Marine Life Colonization of Experimental Reef Habitat in Temperate Ocean Waters of New Jersey

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ABSTRACT

A biological colonization study of experimental reef habitats in temperate ocean waters off New Jersey was conducted over a 60-month period. A total of 143 different taxa were identified within the experimental units, including 44 arthropoda, 43 annelida and 33 molluska. Individual organisms had an estimated mean abundance of 432,022 organisms/m² of habitat footprint, including 133 fish, 3,346 crabs and 22 lobsters. Colonial organisms covered 85,035 cm² of the habitat surface area. Mean total biomass of the organisms inhabiting the units was 58,358 g/m², with blue mussel comprising 54.8 percent of the total. Predation accounted for a 45 percent decline of biomass between surfaces exposed and not exposed to predators. There was no statistically significant differences in biological colonization rates on concrete, rock, steel and rubber substrates. On an equivalent area basis, the biomass enhancement ratios of the experimental reef habitats over surf clam-dominated and polychaete crustacean-dominated sand bottom habitats ranged from 24 to 123 and 771 to 2,195 times, respectively. The results suggest that complex reef habitats provide both attachment surfaces and refuge habitats that support a diverse and abundant marine life community.

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INTRODUCTION

An inventory of the biological attributes of marine life communities inhabiting reefs, including species diversity, biomass, life stage, predation, habitat preference and succession, is an essential ingredient of any reef-building program. Biological monitoring is especially important in assessing the effectiveness of New Jersey's reef program in meeting its primary objective of providing habitat for fish and invertebrates (NMFS 1995).

While most artificial reefs are built for fish, shellfish (lobsters, oysters) and/or fishermen, the epifaunal invertebrate community is an important ecological component of the reef community providing the basis of the food chain that supports harvestable resources and comprising the vast majority of life, by numbers and biomass, inhabiting ocean reefs. The intention of this investigation was to inventory the smaller, mobile and sessile invertebrate communities and juvenile fish inhabiting New Jersey reefs. No attempt was made to examine adult fish populations.

Turf or fouling communities, composed of sessile, invertebrate epifauna and algae in shallower waters, are inventoried in a variety of ways. Palmer-Zwahlen and Aseline (1994) used divers to identify fouling organisms found within randomly selected quadrats. Feigenbaum et al. (1985) and Foster et al. (1994) had divers scrape reef surfaces and collect samples for laboratory analysis. Wendt et al. (1989) combined scrape samples with underwater photographs to inventory turf communities. Many researchers have placed settlement plates of various reef-building materials on sea floor racks that can later be retrieved by divers for laboratory analysis (Sheehy 1983; Woodhead and Jacobson 1985; Bailey-Brock 1989; Hawkins 1995; Tumbiolo et al. 1995; Chang and Pearce 1995). The collection of cryptic or mobile epifauna, which includes crabs, shrimps, worms, snails, starfish and small juvenile fish, is more challenging since these animals are small, cryptic and often hide in holes and crevices in reef structures or among sessile epifaunal growth. Benson (1989) used a suction device to capture mobile prey in turf scrape samples. Traps and nylon bags are also used to capture certain mobile invertebrates (Forrest Blau and Byersdorfer 1994). The shortcoming of using traps is that they do not provide information regarding the numbers of mobile invertebrates per unit of habitat. In clear, tropical waters, the common method of evaluating juvenile fish populations is through counts by divers (Gorham and Alevizon 1989; Danner et al. 1994; Jessee et al. 1985; Adams 1993; Bohnsack et al. 1997; Brock and Kam 1991).

The use of divers to observe mobile epifauna and juvenile fish and to quantify their population size underwater on New Jersey reefs is impractical because of poor visibility, and the cryptic habits or large population numbers of many of the species. Another factor that prohibits using diver observations to collect biological information is the vast amount of field time that is needed to accomplish the task. For these reasons, we decided to use specially-designed, miniature reef habitats as experimental sampling units that could be placed on the sea floor and later retrieved by divers, disassembled, and samples returned to the lab for analysis. The experimental habitats were designed to afford extensive colonization surfaces for sessile epifauna, including 8 settlement plates of 4 different, common reef-building substrates, numerous and varied hiding spaces for mobile epifauna and an internal chamber for juvenile fish. Thus, all of the components of the reef community that we were investigating could be collected simultaneously in a few hours and brought back to the lab where a thorough, detailed analysis could be completed.

According to Seaman (2000), our study was designed to obtain first level information about temperate reef biology – species diversity, abundance, biomass, size ranges, and predation pressure. Specifically, the objectives of this reef performance monitoring survey included:

1. an inventory of the sessile and mobile epifauna and juvenile fish inhabiting an experimental reef habitat;

2. a quantification of the standing stock biomass of sessile and mobile invertebrate epifauna and juvenile fish per unit of habitat volume on an experimental reef habitat;

3. an examination of the successional changes in species diversity and standing stock biomass of epifaunal invertebrates on an experimental reef habitat over time;

4. a comparison of the colonization rates of sessile invertebrate epifauna on 4 different reef-building substrates;

5. an investigation of predation pressure on sessile invertebrate epifauna on 4 different reef-building substrates.

METHODS

The Experimental Reef Habitat Sampling Unit

The design parameters that guided the development of the experimental reef habitat sampling unit included:

1. heavy base for undersea stability;
2. height and width dimensions small enough to fit inside a plastic drum;
3. vertical orientation to provide enough height off the bottom to obtain a true reef sample;
4. inside and outside attachment surfaces for 8 colonization plates;
5. a variety of small cavities and cryptic spaces; and
6. a screen enclosure to exclude large, predatory fish.

It should be noted that the experimental reef habitat was a sampling unit and did not represent any structure used to build reefs. Henceforth, they will be referred to as experimental reef habitats, sampling units or simply, units. The structural components of the experimental habitat consisted of a rectangular closed box (height: 77 cm, width: 32 cm x 32 cm) constructed out of 12.5-gauge plastic-coated wire of 2.5-cm-square mesh imbedded vertically into a base made from a truck tire filled with concrete (Figures 1 and 2). The base was used only for ballast and weighed 200 to 250 kg. Vertical plastic pipes were added to ensure rigidity of the box and a reinforcing rod was installed as a lifting eye.

Ten corrugated plastic roofing panels were placed inside the wire mesh box. Each layer was rotated 90° to produce a honeycomb effect. Approximately 50 whelk (Busycon sp.) shells were placed on top of the panels to provide a complex maze of hiding spaces, cavities and attachment surfaces.

The upper portion of the box consisted of a hollow chamber completely enclosed by the wire mesh. Two plates each of four different materials – rubber, concrete, steel and rock – were attached back to back to the upper chamber of the box, with one plate outside and one plate inside the mesh (Figure 3). The plates represented four common reef-building materials and served as colonization substrates for sessile epifauna. The plates on the outside of the wire cage were open to predation from large fish and invertebrates; those inside the cage were protected from large predators, although some crabs that established themselves as juveniles within the unit did grow to adult size and were trapped within the cage.

The experimental habitats have a mean height of 77.3 cm, a sea floor footprint of 1,034 cm^2 and encompass a volume of 79,609 cm^3 (Table 1). The wire cage itself has a mean surface area of 8,626 cm^2, although this attachment surface consists of small diameter (0.3cm) wire. The fiberglass panels (top and bottom) have a combined surface area of 14,855 cm^2. The whelk shells (inside and outside) have an approximate total surface area of 22,730 cm^2. For the colonization plates, only the exposed flat surface and edge were measured, the back-to-back surfaces were not counted. The colonization plates have the following mean surface areas: concrete = 1,053 cm^2; steel = 776 cm^2; tire = 572 cm^2; rock = 574 cm^2. The mean total area of attachment surfaces for the entire habitat is 49,186 cm^2. Each experimental reef habitat provides an increase in surface area of 47.6 times that represented by the sea floor footprint of the habitat. In comparison, a solid block the same height as the experimental habitat would have a surface area to footprint ratio of 10.6. Thus, the experimental habitat provided a complex, cryptic habitat with extensive surface area available to biological colonization.

Study Site

The study site was the Barnegat Light Reef Site. This site is located in the northwestern Atlantic Ocean, 3 NM offshore of Barnegat Light, NJ. The depth is 17m. The sea floor consists of coarse sand, gravel and pebbles. Reef structures placed on the site include concrete-ballasted tire units, Reef Ball concrete habitats, obsolete army tanks and 3 small steel vessels (Figure 4). The total volume of reef structure on this site is 6,138 m^3; the total footprint of reef structure is 5,981 m^2.

Deployment

In October 1996, 30 experimental reef habitat sampling units were placed on the study site from a motorized barge operated by the Ocean County Bridge Department (Figure 5). After the barge was anchored, the experimental habitats were individually lowered to the sea floor using a tether line and submersible float equipped with a release hook. This was done to ensure that the units landed upright. The units were spaced apart in a group about 30 m in diameter (Figure 6).

Retrieval

In October of each year, experimental habitats were retrieved by divers. Each of these units was quickly enclosed within a plastic drum sealed with the tire base (Figure 7) to trap the organisms inside. Once enclosed, each unit was raised to the surface using an inflatable lift bag. The unit was then lifted into the boat using an electric winch and davit and placed inside a plastic tub (Figures 8 and 9). After removing the drum, the wire mesh was cut open with wire cutters (Figures 10-12). The following items were removed and inserted into resealable, 10-liter, plastic bags: 8 colonization plates, 2 fiberglass panels, 5 whelk shells (Figure 13), and a sample of wire mesh. The sample panels and whelk shells were randomly selected. The remaining sand, gravel, shell hash and other debris were scraped off what remained of the box and deposited into the tub. During unit breakdown, large organisms (>3 cm), such as sea stars, crabs, lobsters and fish were removed and placed in plastic, 5-liter jars filled with 10% formalin solution. The contents of the tub were rinsed through a 0.5-mm mesh sieve and bagged as bulk samples. All samples, with the exception of the samples in formalin, were stored on ice in coolers for transport back to the lab, where they were frozen.

Lab Analysis

Various techniques were employed to examine and remove organisms from the different components of the unit. Whelk shells were measured for length, then cut in half with a miter saw equipped with a 2 mm-wide masonry blade to expose the inside of the shell. The shells and the fiberglass panels were analyzed in a similar fashion. All mobile invertebrates and sessile, individual organisms, such as anemones and mussels, were removed, sorted by species, counted, weighed in aggregate, and measured. In 1998 and 1999, weights were measured to the nearest 0.1g on a triple beam balance. In 2000, and 2001, weights were measured to the nearest 0.001g on an electronic balance. All weights were reported as damp weights that included shell. Live barnacles and tubeworms were counted, and when possible, removed and weighed. The surface areas covered by colonial, encrusting bryozoan, hydroid, stone coral and sponge colonies were estimated using sheets of clear plastic printed with a 1-cm-square grid. Due to their fragility, most hydroid colonies did not withstand the freezing and thawing process well enough to do more than obtain weights. The percent area of coverage of the wire mesh by encrusting colonies was estimated for each 2.5 cm wire segment in increments of 25%.

All of the preceding types of samples were then individually rinsed into a 0.5 mm mesh sieve along with residual contents left inside each sample’s collection bag. The contents of the sieve were then placed under a dissecting microscope to sort, identify, count, and measure the additional mobile invertebrates for each sample.

Colonization plates were sorted individually (Figures 14-16). First, all large mobile organisms were removed for later analysis. Second, the percent coverage of plate surface area by colonial species was estimated using the 1-cm^2-square grid. Third, attached sessile, individual organisms, such as anemones, tubeworms, barnacles (Balanus spp.), slipper shells (Crepidula spp.), mussels (Mytilus edulis), and jingle shells (Anomia sp.), were counted. These organisms (when possible to remove in their entirety) were then weighed. Only the organisms found on the exposed surfaces of the plates, i.e. tops and sides, were collected for analysis. Each plate and the bag containing it were then rinsed into a 0.5 mm sieve to retrieve any remaining mobile organisms for later analysis.

The samples of the large animals extracted and placed in formalin from each unit and the mobile invertebrates taken from the colonization plates were independently speciated, counted, weighed and measured. Since these bulk samples proved to be too large to sort and quantify in their entirety, the following procedure was used to obtain random subsamples of at least 10% by weight for each unit: First, the sample was weighed; second, the sample was thoroughly mixed and spread to an even depth on a tray; third, a spatula was used to scoop subsamples from randomly chosen locations on the tray; fourth, the subsample was weighed on a triple beam balance, speciated, and enumerated following the same procedures used for the preceding samples.

Samples of certain attached or encrusting taxa, such as barnacles, bryozoans, hydroids, stone corals (Astrangia astrelformis) and sponges, were removed and weighed to determine a per unit weight, by number for barnacles, and by area for the colonial encrusting organisms. The total weights of these taxa were estimated, when necessary, by expanding per unit weights to the total number for barnacles and the total surface area for colonial invertebrates.

Length frequencies by species were obtained by measuring individuals to the nearest mm as follows: fishes (total length); crabs (carapace width); lobster (Homarus americanus) (rostrum to tail length); and blue mussel (shell length).

RESULTS

Nomenclature

The taxonomic classification and common and scientific nomenclature of marine life identified in this study are presented in Table A.

Sample Size

Between 1998 and 2001, 10 experimental reef habitats were retrieved and analyzed as follows:

Year	Number of Units
1998	1
1999	3
2000	3
2001	3

These 10 units contained a total of 80 colonization plates, 20 of each different reef-building material. The plates were also separated into two treatments – inside and outside the mesh cage. The numbers of plates sampled by material and treatment are as follows:

Material	Inside	Outside
Rock	10	10
Concrete	10	10
Steel	10	10
Rubber	10	10

For comparative purposes with other studies, the results concerning both the entire unit and the colonization plates were expanded to a m² base. In the case of the entire unit, results were extrapolated to a m² of sea floor footprint. For colonization plates, the unit represented a m² of surface area. The expansion factors used to extrapolate survey findings to the appropriate m² base are as follows:

Habitat Component	Expansion Factor (Range)
Experimental habitat	8.4-10.1
Colonization plates	
Rock	21.7-57.1
Concrete	14.4-21.8
Steel	24.4-26.9
Rubber	29.2-45.7

Species Diversity

During the 60-month study, a total of 143 different taxa were identified on the experimental reef units (Table 2; Figure 17). All of the phyla encountered were from the Kingdom Animalia; no plant taxa were observed on the experimental habitats. A total of 106 genera (Figure 18) and 82 species (Figure 19) were identified. The taxa included representatives from 9 phyla. In terms of identified taxa, the most diverse phyla included arthropoda (44), annelida (43) and molluska (33) (Table 2). The habitats included 7 colonial and 136 individual-organism taxa; 35 sessile and 107 mobile (1 unknown) taxa; and 7 vertebrate and 136 invertebrate taxa. There were 38 taxa strongly associated with sediments and were probably present in the experimental habitats due to their subsidence into the sandy sea floor; these taxa included 13 mulluska, 14 arthropoda, 8 annelida, 1 cenidaria, 1 echinodermata and 1 nematoda.

Between 1998 and 2001, the number of taxa identified on the experimental reef habitats rose from 39 to 143 (Figure 17). The number of taxa identified in all samples in the 2001 survey was 87, only slightly more than the 83 taxa identified in 2000. Although the absolute number of taxa identified throughout the survey continues to rise (Figure 20), the number of new taxa discovered each year declined after 1999. New taxa are generally represented by a small number of individuals that provide community diversity, but do not constitute a significant portion of the overall biomass. The slope of the curve suggests that many new taxa inhabiting the experimental reef habitats will be identified over the next few years.

