Middle Atlantic Bight shipwrecks (○) in the NOAA NOS's AWOIS (1997) considered to be a concern for navigation. The targets that appear inland are in the AWOIS database for rivers.

militarized combat vehicles and a variety of ships as available at a reasonable cost (Steimle, 1982; Joint Artificial Reef Technical Committee, 1998). In the last decade, prefabricated artificial reef units that are specifically designed and constructed as habitat for fishery resources are increasingly being deployed (Sheehy and Vic, 1992). The contribution of artificial reefs to reef-fish productivity has been controversial and the debate continues and fish or fishery productivity may vary among reef locality and other factors (American Fisheries Society, 1997).

A summary of all reef or reef-like habitats, i.e. Fig. 2–5, is shown on Fig. 6, which should be considered a minimum estimate of the distribution and relative abundance of this habitat in the Bight, because of the reasons previously mentioned. The term, "non-biogenic" is used on this figure to note that live coral, mussels, and oyster beds/reefs are not included.

The concept of a reef habitat is more complex than being either natural or man-made and involves a variety of conditions under which a reef or reef-like conditions exists in the Bight. Some characteristics of different reef or reef-like habitats found in the Bight are summarized in Table 1.

Reef-associated Fishery Resources in the Bight

Reef habitats of all types within the Bight are used by a wide variety of fishery resources (Hildebrand and Schroeder, 1928; Bigelow and Schroeder, 1953) and a few threatened or endangered species (Lutz and Musick, 1996). Table 2 summarizes most of these species and notes their known or suspected reef habitat associations; however, it should be noted that very little information is available on the invertebrate or fish fauna on reef habitats in the Bight, especially in relatively deep (>30 m) waters.

Although many fishery species are closely associated with reef habitats, the reef may not adequately supply all of their needs, especially food, and the availability of non-reef resources can be important to these species. For example, black sea bass, which is a common reef habitat-associated fish mostly found during the warmer months in the Bight, may obtain much of its food from the sandy bottom or water column around a coastal artificial reef habitat (Steimle and Figley, 1996). Thus, the near-reef, open bottom/water habitat and its biological resources are linked to the fishery resource production function of a reef habitat. The open sandy bottom fauna near reef habitat, conversely, can be affected by the presence of a reef and its predatory fauna.

The habitat needs of reef-associated fishery resources often shift during ontogenetic development. Many reef species use the marine water column as larvae, estuarine structures as juveniles, and gradually return to deeper and more marine habitats at the end of their first season. In the Bight there can also be a seasonal shift in habitat use among subadults and adults of certain species, i.e. winter and summer habitat use can also differ significantly (Steimle et al., 1999 b-f; Steimle and Shaheen, 1999; NMFS, 1999a).

Other Potential or Transient Reef-associated LMR's in the Bight

Some reef associated taxa or species, that are not included in Table 2 and are not presently considered a "living resource" in a fishery management sense, might be of greater value in the future, e.g. for biomedical-pharmaceutical research and industry (Faulkner, 1984). Reef-associated taxa known to have

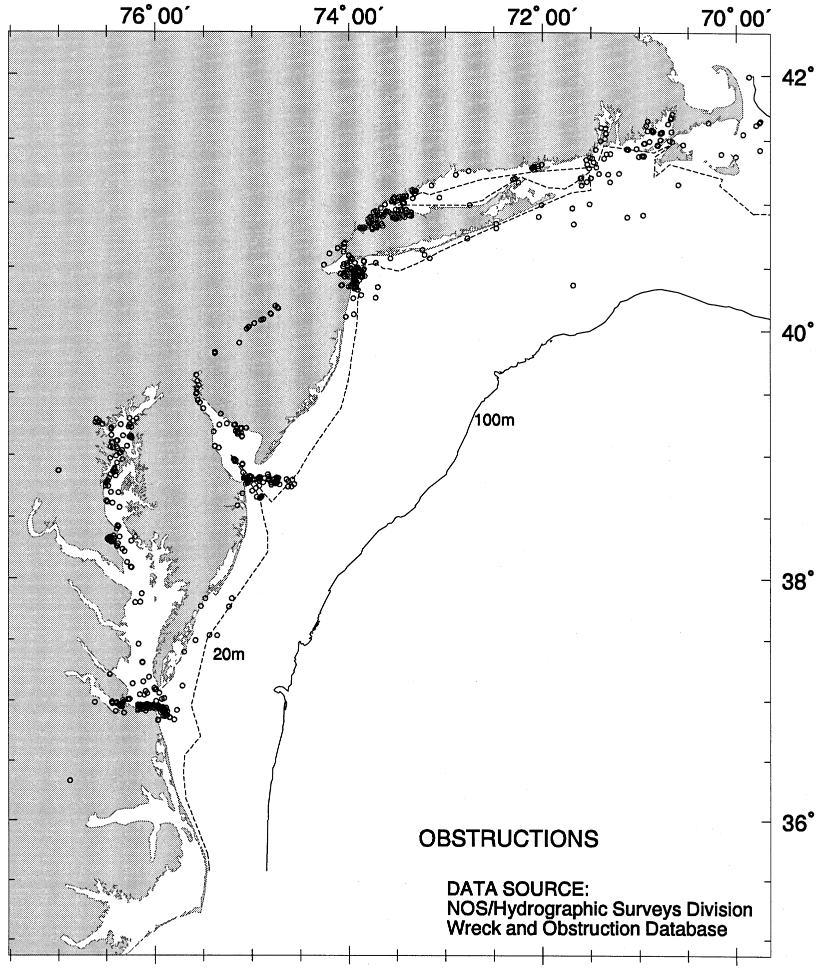


Figure 4.—Distribution of "obstructions" (○) in the NOAA NOS navigational chart database. The targets that appear inland are in the AWOIS database for rivers.

Table 1.—Summary of physical and biological characteristics of natural and man-made reef or reef-like habitats in the Middle Atlantic Bight.

Natural: These are submerged rocks and other hard materials or solid structures made by living organisms (biogenic materials).

Estuarine: Reefs in this environment consist of oysters, mussel, sponge, and tube worm beds: exposed stiff clay, peat, or rocky outcrops; waterlogged trees; or boulder or cobble fields. Oyster and mussels are fishery resource species in their own right, and these estuarine biogenic and non-biogenic habitats provide shelter and food for a variety of juvenile to adult fish (see below).

Coastal (< 12 miles): Mussel and stone coral beds form biogenic reefs here, and other reefs consist of rocky outcrops, such as soft marl off northern N.J. and harder rock from N.Y. Harbor east along the southern New England coast (Fig. 2); glacial erratic boulders or cobble accumulations from eastern Long Island to Cape Cod with other submerged cobble/ gravel banks reported off New Jersey, Delaware, and Maryland[1]; relict shell fields; exposed stiff clay or peat deposits; and kelp beds are found along southern New England.