Abundance and Biomass

During the 60-month study, the mean abundance and biomass of marine life inhabiting 10 experimental reef habitats are summarized in Table 2. The abundance of colonial species was measured in terms of surface area coverage; the mean coverage of all colonial species amounted to 85,035 ± 13,845 cm² per m² of unit footprint. Individual organisms were counted; the mean abundance of individual organisms was 432,022 ± 76, 150 (SE) per m². Over the course of the 60-month survey, only 1 taxa (blue mussel) numbered more than 100,000 individuals (Table 3). Only 35 percent of the taxa were represented by more than 100 individuals per m². The mean total damp weight biomass of all marine life averaged 58,358 ± 8,745 g per m² of experimental reef habitat footprint. Molluska was the dominant phylum, representing 54.8 percent of the total unit biomass, followed by arthropoda (22.1 percent), and cnidaria (13.8 percent, (Figure 21). Other important phyla included ectoprocta (3.5 percent), annelida (3.1 percent), echinodermata (2.9 percent) and chordata (2.2 percent). Nematoda and porifera represented a combined total of only 0.1 percent of the overall biomass.

For molluska, blue mussel was by far the dominant species in terms of biomass, followed by two species of slipper shells (Figure 22). The arthropoda were dominated by a sessile genus, barnacle, and a mobile species, Jonah crab (Cander borealis)(Figure 23). Although 7 species of fish were captured on the habitats, cunner (Tautogolabrus aospersus) was by far the most numerous and comprised the greatest combined biomass (Figure 24). During all sampling periods combined, the mean number of fish was 133.5 ± 37.8 per m^2. These included only small fish, less than 165 mm in TL, that were able to swim through the 2.5-cm- square mesh. Most of these were juvenile fish. The actual number of small fish inhabiting the experimental habitats may be much greater, since some fish congregating outside the unit may have been scared away by the divers. Divers observed large, adult fish retreat from around the experimental habitats at their approach. The only important game species was black sea bass (Centropristis striata), with a mean abundance of 4.7 ± 2.6 fish per m^2, but representing only 3.5 percent of the fish by number (Table 2).

Arthropoda are important forage species for marine food and gamefish. The mean abundance of arthropoda was 135,489 ± 23,404 individuals per m^2 of unit footprint. Eleven species of crab accounted for a mean of 3,545 ± 982 individuals per m^2. All life stages of crabs, from megalops larvae to adults, were present within the unit. Some Jonah and rock crabs (Cancer irradians) had grown so large (over 40 mm carapace width) that they could not pass through the mesh and spent their entire lives inside the small, experimental habitat. The small cavities of the unit provided escape cover for juvenile American lobster, which had a mean abundance of 22.4 ± 3.7 individuals per m^2.

The mean standing stock biomass of all taxa inhabiting experimental reef habitats fluctuated between 35,716 and 94,064 g/m^2 of unit footprint during the 4 sampling years, with 2001 showing the greatest biomass (Figure 25). Colonial organisms showed a steady increase in biomass over time, while individual organisms accounted for most of the variation between years (Figure 26). The fluctuation in standing stock biomass between 2000 and 2001 collections was extreme, exhibiting a 263 percent increase. Annual variations in biomass for 9 taxa are presented in Figures 27-35. Examining 4 sampling points collected during 4 separate years, arthropoda, annelida, nematoda, and cnidaria exhibited trends of increasing abundance.

Colonization Plates

Over the 60-month study, 18 genera of sessile epibenthic invertebrates were found attached to the colonization plates, including 6 colonial and 12 individual genera. Although mobile invertebrates were also observed on the plates, they were not included in the plate analysis.

In terms of mean total biomass, colonization was greatest on concrete (1,004 ± 184 g/m²), followed by rock (943 ± 231 g/m²), rubber (833 ± 215 g/m²) and steel (730 ± 157 g/m²) (Table 4; Figure 36). However, none of the differences was statistically significant (P=0.05), indicating that marine life had equal success colonizing the 4 reef-building materials used in New Jersey (Table 4). Man-made materials (concrete, steel and rubber) were just as effective as a natural one (rock) in supporting colonization by encrusting marine life. Individual organisms represented between 75 and 85 percent of the biomass of all organisms colonizing the various plate materials (Figure 37). The combined standing stock biomass on colonization plates of all materials declined between 1998 and 2000 and then increased substantially in 2001 (Figure 38). During 1998-2000, colonial invertebrates increased in biomass, while individual invertebrates sharply declined (Figure 39); in 2001, however, a shift occurred, with the colonial genera declining and the individual-organism genera increasing over threefold in biomass over the 2000 collection.

Comparisons of mean standing stock biomass colonizing the 4 reef substrates broken down by taxa is presented in Table 4. While the mean biomass of several taxa appears to be substantially different on different substrates (e.g., Astrangia: concrete vs. rock), very few comparisons were statistically significant (Table 5). This was due to high year-to-year and sample-to-sample variability. All of the statistically significant substrate comparisons involved rubber. The findings suggest that rubber is a better substrate than concrete and steel for hydrozoa, but a poorer substrate than concrete for colonization of Astrangia and hydroids, than steel for bryozoa and hydroids and than rock for Balanus.

Predation

In an attempt to examine predation of reef habitat colonizers by large fish and crustaceans, colonization plates were located inside the mesh box and outside the mesh. The plates outside the mesh were open to predation by large, free-ranging predators, the plates inside the mesh were limited to predation from small predators living within the habitat. Combining all substrates over 4 sampling years, the mean standing stock biomass of sessile epibenthos was significantly greater on the inside (1132.8 ± 166.4 g/m²) of the mesh as opposed to the outside (623.3 ± 89.5 g/m²), (Student's t-test, Analysis of Means; T =2.70; P=0.008) suggesting that predation resulted in a 45 percent decrease in standing stock biomass (Table 6; Figure 40). These data suggest that an average of 509.5 g of epibenthic biomass was removed from each m² of colonization surface by predation during the 4 sampling periods. However, when examining each substrate separately, only rock exhibited a statistically significant difference (T=2.40; P=0.03) in biomass inside and outside the mesh (Figures 14-16). The data also revealed another trend. While the mean biomass of sessile individual epibenthos was 162 percent more abundant inside the mesh, the exact opposite was found for sessile colonial invertebrates, which were 74 percent more abundant on the outside of the mesh, suggesting that little predation occurred on these organisms outside the mesh. Undoubtedly, with the presence of crabs, lobsters, sea urchins, starfish, juvenile fish and other predators inside the box, some level of predation also occurred inside the protective mesh. Thus, the predation rate difference, inside vs. outside was probably even greater.

The effects of the enclosed mesh box on water circulation, colonization of larvae, food distribution and consequent growth of epibenthos was not examined, but may have influenced these results. For individual organisms, Metridium abundance constituted the greatest disparity between inside and outside the mesh, followed by blue mussel. For the colonial epibenthos, hydroids and bryozoan made up the bulk of the difference, being much more abundant outside the mesh.

Observations

In an attempt to provide suitable habitat for a diversity of sessile and mobile invertebrates and vertebrates, the experimental habitats were designed to have a variety of substrates and a complex matrix of crevices and chambers. While an optimum habitat was probably not achieved, we did succeed in enticing 145 identifiable taxa to use the experimental units as living space.

The wire mesh, probably because of its thin diameter and possibly its vinyl coating, did not provide a good attachment surface, except for hydroids and bryozoans.

While blue mussels attached to all of the colonization plates and internal substrates, large individuals were found in the secluded crevices of the corrugated panels and whelk shells. On exposed surfaces, only yoy mussels were found. This was most likely due to predation in exposed locations. Even when tucked inside the unit, water circulation was apparently sufficient to provide the necessary flow of food to these filter-feeders.

Crabs, shrimps, juvenile lobsters and small fish used the numerous holes and chambers for seclusion. The unit's large whelk shells provided exceptionally good homes for crabs and lobster. Unfortunately, whelk shells provide only short-term habitats due to the destructive activity of boring sponge and fan worms. After 60-months, the shells exhibited structure loss and were disintegrating. The honey comb cavities of the corrugated panels were also used by these mobile species.

Over time, the experimental habitats slowly subsided into the sandy bottom. During the last collection, the lowest few cms of the panels were covered by sediment. Panels buried in sediment were devoid of epibenthic growth. The presence of nematoda, surf clams (Spisula solidissima) and other sea floor denizens in later-aged collections is undoubtedly due to the subsidence of the experimental habitats and the accumulation of sediment in the lowest portions of the units.

Depending upon species, fish used the experimental habitats as cryptic living space or escape cover. Conger eel (Conger oceanicus), radiated shanny (Ulvaria subbifurcata) and ocean pout (Macrozoarces americana) probably lived in small crevices and holes; cunner and black sea bass, in contrast, schooled around the periphery of the habitat, scooting inside the protected mesh when disturbed by divers.

DISCUSSION

While most investigations regarding reef biology are focused on fish and a small number of harvestable macroinvertebrates, as upper level consumers, these animals represent, in terms of species diversity, abundance and mass, a relatively small portion of living reef communities. Danovaro, et al. (2000) refer to such investigations as the "top-down approach" of examining reef community secondary productivity. Studying the largely overlooked component of a reef's biological community is far more important to understanding the overall productivity of a reef, its function as a food web and its influence upon the surrounding marine environment (Steimle, et al. 2002). In the current study, small fish represented only 2.2 percent of overall biomass (although most adult fish were not included) and lobster accounted for only 0.3 percent of overall biomass. Other important components of the reef community, which were not investigated in this study, but should be recognized for a complete picture of the ecology of hard-substrate habitats, include algae (Turner, Ebert and Given 1969), microinvertebrates, ichthyoplankton (Stephens and Pondella 2000) and microorganisms (Turner, Ebert and Given 1969).

Factors Influencing the Study

While 10 experimental habitats had an average of 47.6 times more surface area than the footprint of sandy sea floor they covered, they only had 4.5 times more surface area than a solid block of the same dimensions. Even so, the experimental habitats probably have greater surface area per volume than most other reef materials, such as shipwrecks, concrete and Reef Balls; broken-up substrates, like rock piles, however, may have surface area to footprint ratios closer to those of the units. Wire comprised 18 percent of the habitat's surface area. Wire was not well colonized and therefore, provided little value as colonization substrate for epibenthos. With greater surface area available for biological colonization, it is reasonable to assume that the experimental habitats had greater levels of biological colonization than equal volumes of other reef structures. It is also reasonable to conclude that the experimental units did not represent the optimum habitat for most, if not all, species and thus, it is probable that even more productive habitats could be designed by increasing surface area and providing more suitable living spaces. A certain way to increase biomass per footprint would be to build a habitat with a greater profile.

The colonization plates represent a more direct relationship between the surface area provided by the experimental habitats and that of actual reef substrates of the same material. One difference between the experimental plates and in situ reef substrates is that the colonization plates were all vertically oriented. Wendt et al. (1989) found that epibenthic colonization was significantly greater on vertical than horizontal surfaces. In a Delaware Bay study, the underside of horizontal reef structures was most productive (Steimle et al. 2002).

The proximity of the experimental habitats to the sea floor and their relatively low profile (77 cm) may also have influenced the survival of many marine colonizers, some positively, some negatively. Animals that live in, on or near the sea floor, like crabs, urchins, starfish and tube worms probably benefited from a low profile habitat. Other attached organisms, such as blue mussels, barnacles, and anemones may have been negatively influenced by colonizing near the bottom, since they are more susceptible to predation and sand scouring during storms. General observations by divers suggest that mussel colonies are denser and comprised of larger individuals on the upper portions of shipwrecks.

The effect of physical and chemical parameters, such as storms, temperature and hypoxia, on the marine life assemblages colonizing the units was not examined, but is recognized as possibly influencing year-to-year fluctuations in marine life diversity and abundance.

The units were retrieved in October, in an attempt to maximize the presence of yoy fish recruited before they migrated in response to declining water temperature. It is expected that our findings would have been different if the season of retrieval was varied.

Since many taxa were not identified to the species level, the total number of species inhabiting the experimental habitats probably exceed the 145 reported taxa. The improved ability to identify species and better preservation of samples following the first-year sampling may have led to greater numbers of taxa and species being identified in latter samples.

Abundance

Sessile Epibenthos

On steel (shipwrecks) substrates in a different zoogeographical region off South Carolina and Georgia, Wendt et al. (1989) found that scrape samples had a standing stock biomass of sessile epibenthos of 2,486 to 3,916 g/m² on horizontal surfaces and 4,218 to 7,726 g/m² on vertical surfaces. On New Jersey reefs, Figley (1989) observed an average sessile biomass of 1,383 g/m² on the exposed outside of concrete-ballasted tire units and 3,381 g/m² on the protected interior. On a marine reef located at the mouth of Delaware Bay, Steimle et al. (2002) compared the annual production of epifauna on a concrete reef structure with that of the infauna of the surrounding sandy bottom over the 5-year period 1989-1994. On an equal footprint basis, the production of natural bottom infauna was 217-251 kcal/m²/yr as compared to 3,994-9,281 kcal/m²/yr of epifauna on the reef substrate. The current study found an average of 623 g/m² of sessile epifauna on external colonization plates and 1,133 g/m² on internal ones. These values are below those of the previous studies (Wendt et al. 1989, Figley 1989 and Steimle et al. 2002).

No studies in temperate waters were found that also included mobile invertebrates and small fish in their investigations of biomass of reef substrates. In our study, the inclusion of these other organisms and the additional attachment surfaces provided by the entire three-dimensional experimental habitat for sessile epifauna increased the biomass/footprint ratio substantially over that of just fouling growth. The mean biomass of all organisms on 10 habitats over the 60-month study period was 58,358 g/m² of sea floor footprint. Off New Jersey, blue mussel dominates reef epifauna, accounting for 51.4 percent of the overall biomass throughout the current study. Similarly, Steimle et al. (2002) found that the substantial annual variability in reef epifaunal biomass was attributable to the recruitment success of mussels.

Small Fish

Over a 14-year study, Pondella and Stephens (1999) found that the density of cryptic fishes varied from 0.016 to 0.640 individuals per m² on a California reef. Adams (1993) observed large numbers of yoy (<3 cm) black sea bass, scup (Stenotomus chrysops), cunner and other species using an artificial reef off Virginia. During a 5-month study in which plastic boxes filled with clam shells were used to mimic reef structure on a New Jersey reef site, Figley (1994) found mean densities of 47 yoy and 8 post-yoy fish/m² of 8 species living within the artificial habitats.

The density of small fish trapped within the experimental habitats of our investigation far exceeds those of the other studies. Over the 4-year study, an average of 133.5 small fish were found per m² of experimental reef habitat. These findings indicate that complex reef habitat that offers crevices and small enclosed spaces provides excellent habitat for small fish.

Small fish represented only 2.2 percent of the average total biomass of all taxa on the experimental habitats. Therefore, the ratio of forage base to small fish biomass was 45.4. This ratio suggests that a complex habitat provides an extensive forage base for small fish. Since adult fish are not included in this survey, it is not possible to calculate a complete ratio between forage and fish. Frank Steimle conducted a food habits study of the fish, lobsters and crabs captured on the units. The results of this investigation will be reported separately.