Shelf: Reef habitats are scarcer in deeper water but glacial erratic boulders; exposed rock or stiff clay at or near the edge of the continental shelf or at the shelf edge heads of submarine canyons; relict clay or peat deposits; and shell fields provide patches or bands of reef-like habitat.

Man-made: These types of structured habitats have been available since the 17th century, and a good part of this habitat is from shoreline construction, such as piers and jetties, but also include the remains of shipwrecks and various materials deposited to provide an artificial reef-type habitat, as per Fig. 3-5.

Estuarine: This type of habitat is often formed by shoreline development, including functional and decaying bulkheads, bridge abutements, piers and docks, protective rip rap, groins and jetties; navigational aids such as lighthouses and buoys; clay or rock exposed by dredging; submerged natural gas, storm water, processed sewage effluent pipelines; exposed communication cables; sunk or abandoned vessels (including ballast rock piles); and other small to medium sized materials ranging from beverage containers to vehicles; waterlogged timber; and artificial reefs build of various reused and some specifically designed materials to support shell- and finfisheries.

Coastal (< 12 miles) and Shelf: Man-made structured habitats in this broad marine zone consist of basically many of the same materials or structures as are found in estuaries, although some structures are larger in size, e.g. shipwrecks and artificial reefs, but can include lost ship cargos, and exposed exploratory oil and gas pipe heads in deeper waters.

[1] Monty Hawkins, partyboat captain, Ocean City Md, personal commun., 2000.

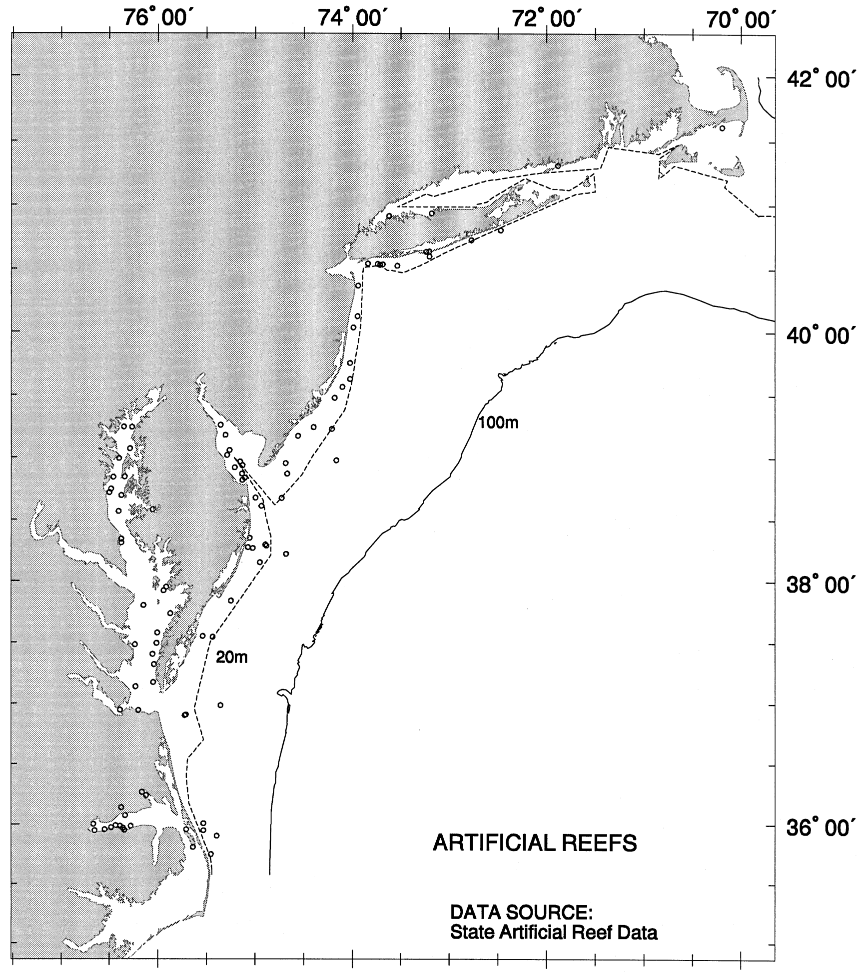


Figure 5.—Distribution of artificial reefs, or fish havens, (○) in the Middle Atlantic Bight, based on individual state artificial reef program data.

such potential qualities include: algae species, sponges, coelenterates, nudibranch mollusks, and tunicates (Lustigman et al., 1992).

Other fishery resources commonly caught or observed above or near high profile reef habitats are bluefish, *Pomatomus saltatrix*; mackerels and tunas, Scombridae; jacks, Carangidae; and some benthic species such as summer flounder, *Paralichthys dentata*. These fish predators take advantage of aggregations of prey on the reef or may be behaviorally attracted to the reef structure or the flow refuge effects of structure (Westman, 1958; Figley, 1996).

The fish that frequent reef habitats are often less subject to commercial fishing pressure, because the relatively high relief and complex structure of many reefs inhibit the use of towed fishing gear, or the reefs provide shelter when this gear passes over a low profile structure; however, lobster and fish traps and gill nets are often effective on or near reefs. Most reefs are heavily used by recreational fishermen and divers.

Reef Communities in the Bight

Reef habitats support biological communities (used here to mean organisms that are commonly found together with some degree of interaction) that are dependent upon or which significantly benefit from this habitat type. These communities range from microscopic algae and large kelp (in cooler waters) growing on reef surfaces to fishes and possibly sea turtles (Cheloniidae). Below is an overview of the communities known to be commonly found on subtidal reef structures in the Bight. The type of reef surface, i.e. rock, wood, metal, or other, has a variable effect on the community formed on that surface, but this effect is only briefly discussed here because of the limited available information. Intertidal, semi-hard surface communities (e.g. peat banks) and submerged aquatic vegetation also provide some of the habitat characteristics of reefs, and these functions are becoming better known (Able et al., 1988) and are also not discussed here. Ducks and other vertebrates are included in the habitat use synopsis below, when appropriate, as a reminder of their possible predatory or competitive interactions with reef fish and other reef-associated LMR's. Scientific names are included only for species not found in Table 2.

Estuarine Reef Communities

Epibenthic and Epibiotic (Organisms Attached to Reef or Shellfish Surfaces)

Several types of polyhaline estuarine reef epibenthic communities exist in the Bight. These communities include oyster beds; blue mussel beds; communities attached to nonbiogenic hard surfaces such as rock, wood, and metal; and those using semi-hard surfaces such as stiff clay and peat.