Lobster

Our study also demonstrated the importance of cryptic habitat as escape cover for juvenile lobster. Over the 60-month study, a mean of 22.4 young lobster (rostrum to telson length: 24-145 mm) were observed per m² of experimental habitat footprint. With an extensive sandy sea floor, it is reasonable to assume that the scarcity of cryptic habitat for the survival of young lobster is a limiting factor to recruitment of adult lobster in New Jersey. The potential for man-made reefs to increase survival and recruitment of lobster may be substantial, although the characteristics of the reef structure must fit the habitat requirements of post-larval and juvenile lobster.

Colonization Substrates

The rate and extent of colonization by sessile epibenthos is influenced by the type of fouling substrate. Smooth or slippery surfaces, such as glass, may make attachment difficult and therefore, decrease the fouling rate. The presence of toxins, such as active lime in fresh concrete, zinc on metal surfaces or anti-fouling ingredients in paint, also reduces fouling. In general, rough substrates are considered best for bio-fouling.

In California, Turner, Ebert and Given (1969) used wooden blocks to monitor fouling, but saw the wooden substrate disintegrate rapidly due to wood-boring crustaceans. In an experiment evaluating a variety of reef substrates, Chang and Pearce (1995) ranked their study materials in terms of biological colonization rates in the following order:

Rubber > Concrete > Steel > Wood > Aluminum

During the current study, we examined 4 common reef-building materials and found the following rank:

Concrete > Rock > Rubber > Steel

However, the differences in mean biomass of the four materials were not statistically significant, suggesting that all four reef-building materials used in New Jersey's Reef Program are relatively equal in production of fouling growth. Thus, it is reasonable to conclude that all of the reef-building structures used in New Jersey – rocks, concrete pieces, tires (not used anymore), Reef Balls, shipwrecks, army tanks , steel-armoured cable and subway cars – provide substrate of similar value to the fouling community and would be expected to produce similar biomasses of encrusting marine life per unit of substrate surface area.

Unlike the other 3 materials, steel has the unique property of corroding and flaking. The sloughing of the surface layer precipitates an accompanying loss of encrusted growth and the presentation of a clear surface open to subsequent colonization (Steimle, personal communication). The flaking property may have been responsible for steel's low rank in fouling biomass.

Predation

The grazing of reefs by both vertebrate and invertebrate predators can greatly reduce the biomass of the fouling community. Falace and Bressen (1999) found significant grazing of macrophyta by sea urchins on a reef in the Ligurian Sea. Off New Jersey, dense mats of blue mussel spat that appear in spring are often grazed clean by fish, crustaceans and starfish before winter. Over the 60-month current study, the mean biomass on colonization plates exposed to predation on the outside of the experimental habitats was 45 percent less than plates inside the mesh. Since there were also predators, such as crabs, lobsters, starfish and sea urchins, on the inside of the unit that undoubtedly grazed on the protected fouling growth, the actual predation rate on the unprotected plates was probably considerably higher than that observed. Standing stock biomass is only a static measurement of the (secondary) productivity of a reef. It is not an indication of all the biomass that was produced over the extended time period before samples were collected.

Succession

It is generally noted that fast-growing, short-lived species are usually the first fouling organisms to colonize temperate reefs, followed by slow-growing, long-lived species which eventually replace the initial colonizers. Off New Jersey, hydroids, bryozoans, barnacles and blue mussels are the first visible organisms to appear on reef substrates, followed by anemones, stony coral and sponges. However, succession is often interrupted by dynamic events, like storms, which scour life from lower reef surfaces and allow for fresh colonization and a repeat of successional events.

In a California study at a similar depth to the current study, Turner, Ebert and Given (1969) identified the following successional stages on reef structures over a 5-year period:

1. algae - bacteria
2. barnacle - hydroid
3. mollusk – polychaete
4. ascidian – sponge
5. ectoproct
6. anemone – stony coral

Wendt, Knoll and Van Dolah (1989) found no difference in species diversity, abundance and percent coverage of epibenthos on shipwrecks of ages between 3 and 10 years off South Carolina and Georgia. They reported no sponge or hard coral growth on wrecks as old as 10 years. During a 25-month study of colonization plates located off the New Jersey coast, Chang and Pearce (1995) reported successional changes in epibenthos assemblages. They noted that the presence of some species excluded the subsequent appearance of others. In a study of epibenthic colonization of tire rubber surfaces on New Jersey reefs, Figley (1989) found that the initial colonizers (123 days) were hydroids and bryozoans, followed by mussels and barnacles on older-aged surfaces (up to 823 days). Early colonizers and possibly initial succession may be influenced by the coincidence of reef deployment and spawning activities of fouling species.

In the current study, ectoprocts, mussels and barnacles quickly colonized the experimental habitats. Slower growing taxa, such as stony coral and cnidaria, increased in abundance over time. Oddly, sponge showed a gradual rise in abundance and then a drop during the 60-month sampling period. Sponge had a very low biomass in all sample periods and may take a much longer time period before it attains a significant level of abundance. It is believed that the rise in annelida and nematoda abundance over time was primarily a function of the units sinking into the sandy bottom and/or accumulating silt in unit spaces where these taxa thrive.

Enhancement Value

The following comparison of standing stock biomass of benthic fauna from the sandy sea floor in 10 to 20 m depths off central New Jersey with that of experimental reef habitats was prepared in most part by Frank Steimle, James Howard Marine Lab, National Marine Fisheries Service.

A review of databases suggest that the sandy benthic infauna and sessile epifauna of the area near our reef study site has two common community abundance states. One state is when the benthic sand community is colonized and dominated by population of either or both the surf clam or the sand dollar (Echinarachnium parma) and species commonly associated with these two species, such as predatory moon snails (Euspira heros), or sea stars (Asterias sp.). The other state is when the benthic community is dominated by a mixture of polychaetes, small crustaceans such as amphipods, smaller less-domineering molluscs, and other macrofauna.

When there has been a successful recruitment and sustained population of surf clams or sand dollars, the wet wt biomass of the area can be about or greatly exceed 500 g/m^2 (Table 7). When either of these two species are not colonizing an area, the wet wt benthic community biomass is commonly an order of magnitude less, or about 30-50 g/m^2.

The enhancement ratios of standing stock biomass of the mussel-dominated experimental reef habitats (57,075 g/m², minus fish biomass) vs. sand sediment infauna range from 24 to 123 times for surf clam-dominated sand substrate and 771 to 2,195 for polychaete crustacean-dominated sediments. Steimle et al. (2002) found that a concrete reef located at the mouth of Delaware Bay exhibited an enhancement ratio of 168 to 354 times the infaunal biomass from an equivalent area of the surrounding sandy sediments. This community state dichotomy on New Jersey coastal sandy sediments is similar to the dichotomous situation on hard surfaces in the same area where the basic epifaunal community is usually controlled by the presence and abundance of the blue mussel (Steimle et al. 2002). Another reef state, which may be an ultimate successional stage, is dominated by cnidarians, such as anemones, coral and hydroids. These animals may inhabit the colonization of mussels by occupying reef substrates and feeding on mussel spat. Their dominance may be prolonged due to reproduction through budding rather than larval recruitment. Dramatic events, such as storms may be necessary to displace cnidarian communities and open reef substrates to colonization by mussels and other encrusting epibenthos. While mussels dominated the experimental reef habitats over the 60-month study, cnidarian populations increased continuously. Cnidarians are of little value as food for other marine life, and this represents a much less productive reef community in terms of providing habitat for fish and lobster. Therefore, the enhancement ratio of a cnidarian-dominated reef would be much lower than that of a mussel-dominated reef structure.

The high biomass of surf clam-dominated sand bottom illustrates the importance of the open sand in providing a food resource for reef inhabitants. For this reason, reefs should be constructed apart from each other, separated by extensive expanses of sandy bottom. Anecdotal and other evidence suggests that reef habitat in this area is usually dominated by mussel recruitments in the summer so the per square meter of seabed benthic enhancement is probably in the range of between ~100 to 1400, depending upon whether there is a significant surf clam or sand dollar recruitment to the sediments around an artificial reef in this area. The recruitment patterns of these species can be seemingly random and a major recruitment around a reef habitat is possible. Juvenile surf clam and sand dollars, near a reef, can be an important prey source for artificial reef predators, too. This range of estimated benthic enhancement is slightly higher to that reported, ~1-1100, for a similar study in nearby Delaware Bay (Steimle et al. 1995).

Application of Results

The biological objectives of New Jersey's Reef Program (Figley 2003) include:

1. create hard substrate, reef habitat for marine fish, crustaceans, shellfish and encrusting organisms;
2. provide spawning, nursery, refuge and feeding areas for marine life;
3. increase diversity and abundance of marine life.

While the study results suggest that reef structures are meeting many of these objectives, they also provide relevant applications for designing both reef structures and reef sites.

The reef materials currently used by the Reef Program to build reefs - rock, concrete and steel – all provide suitable substrate for the colonization of sessile, encrusting marine life. Reefs can be more productive by designing structures with greater surface area. Greater surface area per sea floor footprint can be achieved by increasing structure profile, by using hollow structures and by having irregular, rather than flat, substrates.

Reef structures should also be complex, with a variety of openings, crevices and chambers. Complexity provides the protective habitat needed by mobile invertebrates and yoy fish. Most reef structures, such as vessels, concrete pieces and Reef Balls, do not optimize surface area or complexity. Off New Jersey, rock piles may represent the most complex reef structure because of their irregular substrate and numerous small openings. There are currently no commercially available reef structures that maximize surface area and complexity. Many commercial reef structures, especially those from Japan, maximize space (volume) and minimize structure (area). This approach provides the greatest volume of reef structure for the least cost. The result is large, open structures that are used extensively by large numbers of adult fish; for fishing, this is preferred. From an ecological perspective, however, this approach in reef design may be illusory. An ecologically healthier tactic is to create a habitat dominated by taxa from the lower levels of the food chain. The higher the forage base to fish biomass ratio, the closer the reef community will resemble a natural marine food chain. By using reef structures that do not concentrate large numbers of adult fish in small areas, fishing mortality can also be reduced. Furthermore, complex reef habitats may increase survival of yoy fish and lobster, which eventually will recruit to and benefit fisheries. Unfortunately, the fabrication and deployment of significant quantities of specially-designed, complex habitats is economically prohibitive at this time.

The results of the experimental reef habitat colonization study also suggest that variety in habitat is an important factor influencing biological diversity. The more diverse a reef site is in terms of types, sizes, heights, shapes and complexities of the various reef structures of which it is comprised, the more diverse the biological community colonizing the site. Thus, many types of reef structures should be dispersed on each reef site. Both the sandy bottom and open water column are also important components of the reef site. Reef sites should be designed to maximize the edge and interspersion of reef structures with these other 2 environs.

CONCLUSIONS

1. During the 60-month study, a total of 143 taxa were identified living within the experimental reef habitats.

2. Over the course of the 60-month survey, experimental reef habitats were colonized by an average of 432,022 individual marine life organisms and had a total mean biomass of individual and colonial organisms of 58,358g per m^2 of sampling unit footprint. Colonial organisms covered 5,035 cm^2 of surface area/m^2 footprint.

3. The experimental reef habitats were more complex and had greater surface area than most actual reef structures and consequently, probably also had a greater density of marine life than would be expected on currently used reef structures of the same profile.

4. The biomass/footprint ratio of the experimental reef habitats could be increased by optimizing hiding spaces and by increasing both surface area and profile.

5. There were considerable year-to-year fluctuations in sampling unit total biomass, with the dominant species, blue mussel, largely responsible for such variations.

6. The experimental habitats provided refuge cover for large numbers of small and yoy fish (133.5/m^2), crab (3,545.9/m^2) and lobster (22.4/m^2).

7. In terms of mean total standing stock biomass, colonization substrates were ranked as follows:

   concrete > rock > rubber > steel

8. However, since the differences in the colonization rates of the 4 substrates were not statistically significant, the statistical relationship between substrates is actually:

   concrete = rock = rubber = steel

9. Colonization plates inside a protective mesh cage had a significantly higher biomass than those outside the mesh, suggesting that predation reduced standing stock biomass by at least 45 percent.

10. In terms of biomass, the forage base to small fish ratio of the experimental habitats was 45.5.

11. On an equivalent area basis, the biomass enhancement ratios of the experimental reef habitats over surf clam-dominated and polychaete crustacean-dominated sand bottom ranged from 24 to 123 and 771 to 2,195 times, respectively.

12. Reef sites should be constructed from a variety of structures to increase biological diversity.

13. Attention should be focused on designing and deploying complex reef habitats that benefit lower-level consumers and provide refuge cover for both yoy fish and juvenile lobster.

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Table 1.
Mean dimensions of 10 experimental reef habitats, 1998-2001.

Parameter	Unit	Mean	SD
Sea Floor Footprint	cm²	1,034	64
Habitat Volume	cm³	79,609	6,608
Wire Cage Area	cm²	8,626	430
Fiberglass Panel Area	cm²	14,855	1,566
Whelk Shell Area	cm²	22,730	3,130
Concrete Plate Area	cm²	1,053	93
Steel Plate Area	cm²	776	26
Tire Plate Area	cm²	572	42
Rock Plate Area	cm²	574	70
Total Habitat Area	cm²	49,186	4,217

Table 2.

Mean abundance and biomass per m^2 of species colonizing 10 experimental reef habitats after 24 - 60 months on the seafloor.

PHYLUM	CLASS	SUBCLASS	ORDER	FAMILY	GENUS	SPECIES	COMMON NAME			MEAN			
								AREA		NUMBER		BIOMASS	
								(cm2/m2)	(+/- SE)	(n/m2)	(+/- SE)	(g/m2)	(+/- SE)
Colonial Organisms													
Ponfera													
	Desmospongiae			Halidonidae	*Haliclona*	*spp*	Encrusting Sponge	163.9	135.9			3.7	3.1
				Microcionidae	*Microciona*	*porifera*	Red Beard Sponge	522.5	522 5			11.8	11 8
	Ponfera		(unspecified)				Sponge	1,256.7	677.7			28.6	15.5
		Subtotal						**1,943.1**	**1035.3**			**44.1**	**23.5**
Cnidaria													
	Anthozoa												
		Zoanthana	Scleractinia	Astrangiidae	*Astrangia*	*Poculata*	Northern Star Coral	2,767.1	2,008.7			441.6	321.0
	Hydrozoa		Hydroida	Hydractiniadae	*Hydractinia*	*achinata*	Snail Fur	7,149.6	4,110.2			747.1	541.9
		Hydrozoa	(unspecified)				Hydroid	24,137.1	9,049.1			2,254.4	489.9
		Subtotal						**34,053.8**	**10,614.0**			**3,443.2**	**848.7**
Ectoprocta													
	Bryozoa		(unspecified)				Bryozoan	49,038.7	10,264.3			2,017.1	421.7
		Subtotal						**49,038.7**	**10,264.3**			**2,017.1**	**421.7**
Individual Organisms													
Cnidaria													
	Anthozoa												
		Zoanthana	Actiniaria	Actinostolidae	*Cereantheopss*	*americana*	Burrowing Anemone			4.0	4.0	0.1	0.1
				Metridiidae	*Metridium*	*senile*	Colonial Plumose Anemone			4,622.8	2.748 8	32208	1,5613
		Subtotal								**4,626.8**	**2,750.0**	**3,220.8**	**1,561.3**
Nematoda							Nematode			94,051.2	45,627.6	253	¶1.1
	Nematoda (unspecified)												
		Subtotal								**94,051.2**	**45,627.8**	**253**	**11.1**

Table 2.
Mean abundance and biomass per m^2 of species colonizing 10 experimental reef habitats after 24 - 60 months on the seafloor.

PHYLUM CLASS SUBCLASS	ORDER	FAMILY	GENUS	SPECIES	COMMON NAME	AREA (cm2/m2)	AREA (+/- SE)	MEAN NUMBER (n/m2)	MEAN NUMBER (+/- SE)	MEAN BIOMASS (g/m2)	MEAN BIOMASS (+/- SE)
Molluska											
Bivalvia											
Anomalodesmata	Pholadomyoida	Lyonsiidae	*Lyonsia*	*hyalina*	Glassy Lyonsia			7.6	7.6	0.8	0.8
Heterodonta	Myoida	Hiatellidae	*Hiatellidae*	*(unspecified)*	Rock Borer Clam			28.0	18.9	1.2	1.2
	Veneroida	Cardiidae	*Cerastoderma*	*pinnulatum*	Dwarf Cockle			23.4	13.1	1.8	1.3
		Mactridae	*(unspecified)*	*solidissima*	Atlantic Surf Clam			795.2	371.4	8.6	3.8
		Mactridae	*Spisula*		Surf Clam			53.9	52.8	0.1	0.1
		Tellinidae	*Tellina*	*aglis*	Northern Dwarf Tellin			116.5	57.0	0.6	3.4
			Tellina	*spp.*	Tellin			15.0	9.3	1.5	1.0
Ptenomorpha	Arcoida	Arcidae	*Anadara*	*transversa*	Transverse Ark			597.9	319.3	2.2	1.2
	Mytiloida	Anomiidae	*Anomia*	*simplex*	Jingle Shell			517.1	102.7	53.1	19.7
		Mytilidae	*Mytilus*	*edulis*	Blue Mussel			118,651.4	32,253.7	30,016.4	6261.5
		Astartidae	*Astarte*	*castanea*	Chestnut Astarte			5.5	5.5	0.6	0.6
Bivalvia	(unspecified)				Bivalve Mollusk			29.1	21.6	< 0.1	< 0.1
Gastropoda											
Opisthobranchia	Nudibrancha	Pamidellidae	*Aeolidia*	*papilosa*	Maned Nudibranch			1.0	1.0	2.0	2.0
			Nudibranchia	*(unspecified)*	Nudibranch			22.7	22.7	2.3	2.3
	Pycamidellacea	Pyramidellidae	*Odostomia*	*spp.*	Odostome			41.9	34.7	0.1	0.1
			Turbonilla	*spp.*	Turbonille			111.7	43.4	0.8	0.6
Prsobranchia	Mesogastropoda	Calyptraeidae	*Crepidula*	*fornicata*	Common Slipper Shell			901.9	211.9	615.8	154.9
			Crepidula	*plana*	Flat Slipper Shell			13,589.7	5,168.2	1,125.5	252.2
			Crepidula	*spp.*	Slipper Shell			14.9	13.8	2.4	1.7
		Centhiidae	*CenthiopsiS*	*emersoni*	Emerson's Centh			7.6	7.6	0.8	0.8
		Naticidae	*Euspra*	*heros*	Northern Moon Snail			6.0	5.0	< 0.1	< 0.1
			Euspra	*immaculata*	Immaculate Moon Snail			34.7	34.7	< 0.1	< 0.1
			Euspra	*trisenata*	Spotted Moon Snail			29.6	17.1	2.8	0.6
			Neventa	*duplicata*	Sharkeye Moonsnail			12.0	12.0	1.2	0.2
		Rissoidae	*Onoba*	*spp.*	Cingula			61.5	55.1	<0.1	< 0.1
	Neogastropoda	Nassanidae	*Ilyanassa*	*trivittatus*	New England Dog Whelk			176.5	81.1	4.6	1.9
			Ilyanassa	*spp.*	Dog Whelk			57.9	43.6	0.2	0.1
			Nassarius	*vibex*	Mottled Dog Wheik			31.9	31.9	1.6	1.6
		Columbellidae	*Astyns*	*lunata*	Crescent Mitreila			42,152.4	5,789.9	144.5	33.0
		Epioniidae	*Epitonium*	*multistriatum*	Wentletrap			15.9	15.9	< 0.1	< 0.1
			Epitonium	*rupicola*	Lined Wentletrap			12.0	12.0	1.2	1.2
			Epitonium	*spp.*	Wentletrap			1.0	1.0	< 0.1	< 0.1
Gastropoda		(unspecified)			Gastropod Mollusk			216.2	216.2	0.1	0.1
Subtotal								**178,339.3**	**24,973.5**	**31,990.8**	**5,337.0**

Table 2.

Mean abundance and biomass per m^2 of species colonizing 10 experimental reef habitats after 24 - 60 months on the seafloor.

PHYLUM **CLASS** **SUBCLASS**								**MEAN**			
						AREA		**NUMBER**		**BIOMASS**	
	ORDER	**FAMILY**	**GENUS**	**SPECIES**	**COMMON NAME**	(cm2/m2)	(+/- SE)	(n/m2)	(+/- SE)	(g/m2)	(+/- SE)
Annelida											
Polychaeta											
Errantia		Glycendae	*Glycera*	*spp.*	Blood Worm			5.5	5.5	0.6	0.6
		Lumbrinendae	*(unspecified)*	*(unspecified)*	Thread Worm			2.0	2.0	1.1	1.1
		Nereididae	*Neanthes*	*acuminata*	Clam Worm			140.4	140.4	2.1	2.1
				succinea	Clam Worm			35.6	32.5	0.1	0.1
			Nereis	*grayi*	Tube-dwelling Clam Worm			256.1	186.8	4.3	4.3
				pelagica	Pelagic Clam Worm			721.4	426.5	28.8	16.3
			Nereis	*virens*	Common Clam Worm			681.2	344.3	36.5	24.7
				spp.	Clam Worm			717.1	366.9	2.8	1.6
			Platynereis	*dumentii*	Dument's Clam Worm			1.0	1.0	0.1	0.1
		Nereididae	*(unspecified)*	*(unspecified)*	Clam Worm			52.9	47.5	1.6	1.6
		Onuphidae	*Dioptra*	*cuprea*	Plumed Worm			52.9	52.9	0.1	0.1
			Phyilodoce	*mucosa*	Paddle Worm			9.4	9.4	0.1	0.1
		Phyllodocidae		*ssp.*	Paddle Worm			1.0	1.0	< 0.1	< 0.1
			(unspecified)	*(unspecified)*	Paddle Worm			1.0	1.0	< 0.1	< 0.1
			Harmothoe	*extenuata*	Fifteen-Scaled Worm			508.4	213.8	9.1	6.0
		Polynoidae		*spp.*	Fifteen-Scaled Worm			70.3	62.3	0.7	0.5
			Lepidonotus	*squamatus*	Twelve-Scaled Worm			1.098.7	417.4	178.7	57.4
				spp.	Twelve-Scaled Worm			2.553.9	920.0	573.9	215.8
		Polynoidae	*(unspecified)*	*(unspecified)*	Scale Worm			1,462.3	619.5	134.0	60.0
		Sigalionidae	*Sthenelais*	*limicola*	Scale Worm			1.0	1.0	0.7	0.7
		Syllidae	*Exogone*	*spp.*	Syilid Worm			11.0	11.0	0.6	0.6
			(unspecified)	*(unspecified)*	Syilid Worm			330.1	318.1	0.2	0.1
Sedentana		Ampharetidae	*Ampharetidae*	*(unspecified)*	Ampharetid Worn			15.4	11.1	60.3	60.2
		Cirratulidae	*Cirratulus*	*cirratus*	Fringed Worm			45.5	31.5	6.0	4.4
			Cimformia	*grandis*	Fringed Worm			18.8	13.6	6.4	5.9
			Tharyx	*acutus*	Fringed Worm			7.3	7.3	0.1	0.1
			(unspecifled)	*(unspecified)*	Fringed Worm			405.6	164.5	20.5	7.9
		Maidanidae	*Clymenella*	*torquata*	Bamboo Worm			286.9	135.0	25.1	14.7
			Clymenella/Euclymene	*spp.*	Bamboo Worm			568.4	156.4	23.3	8.3
			Euclymene	*zonalis*	Bamboo Worm			1.0	1.0	< 0.1	< 0.1
			(unspecified)	*(unspecified)*	Banboo Worm			82.2	78.9	1.1	1.1
		Sabellanidae	*Sabellana*	*vulgans*	Reef or Sand-Builder Worm			529.7	216.2	81.2	41.0
			Pseudopotamilla	*reniformis*	Featherduster Worm			2,156.7	765.3	92.6	34.9
			(unspecified)	*(unspecified)*	Featherduster Worm			60.2	41.3	2.0	1.6
		Serpulidae	*Hydroides*	*dianthus*	Carnation Tube Worm			1,755.2	320.0	288.0	71.8
				uncinata	Hard Tube Worm			8.7	8.7	0.9	0.9
		Terebellidae	*Amphitrite*	*affinis*	Spaghetti Worm			16.4	15.4	6.7	6.6
				ornata	Ornate Spaghetti Worm			53.4	26.2	135.3	83.3
				spp.	Spaghetti Worm			45.3	22.8	9.2	8.3
			Neoamphitrite	*figulus*	Spaghetti Worm			1.0	1.0	1.2	7.2
			Pista	*maculata*	Terebellid Worm			12.0	12.0	6.2	6.2
			Scoletoma	*accularum*	Fragile Thread Worm			1.0	1.0	0.3	0.3
Polychaeta (unspecified)					Polychaete Worm			1,842.2	1,043.0	42.7	16.1
Subtotal								**16,626.1**	**2,113.8**	**1,793.1**	**292.9**

Table 2.

Mean abundance and biomass per m^2 of species colonizing 10 experimental reef habitats after 24 - 60 months on the seafloor.

PHYLUM	CLASS	SUBCLASS	ORDER	FAMILY	GENUS	SPECIES	COMMON NAME	AREA (cm2/m2)	AREA (+/- SE)	MEAN NUMBER (n/m2)	MEAN NUMBER (+/- SE)	BIOMASS (g/m2)	BIOMASS (+/- SE)
Arthropoda													
	Crustacea												
		Cirripedea	Thoracica	Balanidae	*Balanus*	*spp.*	Acorn Barnacle			29,610.4	29,310.4	7,343.1	1,255.3
		Copepoda	Harpacticoida		*Harpacticoidea*	*spp.*	Harpacticoid Copepod			49.3	49.3	0.1	0.1
		Malacostraca	Amphipoda										
			Caprellidea	Caprellidae	*Caprella*	*equilibra*	Skeleton Shrimp			860.8	780.4	0.6	0.5
					Caprella	*penantis*	Skeleton Shrimp			14,244.8	6,902.8	21.3	7.7
					Caprella	*spp.*	Skeleton Shrimp			26,348.0	13.474.2	12.2	6.1
			Gammandea	Ampeliscidae	*(unspecified)*		Four-Eyed Amphipod			1.0	1.0	< 0.1	< 0.1
				Aondae	*Unciola*	*spp.*	Unciola Amphipod			59.2	45.4	0.6	0.4
				Caillopiidae	*(unspecified0*		Planklonic Amphipod			48.5	48.5	< 0.1	< 0.1
				Corophiidae	*Corophium*	*insidosum*	Slender Tube Maker			0.9	9.9	< 0.1	< 0.1
					Corophium	*spp.*	Slender Tube Maker			2,434.8	1,174.6	2.4	0.9
					Enchthonius	*brasilensis*	Slender Tube Maker			4.0	4.0	< 0.1	< 0.1
				Lyssianassidae	*(unspecified)*		Lysianassid Amphipod			16.0	16.0	< 0.1	< 0.1
				Stenothoidae	*Parametapella*	*cypris*	Seed Amphipod			30.4	30.4	< 0.1	< 0.1
					Stenothoe	*spp.*	Seed Amphipod			2,796.3	2791.9	1.8	1.8
					Metapella	*augusta*	Amphipod			110.1	100.0	0.4	0.4
					Photis	*macrocoxa*	Photid Amphipod			1.8	1.8	< 0.1	< 0.1
					Photis	*spp.*	Photid Amphipod			38.5	38.5	0.1	0.1
			Gammandea	(unspecified)			Gammandean Amphipod			2,911.6	1,902.7	2.2	1.6
			Amphipoda	(unspecified)			Amphipod			47,454.2	19,774.6	77.7	55.8
			Cumacea		*Cumacea*	*spp.*	Cumacean			3.0	2.1	< 0.1	< 0.1
			Decapoda										
		Crustacea (unspecified)	Anomura	Paguridae	*Pagurus*	*longicarpus*	Longwrist Hermit Crab			21.3	21.3	0.8	0.8
			Astacidea	Nephropsidae	*Homarus*	*americanus*	American Lobster			22.4	3.7	198.0	88.3
			Brachyura	Cancridae	*Cancer*	*borealis*	Jonah Crab			565.8	114.1	4,289.5	699.3
					Cancer	*irroratus*	Rock Crab			34.0	13.9	215.2	180.3
				Majidae	*Libinia*	*spp.*	Spider Crab			1,697.5	347.5	101.8	27.7
				Pinnotheridae	*Pinnotheres*	*maculatus*	Squatter Pea Crao			49.0	35.4	1.2	0.9
				Portunidae	*Ovalipes*	*ocellatus*	Lady Crab			6.4	4.9	2.2	1.2
				Portunidae	*(unspecified)*		Swimming Crab			5.0	5.0	1.0	1.0
				Xanthidae	*Dyspanopeus*	*sayi*	Say Mud Crab			170.0	50.9	116.5	54.2
					Eurypanopeus	*depressus*	Flatbacked Mud Crab			32.0	17.3	40.9	23.4
					Panopeus	*herbsti*	Atlantic Mud Crab			318.3	131.1	294.8	174.4
				Xanthidae	*(unspecified)*		Mud Crab			608.9	209.7	118.1	51.7
			Brachyura	(unspecified)			Megalop of Crab			37.5	21.2	2.3	1.2
			Candea	Alpheidae	*Alpheus*	*formosis*	Snapping Shrimp			5.1	5.1	0.6	0.6
				Hippolytidae	*Lysmata*	*wurdmanni*	Peppermint Shrimp			19.0	17.9	7.4	5.8
					Brachycarpus	*biunguiculatus*	Candean Shrimp			3.0	3.0	0.2	0.2
			Candea	(unspecified)			Candean Shrimp			59.0	48.4	6.0	4.9
			Caridea	Ciroianidae	*Politolana*	*polita*	Greecy Isopod			4.0	4.0	< 0.1	< 0.1
			Isopoda	Limnoridae	*Limnoria*	*spp.*	Wood Borer (Gribble)			2.1	2.1	< 0.1	< 0.1
			Isopoda	(unspecified)			Isopod			1.0	1.0	< 0.1	< 0.1
			Mysidacea	Mysidae	*Heteromysis*	*formosa*	Red Opossum Shrimp			1,780.2	424.8	8.3	2.3
				Mysidae	*(unspecified)*		Mysid Shrimp			1,559.0	687.4	4.1	1.6
							Crustacean Arthropod			1,764.3	865.0	10.5	6.3
	Pycnogonida						Sea Spider			1.0	1.0	< 0.1	< 0.1
		Subtotal:								**135,489.8**	**23,404.1**	**12,883.3**	**1,723.3**

Table 2.

Mean abundance and biomass per m^2 of species colonizing 10 experimental reef habitats after 24 - 60 months on the seafloor.