Oyster reefs The shells of oysters support a diverse epibiotic community that can include barnacles, *Balanus* sp.; ribbed mussels, *Geukensia demissa*; and blue mussels depending on salinity, algae, sponge, tube worms (*Spirobis* sp., *Polydora* sp., and other species), anemones, hydroids (*Obelia* sp. and other species), bryozoa (*Membranipora* sp. and other species), and other taxa (Watling and Maurer, 1972; Maurer and Watling, 1973; Kinner and Maurer, 1977; Larsen, 1985; Zimmerman et al., 1989, Coen et al., 1999). Silt accumulated between the oyster shells can support benthic invertebrates that are also found on the soft bottoms of the area.

Blue mussel beds Many organisms are found epibiotically on mussel shells; these can include many of the same epibiotic organisms found on oyster beds: barnacles, algae, sponge, the same types of tube worms, hydroids, anemones, bryozoa, and slipper shells *Crepidula* sp.(Kinner and Maurer, 1977; Newell, 1989). Additional, nonepibiotic macrofauna (mainly a diversity of polychaetes and amphipods) also benefit from the mussels and live within the interstitial spaces among the mussel shells and byssus threads.

Other hard surfaces (including a diversity of natural and man-made submerged materials) These surfaces, like that of oysters and mussels, can support algae where light is sufficient, barnacles, sponge, tube worms (including *Sabellaria vulgaris* and others), hydroids, anemones, encrusting bryozoans, oysters, blue mussels, the jingle shell *Anomia* sp., northern stone coral, *Astrangia poculata* (in more marine waters), sea whips *Leptogorgia* sp. (in Chesapeake Bay), tunicates *Molgula* sp., and caprellid amphipods (Maloney, 1958; Westman, 1958; Watling and Maurer, 1972; Dean, 1977; Otsuka and Dauer, 1982). Wooden structures within estuaries can also be infested with destructive borers such as *Teredo navalis*, and gribbles, *Limnoria lignorum* (Nigrelli and Ricciuti, 1970) and weathered creosoted or other antiborer-treated pilings can become substrates for some epifaunal colonization, even though borers and others may be temporarily inhibited by the chemical treatment (Stewart, 1983).

Semi-hard clay and Spartina peat "reefs" These softer surfaces can support burrowing mollusks (piddocks such as *Pholus* sp.,*Cyrtopleura costata*, *Barnea truncata*, *Zirfaea crispata*) and epibenthic algae (Able et al., 1988); motile organisms, such as juvenile American lobsters and American eels, also occur in this habitat and are discussed below.

Of note and potential interest to fish recruitment success is that the larvae of certain epibenthic (reef) organisms can be very abundant at times in the meroplankton, e.g. barnacle cyprids and mussel larvae, and be a significant source of planktonic food for some larval fishery resources (Richards, 1963).

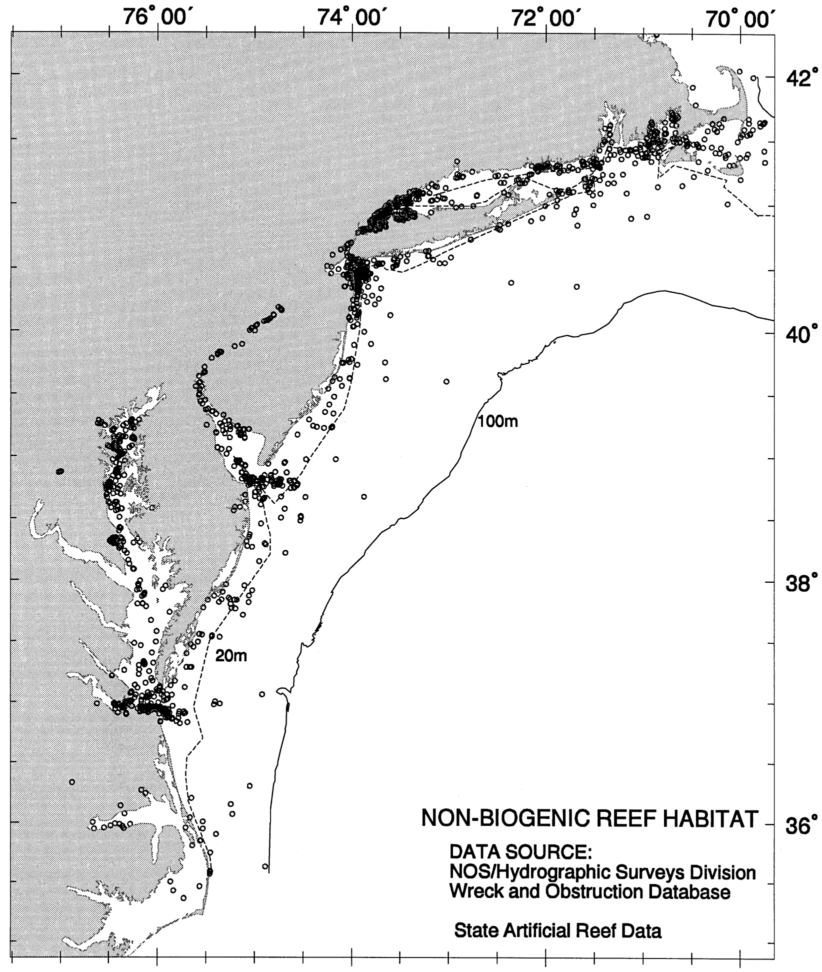


Figure 6.—Summary of all reef habitats (except biogenic, such as mussel or oyster beds) (○), Figs. 2-5, in the Middle Atlantic Bight. The targets that appear inland are in the AWOIS database for rivers.

Motile Epibenthic Invertebrates

These mostly include decapod crustaceans, such as mud (xanthid) crabs; blue crabs, *Callinectes sapidus*; rock crabs; spider crabs, *Libinia emarginata*; and juvenile American lobsters (although this species is scarce south of Delaware Bay, except in deeper waters), and sea stars, *Asterias* sp. and *Henricia* sp. (Jeffries, 1966; Briggs, 1975; Leathem and Maurer, 1980; Able et al., 1988; Barshaw et al., 1994; Wilk et al., 1998).

Fish

A number of fishes are commonly or seasonally found on estuarine reef or reef-like estuarine habitats. They include adults and juveniles, and species that can be prey (e.g. gobies, *Gobisoma* sp.), predators (e.g. toadfish, *Opsanus tau*), or competitors (e.g. cunner) with resource species (Breitburg, 1999). There is a gradual shift in the fish species assemblages that are commonly associated with reef habitats from the warmer waters off Virginia to the cooler waters off southern Massachusetts, and they are thus discussed by subregions.

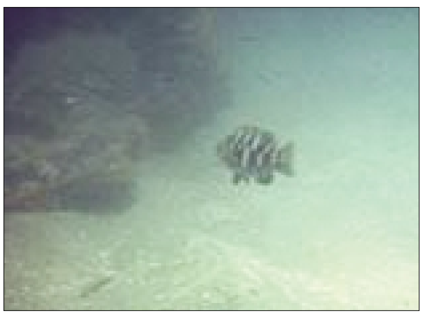
Chesapeake Bight (Delaware–North Carolina) Gobies, spot, striped bass, black sea bass, white perch, *Morone americanus;* toadfish, scup, drum, croaker, spot, sheepshead porgy, pinfish, tautog, and northern puffer, *Sphaeroides maculatus;* have been reported common on reef habitats in this area

Table 2.—List of fishery species that are commonly found on reef or reef-like habitats in the Middle Atlantic Bight.