PHYLUM	**CLASS**	**SUBCLASS**	**ORDER**	**FAMILY**	**GENUS**	**SPECIES**	**COMMON NAME**	**AREA**		**MEAN** **NUMBER**		**BIOMASS**	
								(cm2/m2)	(+/- SE)	(n/m2)	(+/- SE)	(g/m2)	(+/- SE)
Echinodermata													
	Ethunoidea												
		Euecfunodea	Arbacioda	Arbaciidae	*Arbacia*	*punctulata*	All Purple Urchin			2,348.7	373.9	499.5	126.1
			Clypeasteroida	Echinarachnidae	*Echinarachnius*	*parma*	Sand Dollar			38.9	38.9	3.2	3.2
	Holothuroidea		Apodida	Synaptidae	*Leptosynapta*	*spp.*	Sea Cucumber			6.9	4.9	< 0.1	< 0.1
	Stelleroudea												
		Asteroidea	Forcipulatida	Asteniidae	*Astemas*	*forbesii*	Common Sea Star			292.6	76.1	1,162.7	201.3
		Subtotal								**2,687.1**	**366.6**	**1,665.4**	**235.6**
Chordata													
	Ascidiacea		Stolidobranchiata	Styelidae	*Styela*	*spp*	Sea Squirt			4.0	4.0	< 0.1	< 0.1
		Ascidiacea	(unspecified)				Sessile Tunicate			65.0	37.9	0.1	0.1
	Osteichthys			Blenneiidae	*Parablennius*	*marmoreus*	Seaweed Blenny			1.0	1.0	1.1	1.1
				Congridae	*Conger*	*oceanicus*	Conger Eel			0.9	0.9	133.2	133.2
				Labridae	*Tautogolabris*	*adspersus*	Cunner or Bergall			118.8	26.8	1,097.4	331.3
				Pholidae	*Pholis*	*gunnellus*	Rock Eel			4.1	3.2	16.9	11.6
				Serranidae	*Centropristis*	*striata*	Black Sea Bass			4.7	2.6	17.3	10.2
				Stichaeidae	*Utvana*	*subbifurcat*	Radiated Shanny			2.0	1.3	8.2	5.6
				Zoarcidae	*Macrozoaces*	*aamericana*	Ocean Pout			2.0	2.0	1.3	1.3
		Subtotal								**202.5**	**50.3**	**1,275.5**	**352.4**
		Grand Total						**85,035.6**	**13,844.5**	**432,022.8**	**76,149.6**	**58,358.6**	**8,745.4**

Table 3.
The relative mean abundance of individual organisms by taxa per m^2 footprint of experimental reef habitat during 1998- 2001. This table does not include colonial organisms.

Log of Abundance per m^2	Range	Number of Taxa	Percentage
0	(1-9)	40	29
1	(10-99)	47	34
2	(100-999)	27	20
3	(1,000-9,999)	15	11
4	(10,000-99,999)	7	5
5	(100,000+)	1	1

Table 4.
A comparison of sessile epifaunal colonization of four common reef-building materials - concrete, rock, rubber, steel - for sampling years 1998-2001.

		Mean Standing Stock Biomass											
Type	**Species**	**Concrete (N=20)**			**Rock (N=20)**			**Rubber (N=20)**			**Steel (N=20)**		
Colonial		g/m2	SD	±SE.	g/m2	SD	±S.E.	g/m2	SD	±S.E.	g/m^2	SD	±.S.E.
	Haliclona spp.	43	16.3	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Porifera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.9	0.6
	Hydractinia echinata	0.0	0.0	00	0.0	0.0	0.0	4.3	16.8	3.8	14.1	45.2	10 1
	Hydrozoa	48.2	31.7	7.1	63.4	73.7	16.5	127.5	115.4	25.8	55.5	81.6	18.3
	Astrangia poculata	28.9	62.9	14.1	3.1	10.1	2.3	0.3	1.5	0.3	5.4	10.1	2.3
	Bryozoa	58.1	71.2	15.9	76.0	77.3	17.3	39.7	51.0	11.4	95.1	78.8	17.6
	Subtotal	**149.5**	**118.7**	**26.5**	**142.4**	**114.8**	**25.7**	**171.8**	**117.9**	**26.4**	**170.7**	**147.3**	**32.9**
Individual		g/m2	SD	±SE.	g/m2	SD	±S.E.	g/m2	SD	±S.E.	g/m^2	SD	±.S.E.
	Metndium senile	285.9	481.1	107.6	285.1	593.8	132.8	284.0	539.2	120.6	159.1	337.0	75.4
	Ceriantheopsi arnericana	0.1	0.3	0.1	0.0	0.0	0 0	0.0	0.0	0.0	0 0	0.0	0.0
	Anomia simplex	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8	0.2	0.0	0.0	0.0
	Crepidula fornicata	< 0.1	< 0.1	< 0.1	0.2	1.1	0.2	0.0	0.0	0.0	0.1	0.6	0.1
	Crepidula plana	0.2	0.7	0.2	2.7	12.1	2.7	< 0.1	< 0.1	< 0.1	1.8	6.9	1.5
	Mytilus edulis	328.5	594.0	132.8	341.5	630.6	141.0	288.3	556.4	124.4	208.7	549.3	122.8
	Amphitrte omata	0.0	0.0	0.0	0.0	0.0	0.0	< 0.1	0.1	< 0.1	0.0	0.0	0.0
	Clymenella torquata	0.0	0.0	0.0	< 0.1	< 0.1	< 0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Hydroides dianthus	38.1	34.6	7.7	21.3	21.3	6.1	7.5	16.3	3.6	34.4	47.9	10.7
	Pseudopotamilla reniformis	0.3	0.8	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.3	0.1
	Balanus spp.	202.0	251.4	56.2	150.6	150.6	34.9	81.3	105.1	23.5	155.6	209.2	46.8
	Ascidiacea	0.0	0.0	0.0	< 0.1	< 0.1	< 0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Subtotal	**855.1**	**879.9**	**156.5**	**801.5**	**943.9**	**242.4**	**661.4**	**962.0**	**215.1**	**559.8**	**726.6**	**162.5**
	Total	**1004.6**	**821.9**	**183.8**	**1084.0**	**1034.8**	**231.4**	**833.2**	**959.5**	**214.6**	**730.5**	**701.1**	**156.3**

Table 5.
A statistical comparison of the colonization rates (g biomass/m²) if nine taxa of encrusting organisms on four different substrates and two locations.

Taxa	Location On Habitats	t-test: analysis of means (P)					
		Concrete vs. Rock	Concrete vs. Steel	Concrete vs. Rubber	Rock vs. Steel	Rock vs. Rubber	Steel vs. Rubber
Hydractinia,	Inside	--- *	---- *	---- *	--- *	--- *	S = Rb (0.360)
Snail fur	Outside	--- *	---- *	---- *	--- *	--- *	S = Rb (0.837)
Hydrozoa,	Inside	C = R (0.998)	C = S (0.129)	C < Rb (0.031)	R = S (0.379)	R = Rb (0.118)	S < Rb (0.000)
Hydroids	Outside	C = R (0.280)	C = S (0.368)	C < Rb (0.020)	R = S (0.404)	R = Rb (0.106)	S < Rb (0.144)
Astrangia,	Inside	C = R (0.268)	C = S (0.251)	--- *	R = S (0.892)	--- *	--- *
Stone coral	Outside	C = R (0.158)	C = S (0.278)	C > Rb (0.031)	R = S (0.193)	R = Rb (0.462)	S = Rb (0.119)
Bryozoa	Inside	C = R (0.275)	C = S (0.095)	C = Rb (0.122)	R = S (0.848)	R = Rb (0.409)	S = Rb (0.187)
	Outside	C = R (0.771)	C = S (0.728)	C = Rb (0.073)	R = S (0.528)	R = Rb (0.139)	S > Rb (0.036)
Metridium	Inside	C = R (0.558)	C = S (0.738)	C = Rb (0.537)	R = S (0.376)	R = Rb (0.998)	S = Rb (0.376)
	Outside	C = R (0.195)	C = S (0.188)	C = Rb (0.202)	R = S (0.233)	R = Rb (0.556)	S < Rb (0.136)
Crepidula,	Inside	C = R (0.367)	C = S (0.391)	C = Rb (0.202)	R = S (0.748)	R = Rb (0.331)	S = Rb (0.331)
Slipper shell	Outside	C = R (0.332)	C = S (0.332)	C = Rb (0.660)	R = S (0.977)	R = Rb (0.334)	S = Rb (0.334)
Mytilus,	Inside	C = R (0.745)	C = S (0.371)	C = Rb (0.830)	R = S (0.282)	R = Rb (0.605)	S = Rb (0.473)
Blue mussel	Outside	C = R (0.719)	C = S (0.937)	C = Rb (0.926)	R = S (0.807)	R = Rb (0.807)	S = Rb (0.991)
Hydroides,	Inside	C = R (0.524)	C = S (0.581)	C > Rb (0.029)	R = S (0.914)	R = Rb (0.052)	S > Rb (0.035)
Tube worms	Outside	C = R (0.093)	C = S (0.980)	C > Rb (0.013)	R = S (0.260)	R = Rb (0.415)	S = Rb (0.111)
Balanus,	Inside	C = R (0.790)	C = S (0.272)	C = Rb (0.117)	R = S (0.212)	R > Rb (0.032)	S = Rb (0.543)
Barnacle	Outside	C = R (0.245)	C = S (0.595)	C = Rb (0.292)	R = S (0.161)	R = Rb (0.813)	S = Rb (0.188)

- no statistical comparison.

Table 6.
A comparison of sessile epifaunal colonization of four common reel-building materials -- rubber, steel, concrete and rock -- located inside and outside of a 2.5cm mesh cage, 1998 - 2001.

Type	**Species**	**Mean Standing Stock Biomass**					
Colonial		**Inside (N=40)**			**Outside (N=40)**		
		g/m^2	SD	+/- S.E.	g/m^2	SD	+/- S.E.
	Haliclona spp.	2.0	11.6	1.8	0.1	0.6	0.1
	Porifera	0.0	0.0	0.0	0.4	2.0	0.3
	Hydraclinia echinata	4.8	28.6	4.5	4.4	19.6	3.1
	Hydrozoa	45.9	44.5	7.0	101.3	106.6	16.9
	Astrangia poculata	10.1	39.2	6.2	8.8	27.5	4.3
	Bryozoa	53.0	56.7	9.0	86.4	81.8	12.9
	Subtotal	115.9	96.0	15.2	201.3	134.2	21.2
Individual		**Outside (N=40)**			**Inside (N=40)**		
		g/m^2	SD	+/- S.E.	g/m^2	SD	+/- S.E.
	Metridium senile	459.6	595.5	94.2	47.5	214.2	33.9
	Corianthreopsis americana	0.0	0.0	0.0	< 0.1	0.2	< 0.1
	Anomia simplex	0.1	0.6	0.1	0.0	0.0	0.0
	Crepidula fornicata	0.1	0.4	0.1	0.1	0.8	0.1
	Crepidula plana	2.2	9.7	1.5	0.1	0.8	0.1
	Mytilus edulis	381.6	601.2	95.1	201.9	539.3	85.3
	Amphitrite ornata	< 0.1	0.1	< 0.1	0.0	0.0	0.0
	Clymonella toquata	< 0.1	< 0.1	< 0.1	0.0	0.0	0.0
	Hydroides dianthus	18.2	27.1	4.3	32.4	40.7	6.4
	Pseudopotamilla reniformis	0.2	0.6	0.1	0.1	0.4	0.1
	Balanus spp.	154.9	222.3	35.1	139.9	153.7	24.3
	Ascidiacea	< 0.1	< 0.1	< 0.1	0.0	0.0	0.0
	Subtotal	1016.9	1098.7	173.7	422.0	544.8	86.1
Total		1132.8	1052.5	166.4	623.3	566.2	89.5

Table 7.
A summary of reported standing stock biomass (g/m² wet wt) values (rounded) for the benthic infauna and epifauna on sand sediments of the New York Bight and the enhancement ratio of the mussel-dominated biomass of the experimental reef habitats (our study) over that of the sandy sea floor.

Study Area	**Dominant Species**	**Mean Biomass (g/m²)**	**Reference**	**Enhancement ratio reef vs. sand**
Off Barnegat Light NJ, area A, grab sampling	Surf clam	463*	Scott and Kelley, (1998) (Sept-Oct. 1997 sampling)	123
Clam dredge area A off Barnegat Inlet NJ	Surf clam, Moon snail	2384*	Scott and Kelley (1998) (1997 sampling)	24
Coastal NJ, <30 m depth, grab sampling	Various polychaetes and small crustaceans	26	Steimle (1985) (1 stat.) 1982-1985 data	2195
Central NJ, 20 m depth, grab sampling	Sand dollar	606 (summer) – 329 (winter)	Steimle (1990) (station 17, 1979-1985)	94 (summer) 173 (winter)
Clam dredge area B, D, and LBI reference	Lesser amounts of Surf clam	74 (range 11 – 193)*	Scott and Kelley (1998) (1997 sampling)	771
Long Beach Island, NJ areas B and D, and LBI reference site	Diverse molluscs and polychaetes	30 (range 26.8 – 32.5)*	Scott and Kelley (1998) (1997 sampling)	1903
Coastal NJ, <30 m depth, grab sampling	Various polychaetes and small crustaceans	26	Steimle (1985) (1 stat.) 1982-1985 data	2195

* = original AFDW values converted back to wet wt using taxa specific conversions based on Steimle and Terranova (1985), these ranged from 15.3 for bivalve molluscs to 3.8 for benthic crustaceans and minor taxa.