Species	Life stage/reef habitat use	Notes
Algae (kelp, *Laminaria* sp., dulse, etc.)	All stage grow attached to estaurine/ marine hard surfaces.	Grows on inter/subtidal surfaces along southern New England coast as deep as light penetration allow and provides shelter; some are harvested.
Invertebrates		
Mollusks		
Blue mussel *Mytilus edilis*	All stages grow attached to hard surfaces in polyhaline-marine waters.	Colonizes intertidal/subtidal surfaces but becomes scarcer towards N.C.; important prey for many reef fishery resources; harvested as adults; increases habitat structural complexity and biodiversity.
Eastern oyster *Crassostrea virginica*	All stages grow attached to hard surfaces in polyhaline-estuarine waters.	Colonizes hard surfaces and/or creates low profile reefs; harvested as juveniles (spat for transplanting) and adults; increases habitat structural complexity and biodiversity.
Longfin squid *Loligo pealei*	Eggs are attached to hard objects in marine waters.	Hard surfaces of all sizes seem important for egg mass attachment. Eggs and larvae can be prey.
Crustaceans		
American lobster *Homarus americanus*	All post-larval stages use shelter in polyhaline-marine waters.	Lobsters are common reef habitat dwellers but are less common south of Delaware Bay; maintain reef habitat structural complexity by clearing burrows.
Jonah crab *Cancer borealis*	All post-larval stages use shelter in polyhaline-marine waters.	This larger crab is common to reef habitats; claws are harvested.
Rock crab *Cancer irroratus*	All post-larval stages use shelter in polyhaline-marine waters.	Common on reef habitats as well as on most other habitats; juveniles or smaller sizes important prey for fish and lobsters; claws are harvested.
Fish		
American eel *Anguilla rostrata*	Adults found in estuarine to coastal marine reefs as well as elsewhere.	This eel is found seasonally in estuarine areas, including holes in peat banks; harvested by trap and by recreational fishery.
Conger eel *Conger oceanicus*	Juveniles and adults common in polyhaline-marine structures.	This larger eel preys on smaller reef fish; hard to catch but desirable.
Atlantic cod *Gadus morhua*	Juveniles and adults common on polyhaline-marine reefs.	This species feeds on reef organisms; uses structure for shelter; but only found during cooler seasons south of Long Island, N.Y. to about Delaware.
Pollack *Pollachius virens*	Juveniles and adults common on polyhaline-marine reefs.	Uses structure for shelter or for feeding; but only found during cooler seasons south of Long Island, N.Y. to about Delaware.
Red hake *Urophycis chuss*	Juveniles and adults common on polyhaline-marine reefs.	Common reef habitat dweller; preys on small crabs and other organisms found on or near reefs; commercially and recreationally harvested.
Striped bass *Morone saxitilus*	Juveniles and adults common on estuarine and coastal reefs.	Juveniles use estuarine structures for shelter; adults find prey near estuarine and coastal structures.
Black sea bass *Centropristis striata*	Juveniles and adults common on estuarine and coastal reefs.	Juveniles use estuarine and coastal structures, and adults mostly use coastal and midshelf structures during warmer seasons.
Gag grouper *Mycteroperca microlepis*	Juveniles and adults common on southern Bight reef habitats.	Important but variably available fishery species off Virginia and North Carolina.
Scup (porgy) *Stenotomus chrysops*	Juveniles and adults common on estuarine and coastal reefs.	Small schools of this species visit coastal reefs for prey and shelter during warmer seasons; found offshore and to the south in the winter.
Spot *Leiostomus xanthurus*	Juveniles and adults common on estuarine and coastal reefs.	A warm season user of reef habitats north on Chesapeake Bay.
Sheepshead (porgy) *Archosargus probatocephalus*	Juveniles and adults common on southern Bight reef habitats.	Common on estuarine (including oyster beds) and coastal reefs, mostly south of Delaware Bay.
Atlantic croaker *Micropogonias undulatus*	Juveniles and adults common on estuarine and coastal reefs.	Common on estuarine (including oyster beds) and coastal reefs, mostly south of Delaware Bay.
Black drum *Pogonias cromis*	Juveniles and adults common on estuarine and coastal reefs.	Common on estuarine (including oyster beds) and coastal reefs, mostly south of Delaware Bay.
Tilefish *Lopholatilus chamaeleonticeps*	Juveniles /adults use rocky areas or holes in stiff clay at the edge of continental shelf and upper slope.	This species contributes to the creation and persistence of the rough bottom habitat and associated biological community found in certain areas of the outer shelf and upper slope.
Cunner *Tautogolabrus adspersus*	All post-larval stages are associated with marine-polyhaline reef habitats.	A very common small reef fish, especially in the northern Bight; prey for other fish found on or visiting reefs. Hibernates on reefs in cold winters.
Tautog *Tautoga onitis*	All post-larval stages are associated with marine-polyhaline reef habitats.	A common larger reef fish that prey heavily upon mussels; youngest juvenile found in estuaries; may hibernate during cold winters off New England.
Gray triggerfish *Balistes capriscus*	Juveniles/adults are warm-season reef dwellers.	Found on marine reefs and preys on reef dwellers; growing in popularity as food fish.
Ocean pout *Macrozoarces americanus*	All life stages found on reef habitat, including eggs which are nested.	Adults make and possibly guard egg nests within reef structures during the winter.
Reptilia		
Sea turtles Eucheloniodea	Juveniles and adults of several species are associated with reefs.	Sea turtles are common summer visitors to the Bight and are known to use reef structures as sheltered resting areas and can prey on reef crabs.
Mammalia		
Harbor seal *Phoca vitulina*	Juveniles and adults use the above water parts of reefs as resting areas.	Harbor seals are winter visitors to the northern Bight and are commonly observed on dry parts of submerged structures and may prey on associated reef fish.

An assemblage of resident Tautog, *Tautoga onitis*, and cunner, *Tautogolabrus adspersus*, on some concrete pipe artificial reef material off New York. Photographer: Christopher J. LaPorta.

Tautog are common at the interface between the predominant open sandy bottom of the Middle Atlantic Bight and reef-like structures. Photographer: Christopher J. LaPorta.



A tautog, *Tautoga onitis*, that sometimes seeks shellfish prey on nearby sandy habitats, always returns to a reef structure.

(Arve, 1960; Richards and Castagna, 1970; Feigenbaum et al., 1985; Breitburg, 1999; Coen et al., 1999).