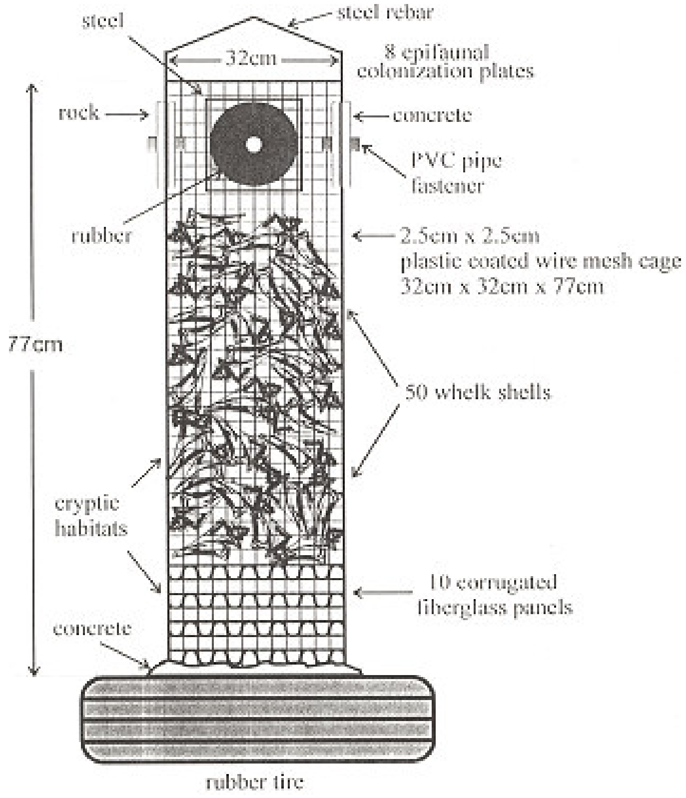

Figure 1. Experimental Reef Habitat

Figure 2. An experimental reef habitat ready for deploymen

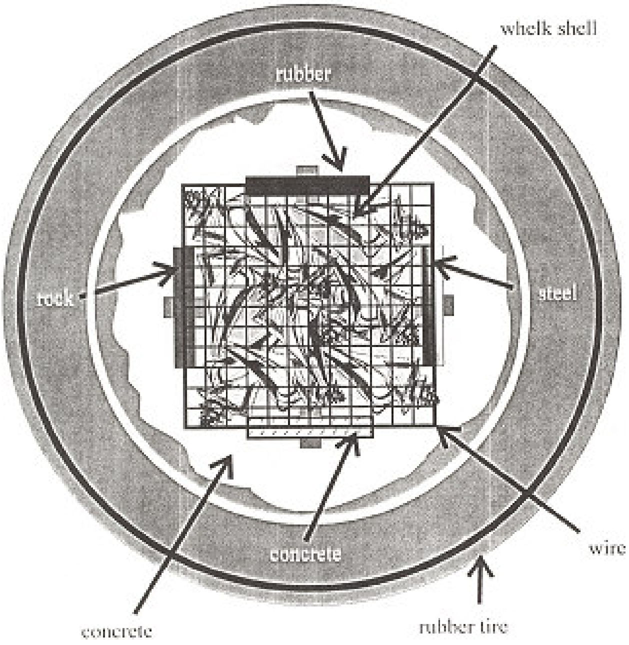

Figure 3. Top view of experimental reef habitat unit

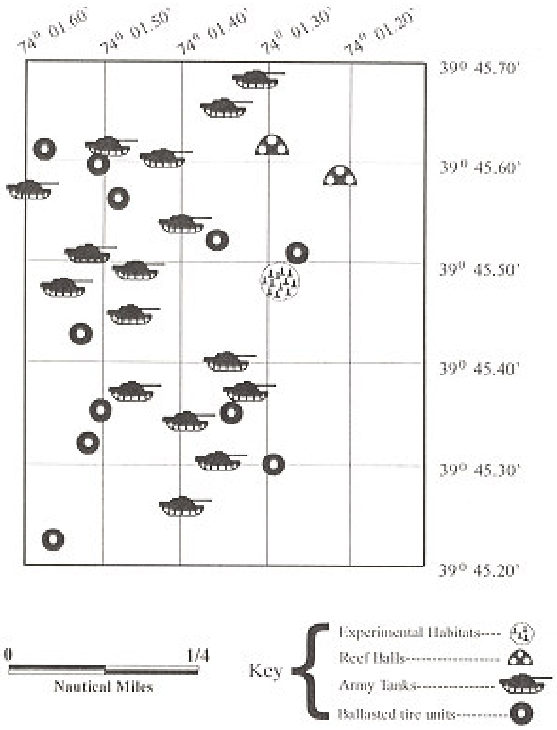

Figure 4. Location of reef structures around experimental reef habitats

Figure 5. Thirty experimental habitats en route to the Barnegat Light Reef Study Site

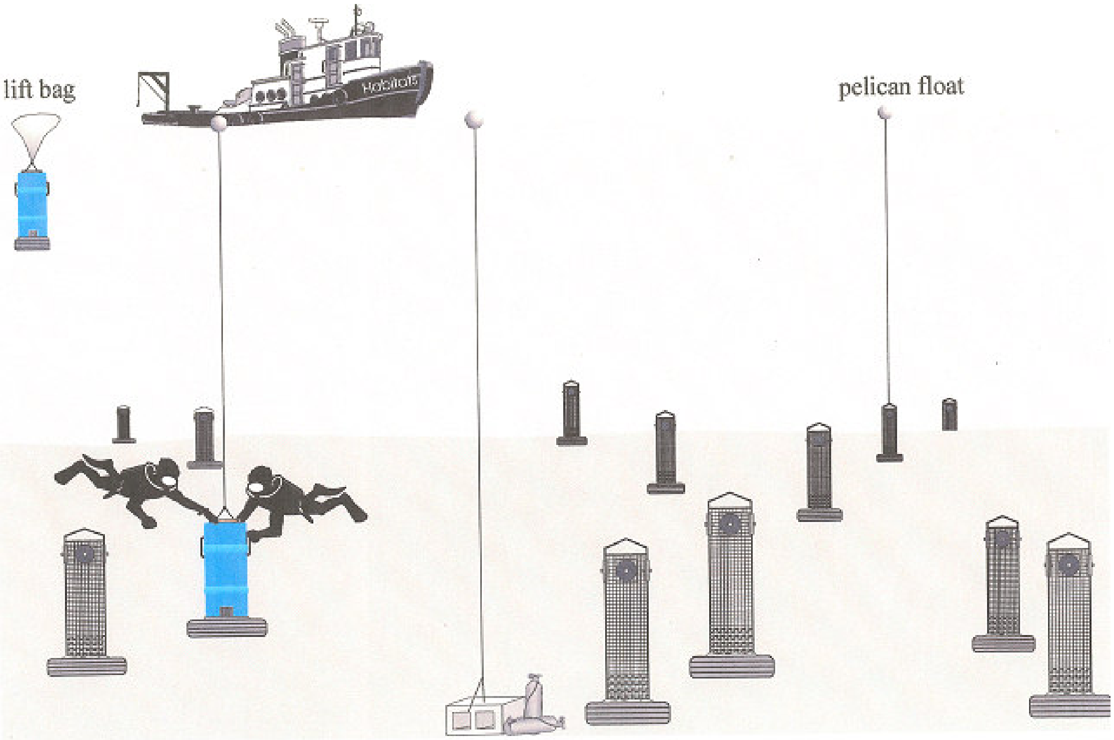

Figure 6. Divers sent the encapsulated habitats to the surface using an air lift bag.

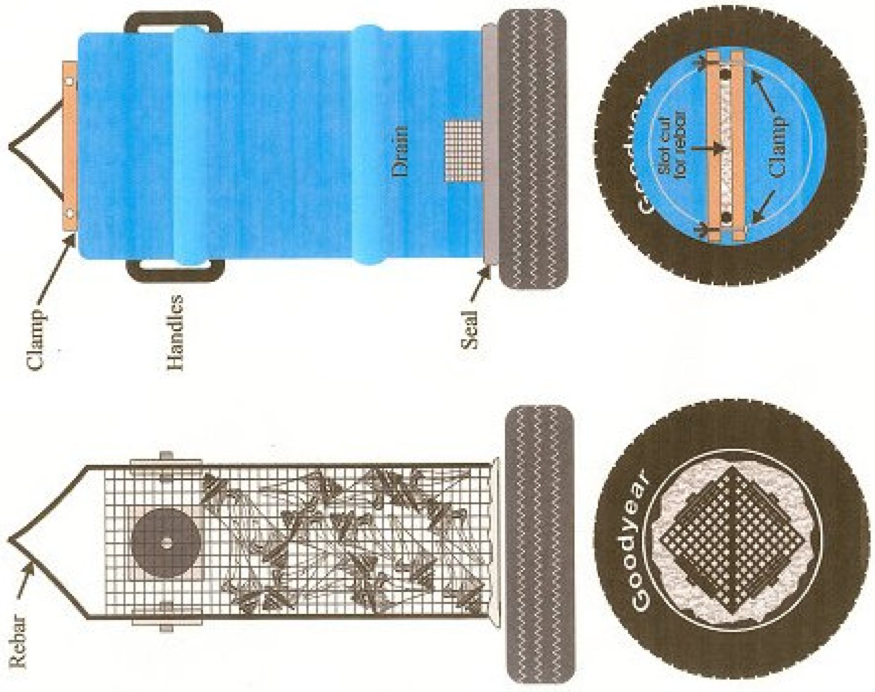

Figure 7. Divers encapsulated the experimental reef habitat units inside a plastic drum, trapping most marine life inside.

Figure 8. Retrieving an experimental reef habitat unit encapsulated in a plastic drum.

Figure 9. The experimental habitat units were placed in a plastic collection pool before being dismantled.

Figure 10. The wire mesh cage is cut open to access experimental substrates.

Figure11. The opened habitat unit showing whelk shells and corrugated panels.

Figure 12. The opened habitat showing upper chamber.

Figure 13. Marine life growth on whelk shell.

(Figure 14 missing)

Figure 15. Marine life growth on rock colonization plates located outside mesh (top) and inside mesh (bottom).

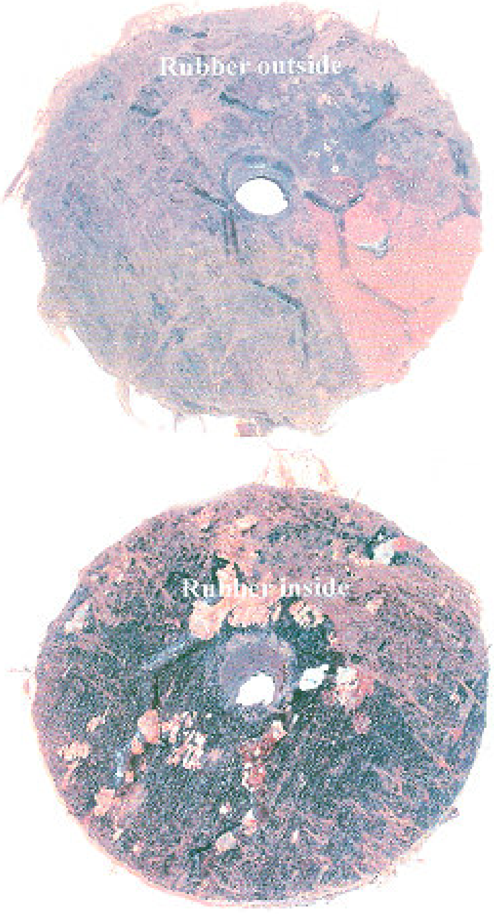

Figure 16. Marine life growth on rubber colonization plates located outside mesh (top) and inside mesh (bottom).

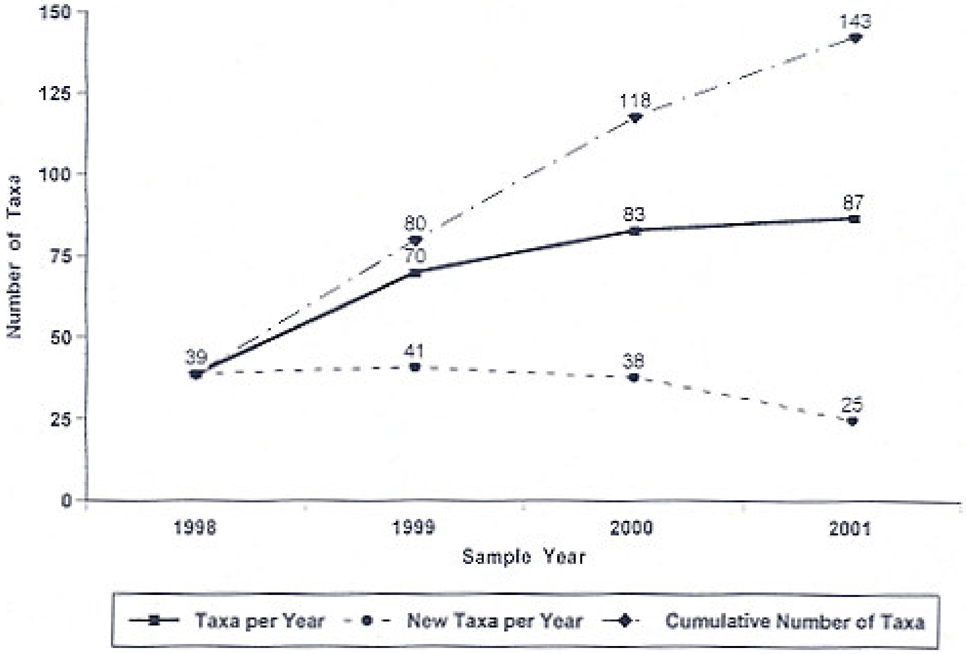

Figure 17. Total number of taxa inhabiting experimental reef habitats analyzed during 1998 through 2001

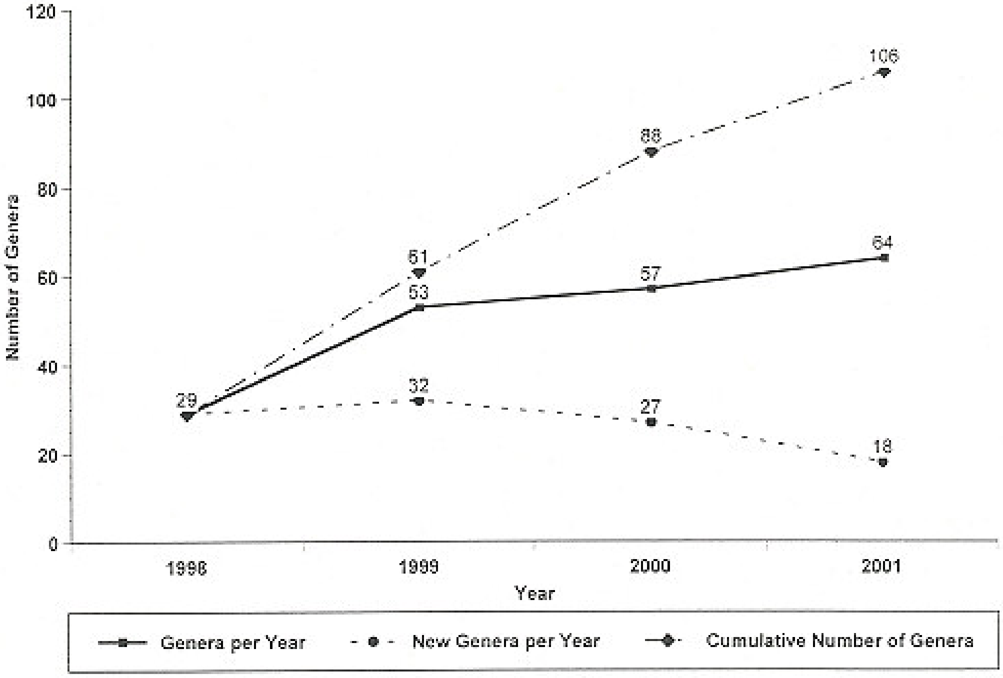

Figure 18. Total number of taxa identified at least to generic level inhabiting experimental reef habitats for sampling years 1998 through 2001.

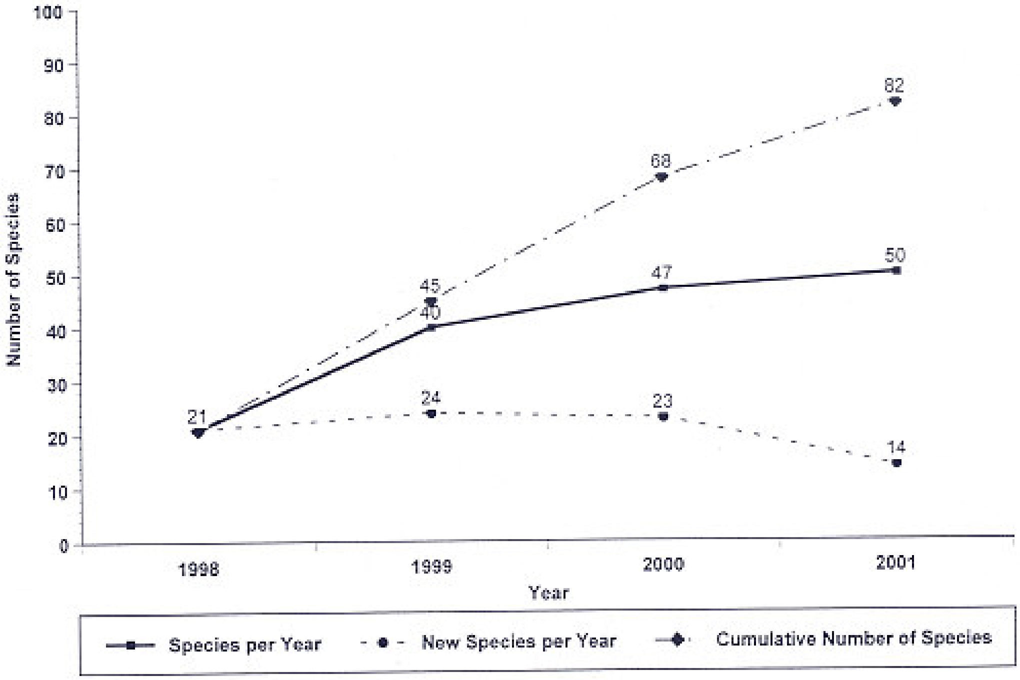

Figure 19. Total number of taxa identified to specific level inhabiting experimental reef habitats for sampling years 1998 through 2001.

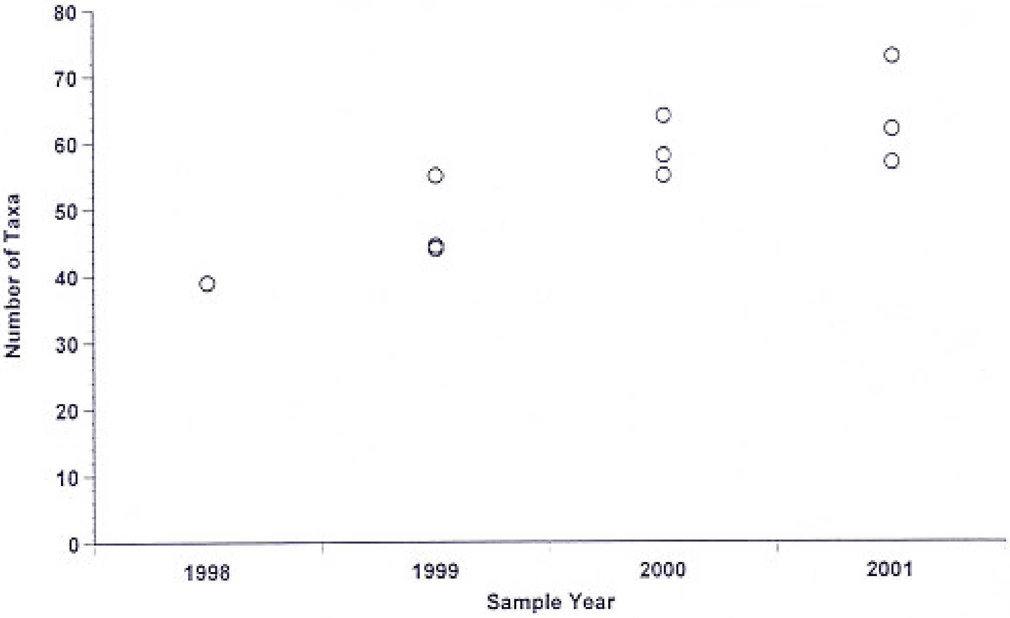

Figure 20. Total number of taxa inhabiting experimental reef habitats for sampling years 1998 - 2001.

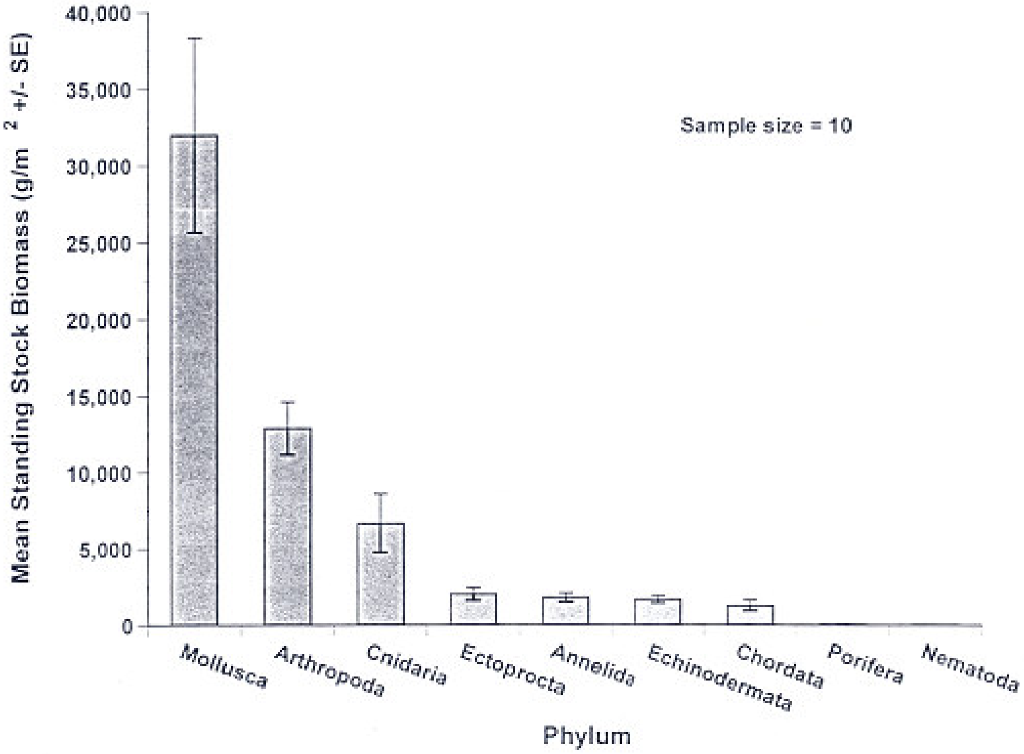

Figure 21. Mean standing stock biomass (g/m^2) of marine life colonizing experimental reef habitats by phyla, 1998 - 2001.

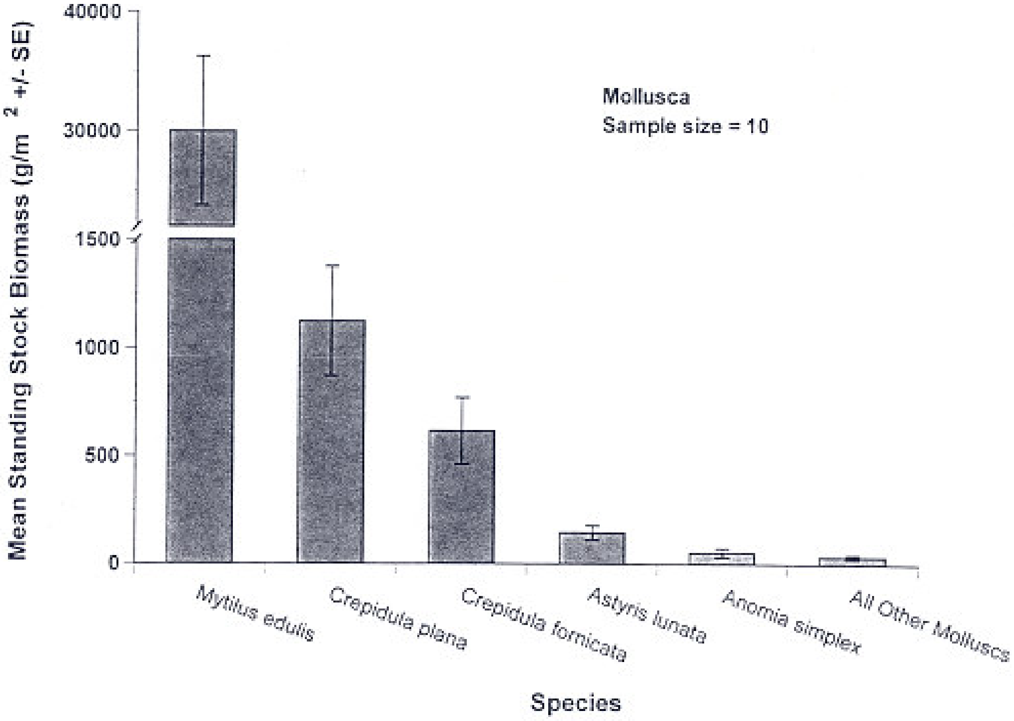

Figure 22. Mean standing stock biomass (g/m^2) of molluscan species inhabiting experimental reef habitats, 1998 - 2001.

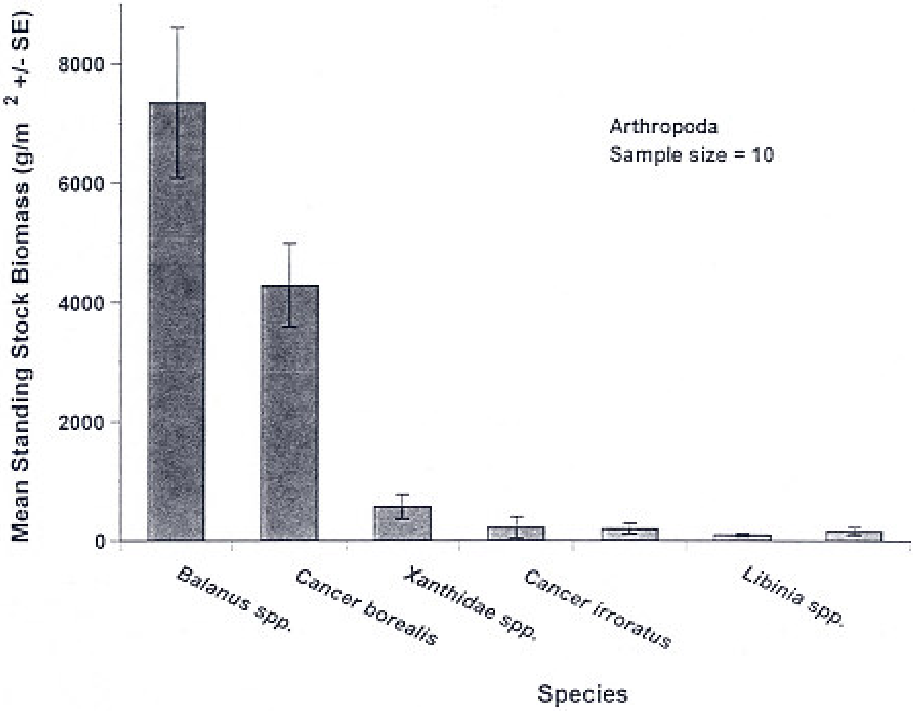

Figure 23. Mean standing stock biomass (g/m^2) of arthropod species inhabiting experimental reef habitats, 1998 - 2001.

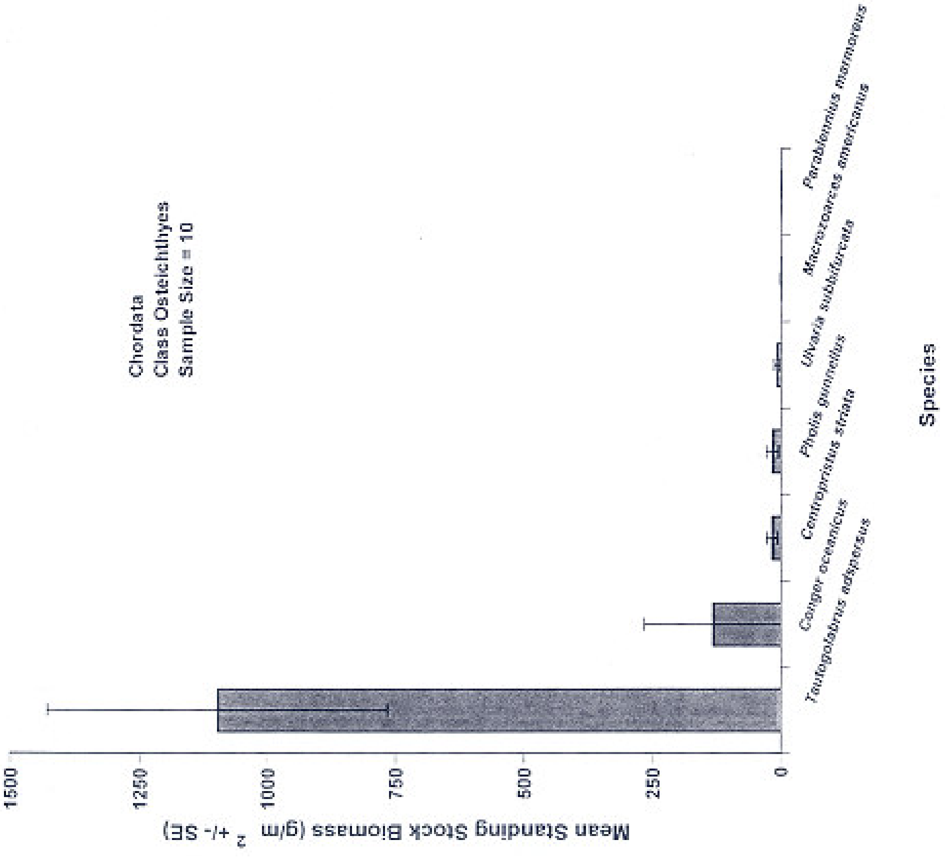

Figure 24. Mean standing stock biomass (g/m^2) of juvenile or small fish species inhabiting experimental reef habitat units, 1998 - 2001.

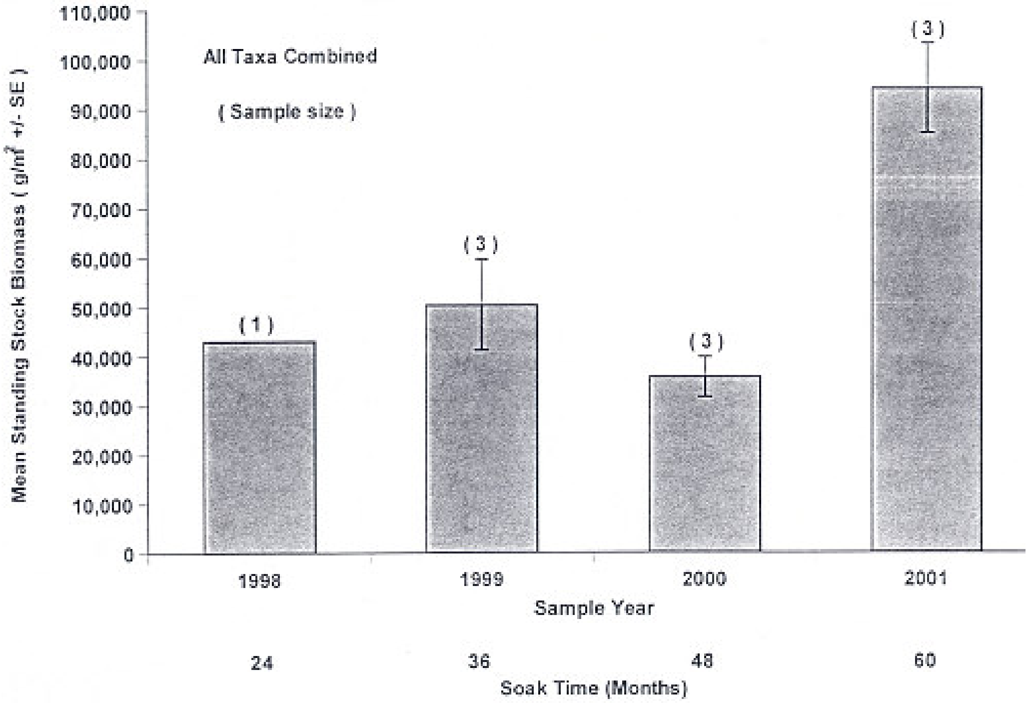

Figure 25. Mean standing stock biomass (g/m^2) of all taxa on experimental reef habitats over time.