New York Bight (New Jersey–southern Long Island, N.Y.) Cunner, toadfish, spot, gobies, striped bass, sculpins, juvenile Atlantic cod, juvenile tautog, black sea bass, scup, rock gunnel, *Pholis gunnellus;* conger eel, American eel, red hake, and northern puffer have been reported on reef habitats in estuaries of this area (Briggs, 1975; Auster, 1989; Able et al., 1998).

Southern New England (Long Island Sound–Cape Cod) Cunner, toadfish, striped bass, scup, tautog, black sea bass, rock gunnel, conger eel, American eel, ocean pout, red hake, white hake, cod, juvenile pollack, and various nonfishery species have been reported on mostly rocky estuarine reefs in this area (Nichols and Breder, 1927; Able et al., 1988).

Other Vertebrates (Diving birds, seals)

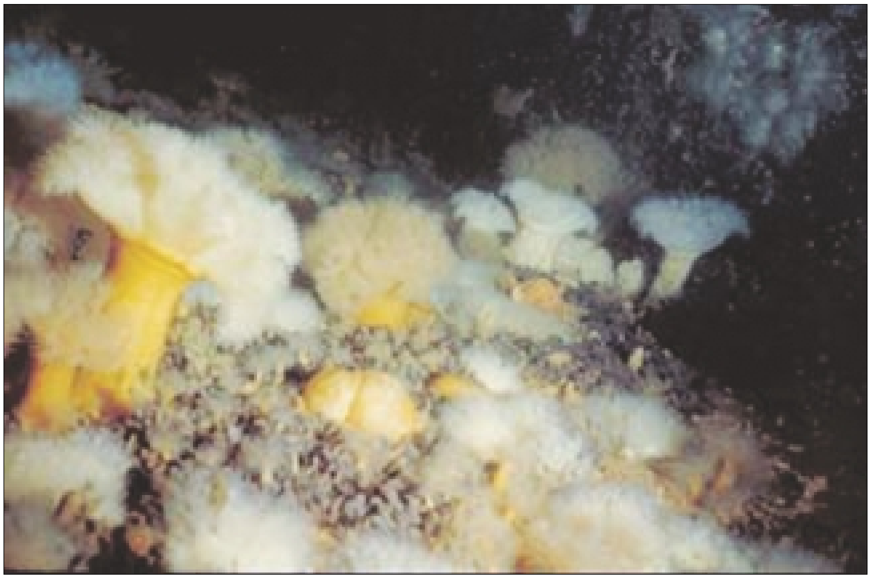
Several species of diving ducks and geese (Anatidae) feed seasonally upon submerged algae, mussels, and other organisms growing upon shallow reef habitats, e.g. brant, *Branta branta*; scaup, *Aythya* sp.; goldeneye, *Bucephala* sp., scoters, *Melanitta* sp., old squaw, *Clangula hyemalis*; eiders, *Somateria* sp.; and Harlequin ducks, *Histrionicus histrionicus*; other species can feed on small fish they find on shallow reefs, e.g. wintering loons,*Gavia* sp.; and mergansers, *Mergus* sp.; and cormorants, *Phalacrocorax* sp.; most of the year (Martin et al., 1951). In the winter, harbor seals, *Phoca vitulina,* visit the Bight, to at least New Jersey, and may find prey around reef habitats near their haul out, resting places.

Coastal (to depths of ~25 m)

Epibenthic

Exposed rock–soft marl (e.g. Shrewsbury Rocks off northern N.J.) Certain boring mollusks (piddocks such as *Cyr-*

Sea anemones, *Metridium senile*, and other epifauna that are typical of a well-established hard surface epifauna community in the Middle Atlantic Bight. Photographer: Christopher J. LaPorta.



White frilly patches of northern stone coral, *Astrangia poculanta*; anemones, *Metridium senile*; and various hydroids often dominate reef habitat epifaunal communities, when blue mussels, *Mytilus edulis*, are absent. Photographer: Christopher J. LaPorta.

Dense epifaunal growth on exposed hard structure or rocks provides abundant opportunities for juvenile or large fishery resources to find shelter.

Small American lobsters, *Homarus americanus*, are common within the shelter provided by reef habitats in the Middle Atlantic Bight, and come out at night to feed on or near this habitat. Photographer: Christopher J. LaPorta.

In the southern Middle Atlantic Bight large sheepshead porgy, *Archosargus probatocephalus*, are common residents of reef structures and feed on epifauna.

Juvenile and adult cunner, *Tautogolabrus adspersus*, are permanent residents of reef habitats in the Middle Atlantic Bight. Photographer: Christopher J. LaPorta.

Blue mussels, *Mytilus edulis*, commonly dominate the epifaunal community on reef structures in the Middle Atlantic Bight and are readily eaten by a variety of fish and crustacean shellfish, including the cunner, *Tautogolabrus adspersus*, that is present in this photo.

topleura costata and *Zirfaea crispata*) add complexity as they gradually degrade this substrate. The epifauna on this substrate also includes that noted below for harder substrate (Westman, 1958).

Harder rock When available, this rock can be colonized by red algae (*Phyllophora* sp.); sponges such as *Halichondria* sp. and *Polymastia* sp.; large anemones (*Metridium senile*, *Tealia* sp., or *Stomphia careola*); various hydroids (*Tubularia* sp., *Obelia* sp., *Campanularis* sp.); northern stone coral, soft coral (*Alcyonaria* sp.) off New England, and sea whips (*Leptogorgia* sp.) south of New Jersey where it becomes part of a "live bottom" community that is most common south of Virginia; barnacles; blue mussels, horse mussels *Modiolus modiolus* in deeper and cooler waters off southern New England; the jingle shell *Anomia simplex*; bryozoans, including *Bugula* sp.; skeleton (caprellid) and tubiculous amphipods, such as *Jassa falcata*; and tubiculous polychaetes, such as *Sabellaria vulgaris* and *Hydroides dianthus*. Much hard rock reef structure has been added to the shoreline of the Bight in the form of jetties, groins, rip rap, and groins that abut the shoreline as beach and other protection; these can support less stabile communities because of the greater environmental extremes and stresses that occur in this littoral zone, although fishery resources frequent them when the rocks are covered by water.

Wrecks and artificial reefs (of various compositions) Wood: When exposed, this provides a substrate similar to soft rock, but can include wood borers (e.g. *Teredo* sp. and *Xylophaga atlantica*) that also degrade this type of reef material, which is why they do not usually persist as significant three-dimensional structures or habitat for more that a few decades, unless periodically covered and protected by sediment.

Metal: As per hard rock, but the tendency of sheets of rust to slough off the wreck surface creates a less stabile community; these surfaces are often colonized by hydroids, like *Tubularia crocea*; anemones, mostly *Metridium senile*; northern stone coral; blue mussels; barnacles; sea stars; and related fauna (Bulloch, 1965; Feigenbaum et al., 1985: Chee[1]).

Kelp *Laminaria* sp. beds occur in Long Island Sound and north and are noted separately from the seaweeds listed elsewhere. Kelp grows only on hard reef-like surfaces and adds vertical relief and more complexity to reef habitats, as well as contributing to primary and detrital production (Alfieri, 1975).

Other materials (such as various plastics and synthetic materials, such as rubber and concrete) These epibenthic communities can be similar to that found on rock and metal reefs (Alfieri, 1975; McCullough, 1975; Woodhead and Jacobson, 1985; Figley, 1989).

Motile invertebrates

American lobsters, rock crabs, Jonah crabs, spider crabs, sea stars, and urchins, *Arbacia punctulata,* are found on these reefs (Westman, 1958; Cobb, 1971; Briggs and Zawacki, 1974; Briggs, 1975; Alfieri, 1975; Sheehy, 1976; Feigenbaum et al., 1985; Lavalli and Barshaw, 1986; Karnofsky et al., 1989a, b; Figley and Dixon, 1994; Mercaldo-Allen and Kuropat, 1994; Chee[1]). Mass aggregations of Jonah and rock crabs were reported on Southern New England rocky ledges (Auster and DeGoursey, 1983). *Loligo* squid usually attach their egg clusters to a hard object, such as a reef surface, or shells, gravel, or other hard surfaces on the seabed (Griswold and Prezioso, 1981; Roper et al., 1984).

Fish

Chesapeake Bight Black sea bass, pinfish, *Lagodon rhomboides*; scup, cunner, red hake, gray triggerfish, black grouper, *Mycteroperca bonaci*; smooth dogfish, *Mustelus canis*; summer flounder, scads, *Decapterus* sp.; bluefish, and amberjack, *Seriola dumerili*, have been reported as common over these reefs (Feigenbaum et al., 1985; Chee[1]).

New York Bight Atlantic cod, gray trigger fish, scup, black sea bass, tautog, ocean pout, red hake, conger eel, cunner, sea raven, *Hemitripterus americanus*; and rock gunnel have been reported on reefs in this area (Westman, 1958; Briggs, 1975; Steimle and Ogren, 1982; Woodhead et al., 1985; Figley and Dixon, 1994).

Southern New England Scup, black sea bass, tautog, Atlantic cod, ocean pout, red hake, conger eel, cunner, sea raven, and radiated shanny, *Ulvaria subbifurcata,* have been reported on these reefs (Alfieri, 1975; Carr and Amaral, 1981).

Other Vertebrates (Diving birds, seals)

These use shallow coastal or shoreline reefs, e.g. jetties, as per estuarine reefs, above.

Shelf (generally depths >25 m)

Epibenthic

Rocks and boulders Few rocky ledges are found on the Bight's continental shelf (these occur off southern New England), and most rocky habitat consists of boulder and cobble residue from periods when glaciers covered New England and icebergs drifted in the Bight, the last glacial period being about 12,000 YBP. Reports of the epifauna in this Bight substrate include most of the species noted in the above Coastal section. The epifaunal colonization of the exposed outer shelf sandstone ridges, reported by Allen et al. (1969), is unreported.

Wrecks and artificial reefs Size, composition, location, and age affect the structure and habitat value of these reefs. These factors also affect the habitat value of artificial reefs that were specifically constructed to support fishing. Few scientific studies are known of the epibenthic fauna of wrecks and artificial reefs on the Bight shelf, and those that are known are mostly within the coastal zone (Figley, 1989; Figley and Dixon, 1994); or are not quantitative or are anecdotal (Bulloch, 1965).

Other solid substrates Exposed submarine communication cables can be colonized by borers and epifauna (Snoke, 1957), and can serve as limited reef habitat for organisms of suitable size.

Motile Invertebrates

Most of the motile organisms noted above for the coastal areas are also commonly found on the shelf, although at the shelf edge, some deepwater taxa occur (Cooper and Uzmann, 1971; Wigley and Theroux, 1981; Theroux and Wigley, 1998).

Fish

Chesapeake Bight Reef fish include resident species (black sea bass, scup, tautog, and cunner), seasonal residents (gag, sheepshead porgy, round herring, and sardines), or transients (amberjack, spadefish, gray triggerfish, various mackerels and small tunas, and the spot-tailed pinfish, *Diplodus holbrooki*) (Eklund and Targett, 1991; Adams, 1993).

New York Bight Gray triggerfish, scup, black sea bass, tautog, Atlantic cod, ocean pout, red hake, conger eel, cunner, sea raven, rock gunnel, pollack, and white hake have been commonly reported on these deeper reefs (Bulloch, 1965; Woodhead et al., 1985).

Southern New England Scup, black sea bass, tautog, Atlantic cod, ocean pout, red hake, conger eel, and cunner occur here (Auster, 1984), as well as other species that are found in the New York Bight.

[1] Chee, P. K. 1976. The ichthyofauna of the Chesapeake Light Tower. Old Dominion Univ., Norfolk, Va., Unpubl. Rep., 26 p.

Outer shelf reefs and clay burrows (and the "pueblo village community" along southern Georges Bank) Tilefish, white hake, and conger eel are reported using this habitat, as well as smaller species (Valentine et al., 1980; Cooper et al., 1987).

Other Vertebrates

This habitat is too deep for those bird or seal species that could use estuarine and coastal reefs.

Significance, Status, and Trends of Bight Reef Habitats and LMR's

The reef habitats in the Bight are significant to fisheries because they expand the range of some reef-associated species and perhaps their population abundance, possibly beyond the apparent extent of seabed area the reefs cover, as per Figure 6. The growing array or network of reef habitats (all types), that occur or have become established or specifically placed along the coast and across the shelf, can also provide corridors of supporting habitat for some reef-associated species, such as black sea bass, to use during seasonal migrations (Fig. 6). As more fine-scale, side-scan sonar seabed mapping becomes available, more low profile hard bottom and reefs will undoubtedly become known or identified, including many of the objects classified as "obstructions" by NOS or known as "snags" by fishermen. Table 2 shows that a variety of important commercial and recreational fishery resources are known to be associated or depend on reef habitats for some or most of their life history, and reef structures can serve as refuges from trawling for some species. Certain commercial fisheries, such as American lobster or fish trapping and gill netting, favor reef habitats, and recreational fishermen have long valued wrecks and reefs as fishing grounds. It is also becoming evident that several forms of estuarine and coastal reef habitats serve as juvenile fish nurseries in the Bight, e.g. oyster and mussel beds, and artificial reefs can increase this function (Heise and Bortone, 1999).

Natural reef habitats occur primarily in the Bight from within and just outside New York Harbor, through Long Island Sound, and along the Southern New England coast, and may be fairly static, although some rock reefs have been removed or reduced because of their hazard to deep-draft ship navigation, or been covered by shoreline development or silt. The reports of sandstone outcrops on the continental shelf off New Jersey and Maryland need further investigation as to their significance as fishery habitat. Oyster reef habitats in many estuaries are greatly reduced, especially since the 1950's (MacKenzie, 1997a, b). Made-man "reefs" of all sizes are continuing to add this type of habitat to the environment in all areas via accidental, careless, and intentional means. South of Long Island Sound, man-made reef habitats probably contribute significantly to the wider distribution of reef-associated species.

Although there have been studies of epibenthic fouling (Maloney, 1958) and fishery use of reef habitats in the Bight (Figley, 1996), reef habitats in this area have not been well studied or examined holistically, with all biological components and their interactions defined. Questions remain about how man-made reef habitats have compensated for functional losses in natural reef habitats or other sheltering habitats, such as eel grass beds, caused by man-made alterations, such as excessive nutrient and silt inputs, and toxic pollution.

Not all reef-associated organisms are benign or beneficial. Some "reef" species can be nuisances or cause human-interaction problems, e.g. wood-destroying Teredo "shipworms," gribbles, and other borers that attack wooden pilings and vessels; fouling organisms that inhibit vessel use efficiency, weigh down navigational aids, and fill pipelines that cycle estuarine or marine waters. Other species can be a source of larval resource species predators, e.g. carnivorous coelenterates such as anemones, or support the sessile stages of "jellyfish," such as *Chrysaora quinquecirrha* and *Cyanea capillata*.

Besides these nuisance organisms, the obvious hazards to vessel navigation and safety, and causing the loss of towed fishing gear and anchors, reefs have other negative side effects. Wooden shipwrecks and other submerged wooden structures can be reservoirs and sources of the nuisance borers, noted above, which can attack wooden (and some concrete and plastic-coated) pilings within harbors (Nigrelli and Riccuiti, 1970). All man-made artificial reefs are subject to degradation processes to variable degrees (depending on the material used and the severity on environmental conditions they are exposed to) and some types were formerly subject to movement of certain reef material out of permitted reef sites, such as automobile tires, which interfered with other uses of the coastal zone, e.g. trawling and bathing. This problem mostly occurred in the early formative and experimental phases of artificial reef development, although some old artificial reefs are still the source of material lost from the reef sites.

Another aspect of the creation of reef habitat (accidental or intentional) on open bottom is that the reef and its associated community displaces previous open bottom communities (Shipp, 1999). It is normally assumed that open bottom habitat is not limited, at least in the Bight, and that open habitat loss caused by the development of new reef habitats will not significantly effect the function of this habitat to support desired population levels of other managed demersal species. It is also a value judgement of whether the reef habitat fishery resource community is of equal or greater value as a harvestable or economic resource, than to that of the soft-bottom community it replaces. These issues are not easy to resolve, and little information is available for such comparisons.

Several reef-associated fishery species are presently considered over- or fully exploited; these include Atlantic cod, haddock, pollack, scup, black sea bass, ocean pout, tilefish, striped bass, and American lobster (Clark, 1998; NMFS, 1999b). Oysters (as a fishery resource in this region) persist in declining natural beds and under culture; but the profitability of labor-intensive culture is declining because of increasing costs and stagnant prices per bushel, and continued investment in maintaining these beds is in question (C. MacKenzie, Jr.[2]). Although the role of habitat in the conservation of these species is still poorly understood, reef habitat losses, at least in estuarine nursery grounds, can be suspected as being contributory (Rothschild et al., 1994).

Human Threats to Bight Reef Habitats and LMR's

Threats to reef habitats, in general, have been discussed by Bohnsack (1992), with emphasis on coral reefs. He noted inadequate knowledge of reef functions, a variety of habitat effects discussed below, and overfishing as being responsible for causing alterations in reef community structure and fishery productivity. There are the "normal" or natural threats to reef communities, as well, including damage from severe storms or other climatic events, and geophysical processes, such as changes in sea level and temperatures, but the scope of these natural threats is usually beyond human management.

A listing of most other threats to temperate reef habitat in the Bight, besides those named by Wilbur and Pentony (1999), includes, in no particular order:

1) Removal of reef habitats deemed navigational hazards or for channel deepening.
2) Siltation of reef habitats owing to ineffective land or coastal soil erosion control, or increased resuspension and distribution by vessel traffic, dredging, etc., which also causes the loss of low-structure, submerged aquatic vegetation (SAV) beds.
3) Damage to older wrecks and to algae and coral beds by towed fishing gear and large anchors (and in the 19th century by dynamiting wrecks to get valuable metals and to harvest fish).
4) Burial by dredged material disposal, including beach sand nourishment loss of shallowwater wrecks, and by shoreline jetties and groins.
5) Discharges or accidental coastal spills of toxic materials.
6) Removal of docks and piling fields in urbanized estuaries; these fields may replace lost shoreline trees, and SAV or oyster beds and other submerged or partially submerged natural habitat formerly available as LMR habitat.
7) Nonpoint source pollution in estuarine and coastal waters, some of which can be toxic to reef dwellers.
8) Loss of biogenic reef habitat, such as oyster and mussel beds, because of disease, overharvesting, other factors in this listing or unknown factors (Rothschild et al., 1994).
9) A strong preference or dependence on reef habitats can cause reef fish and lobster mortalities during occasional estuarine-coastal episodes of anoxia/hypoxia (Ogren and Chess, 1969; Steimle and Sindermann, 1978).
10) Power plant water use can kill the eggs and larvae of reef-associated species that are generally available in waters drawn into the plants, but especially from the spawning of species that use the rip rap or other hard surface linings of water intake canals or conduits as reef habitat.
11) Coastal or estuarine sand mining and redistribution activities.

Man-made Reefs as LMR and Habitat Management Tools

The planned placement of reef structures is a habitat management action, and this management action can be applied for various purposes, besides that of traditional fishery enhancement or one-to-one reef habitat replacement. Below is a list of habitat or fishery issues that can be addressed by reef habitat conservation, expansion, or manipulation, in no particular order:

1) Habitat fragmentation: Artificial reefs can mediate loss of structured habitat (reefs and SAV), especially in estuaries (Rothschild et al., 1994; Eggleston et al., 1998). The continued input of man-made reef material (intentionally or otherwise) into the environment is reducing natural habitat fragmentation for reef-associated species and perhaps supporting their population expansions, especially on the continental shelf south of Long Island where reef habitat is naturally limited (Fig. 2). The system of wrecks and man-made reef-like structures across and along the continental shelf and coastal areas has created an array of reef habitats (only partially evident on Figure 6 owing to the limitations of the NOS database) that can act as corridors or a network that better supports the migrations or other movements of shelter-using species, such as black sea bass and American lobster, than occurred a century or two ago. Although, in the absence of better shelter, fish and megafauna often create or use previously created shallow depressions in soft sediments or low-profile biogenic structure (e.g. amphipod, polychaete, or anemone tubes) or molluscan shell accumulations for shelter (Auster et al., 1995).
2) Maintain biodiversity: Hard-bottom or reef habitats maintained or introduced among other habitat types, such as flat sand or mud bottoms, can increase habitat structural and biodiversity for algae, invertebrates, and fish (Sebens, 1991).
3) Provide refuge from excessive or damaging fishing: Introduction of solid high profile and complex-surfaced reef structures into an area can restrict the use of certain towed fishing gear in that area and promote a refuge function (Bombace, 1997). Artificial reefs that are under the control of state or Federal fishery resource agencies can be established as special management zones, reserves, or refuges from all or most harvesting (Bohnsack, 1992).
4) Expand limiting habitat: In some areas of the Bight, reef-associated fauna can be habitat limited because of inter- and intra-species competition for shelter (Richards and Cobb, 1986). As the density of all types of reef structures increase in the Bight and are more widely distributed across the open, sandy bottom, there will be more opportunity for

[2] C. L. MacKenzie, Jr., U.S. Dep. Commer., NOAA, NMFS, J. J. Howard Marine Science Laboratory, Highlands N.J. Personal commun., 2000.

epifaunal species with relatively short lived larvae to find suitable habitat for colonization and thus gradually expand the distribution of hard surface, reef dwellers.

5) Maintain access for land-based fisheries: Some reef-like structures in estuaries, such as obsolete docks and piers in ports, can be preserved or maintained because, besides attracting certain fishery resources or their prey to submerged structures, they can also be used by human urban dwellers to support subsistence or low-income recreational fisheries (Hawkins et al., 1992; Able et al., 1998). Docks and piers also offer physically disabled people more opportunities to participate safely and comfortably in recreational fishing.
6) Estuarine/coastal nutrient removal: Experiments with artificial reefs suggest an abundant filter-feeding epifauna supported by reef surfaces, such as mussel populations, can potentially reduce and entrain eutrophic phytoplankton production in a reef area and in some cases reduce nutrients when attached algal colonies are established (Laihonen et al., 1997).
7) Compensation for unavoidable habitat loss: In cases where aquatic habitat loss is unavoidable, and in-kind habitat replacement is not available or feasible, reef habitats can be used to enhance productivity of fishery forage species, if not fishery species, as out-of-kind mitigation (Burton et al., 1999).
8) Provide opportunities for scientific research: The ability to plan the deployment and design of artificial reefs offers a range of opportunities for scientists to test hypotheses about issues, including the behavior of reef-associated species, the role of habitat size and complexity in species' use, and a number of other topics, such as those discussed below.

Information Deficiencies and Research Needs

Because of the difficulty in surveying many reef habitats without the use of divers or remote in situ cameras, much less is known about these habitats and their associated biological and fishery communities than is known for open seabed habitats and communities, and often only anecdotal information or observations are available. However, shipwrecks and reefs are now being given serious scientific attention as habitat for epifauna and fishery resources (Leewis and Waardenburg, 1991). But the characteristics and advantages of this habitat and its biological association are not considered in analyses and multiple regression models of associations among mixed demersal species, which often use only bathymetric and thermal metrics, but not benthic habitat structure as a distribution variable (Colvocoresses and Musick, 1984; Murawski and Finn, 1988). The developers and managers of artificial reefs for recreational fishing have noted some of their general information needs (Steimle and Meier, 1997), and these include: feasibility of estuarine applications, a better understanding of noncoral reef community ecology, better information on the life histories of reef-associated species, best reef designs for different applications and situations, better information on the population dynamics of reef resources, more information on reef productivity compared to other habitats, more information on the use of reefs to mitigate habitat loss, and socioeconomic data on the value of reef fisheries.

Some other specific information needs for the Bight include, in no particular order:

1) Diurnal and seasonal use of Bight reef habitats by LMR species.
2) Use of Bight reef habitats by the early benthic phase of LMR species.
3) Winter habitat requirements of south and offshore migrating Bight LMR's with strong summer reef-associations, e.g. black sea bass and scup.
4) Role of man-made reef habitat in conserving and enhancing fishing resources is poorly known, including the use of these reefs as refuges or reserves.
5) Ecology and LMR species use of deep-water reefs, besides the submersible studies associated with tilefish and submarine canyon habitat.
6) Ecological stability and dynamics of epifaunal communities should be better studied because many "fouling" species are relatively unstable and unpredictable in time and space because of their unpredictable recruitment and low survivorship, although some encrusting communities of bryozoans, compound ascideans, colonial cnidaria, and sponges are long-lived. (Dayton, 1984), and little is known of long-term community dynamics of subtidal reef communities, which can have several community states, some to the disadvantage of fishery resources, i.e. when coelenterates dominate (Steimle et al., 1999a).
7) To support the development of EFH parameters for managed fishery resources associated with structures or reefs, an inventory of significant structured habitats and concentrations of habitats with limited structural components, e.g. shell fields that may be important to juveniles, are needed, especially in the Bight. More side-scan sonar surveys are needed to define the distribution and abundance of hard-bottom and reefs in estuarine and marine waters, as per Smith and Greenhawk (1998), and to define, document, and monitor the shape and surface complexity of various wrecks and reefs and link this with LMR use.
8) Small scale spatial studies of the functional aspects (use) of reef habitats are needed especially to relate the size and complexity of reef habitats and interactions with hydrographic environment with LMR use (Auster, 1988).
9) The experimental approaches that are conducted in warmer temperate or tropical waters on the use and value of reef habitat, and the interrelationships of habitat size, shape, and complexity of fishery species use (Bohnsack et al., 1994) need to be attempted in the cooler temperate waters of the Bight to address similar information issues.
10) The generators of waste materials that are not readily or cost-effectively recyclable or disposed of on

land, will continue to consider the sea as an disposal option and a wide diversity of solid materials, including nonsolids such as incineration ash incorporated into a solid matrix such as concrete, are often proposed for use in developing artificial reef materials. Inadequate information is usually available on the sustained value of these diverse materials as non-toxic and positive habitats for fishery resources.

11) Models are needed to explore the effects of changing the density or distribution of artificial reef habitats on resident or seasonal fishery resource population dynamics and movements.

Summary

Man-made habitats have become a growing integral part of the coastal and shelf ecosystem in the Bight over the last 150 years and they support populations of managed fishery resources, at least seasonally. Recognition of these habitats, their availability, and their use by fishery resources can support the use of this information in fishery resource population abundance estimates (these habitats can be a refuge from survey trawls).

Recognition of this habitat can help understand the probable migration pathways of shelter-associated species that may benefit from the growing array of man-made reef habitats. Recognition is a step toward conserving and making better use of this habitat to support appropriate fishery management goals, by habitat manipulation or enhancement, and thus diversifying fisheries in many areas. This summary is also a preliminary effort towards developing a baseline habitat inventory for the Northeast Region.

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