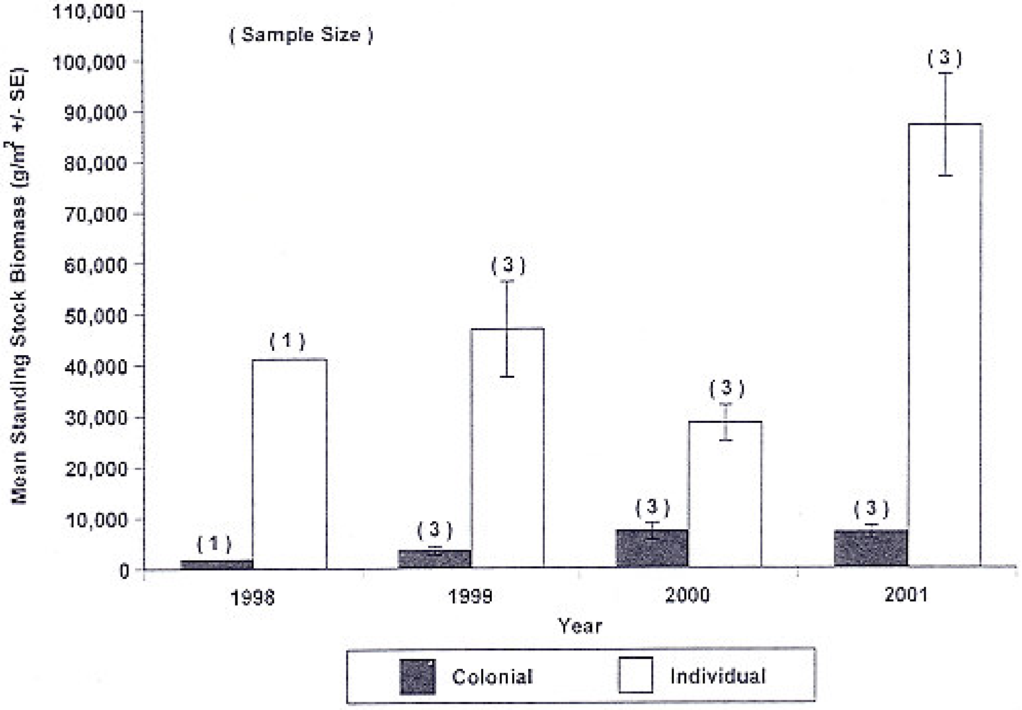

Figure 26. Mean standing stock biomass (g/m^2) of all organisms colonizing experimental reef habitats by organism and sampling year, 1998 - 2001.

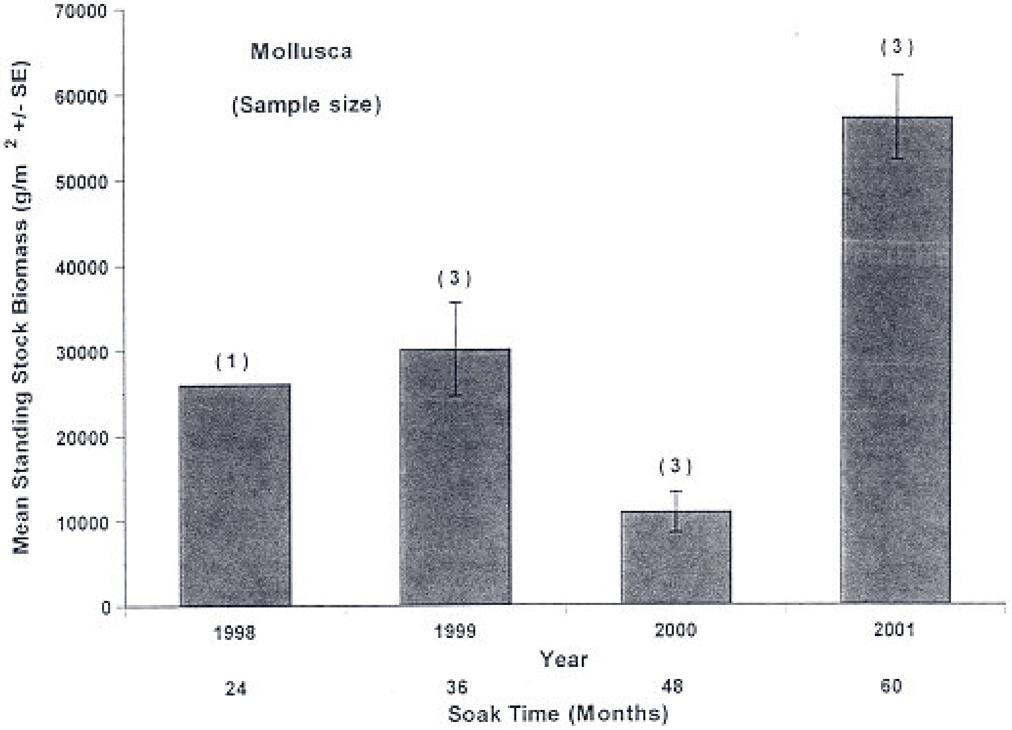

Figure 27. Mean standing stock biomass (g\m^2) of mollusca on experimental reef habitats over time.

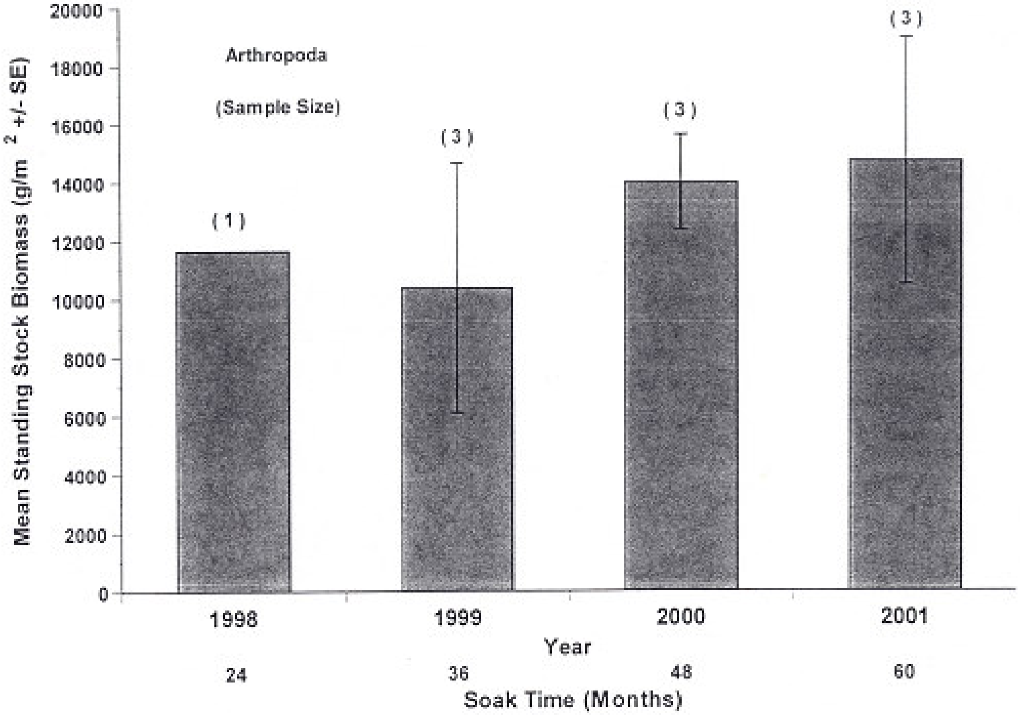

Figure 28. Mean standing stock biomass (g\m^2) of arthropoda on experimental reef habitats over time.

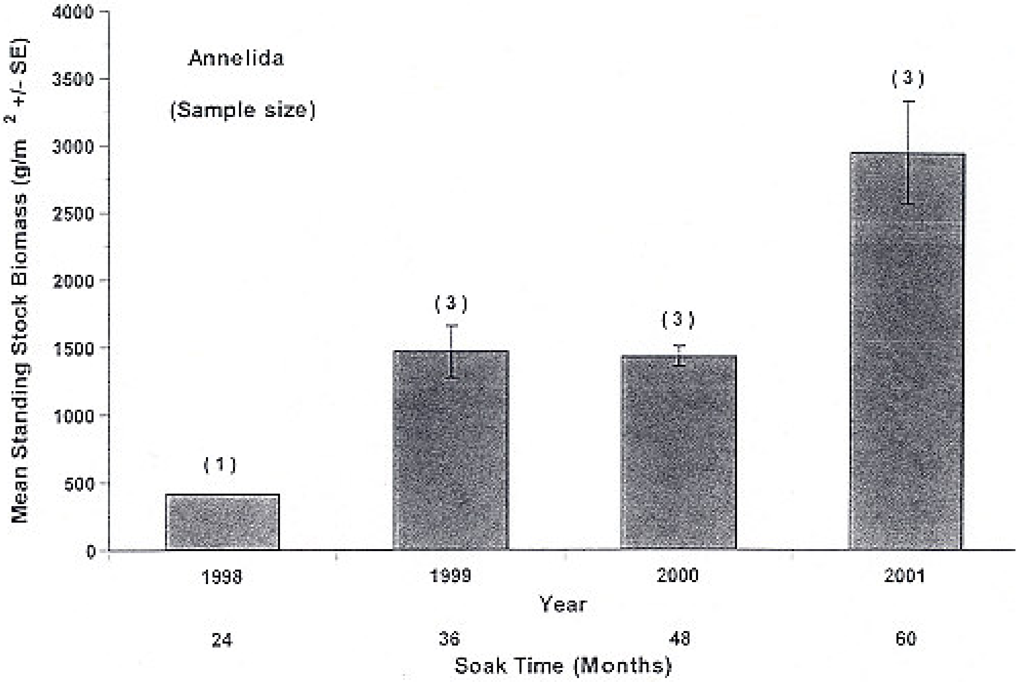

Figure 29. Mean standing stock biomass (g\m^2) of annelida on experimental reef habitats over time.

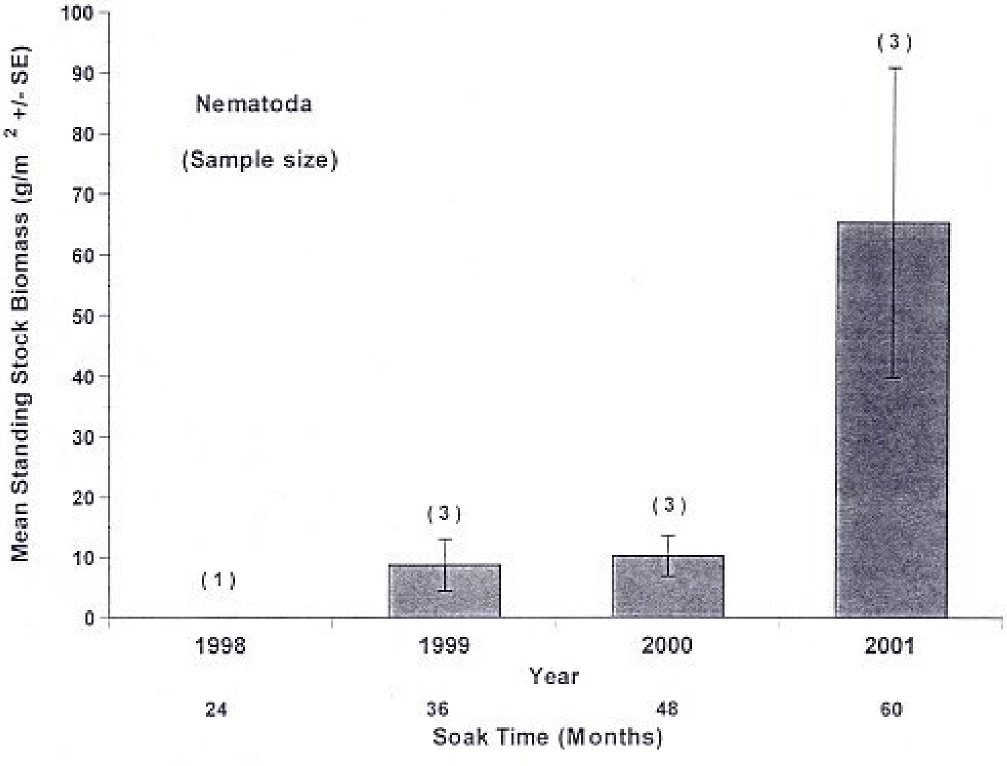

Figure 30. Mean standing stock biomass (g\m^2) of nematoda on experimental reef habitats over time.

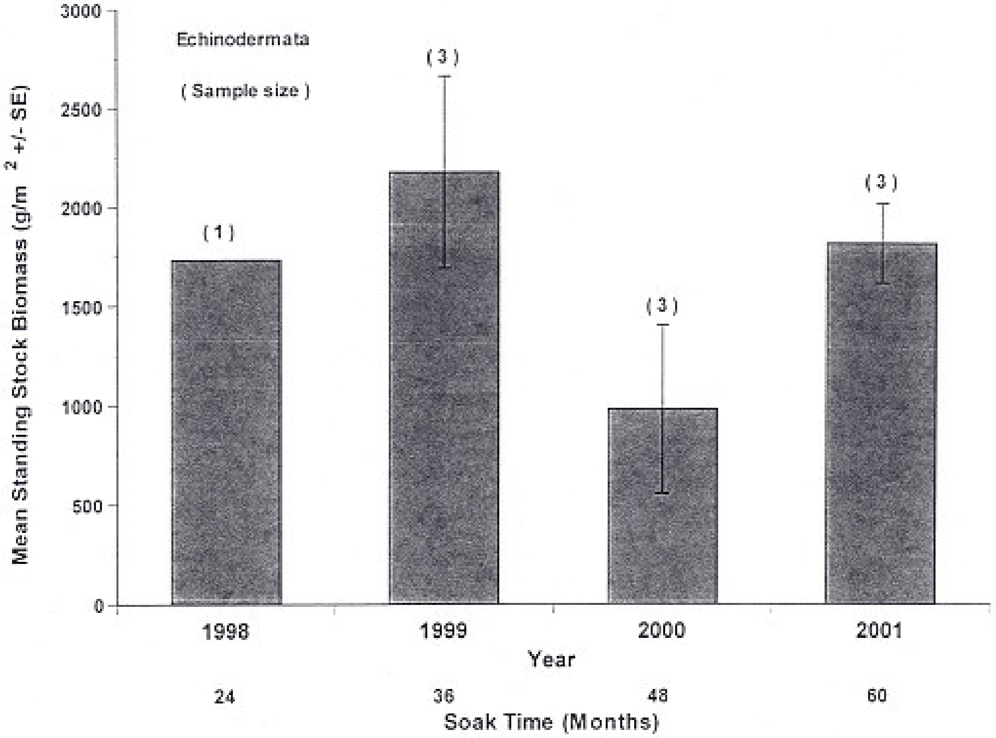

Figure 31. Mean standing stock biomass (g\m^2) of echinodermata on experimental reef habitats over time.

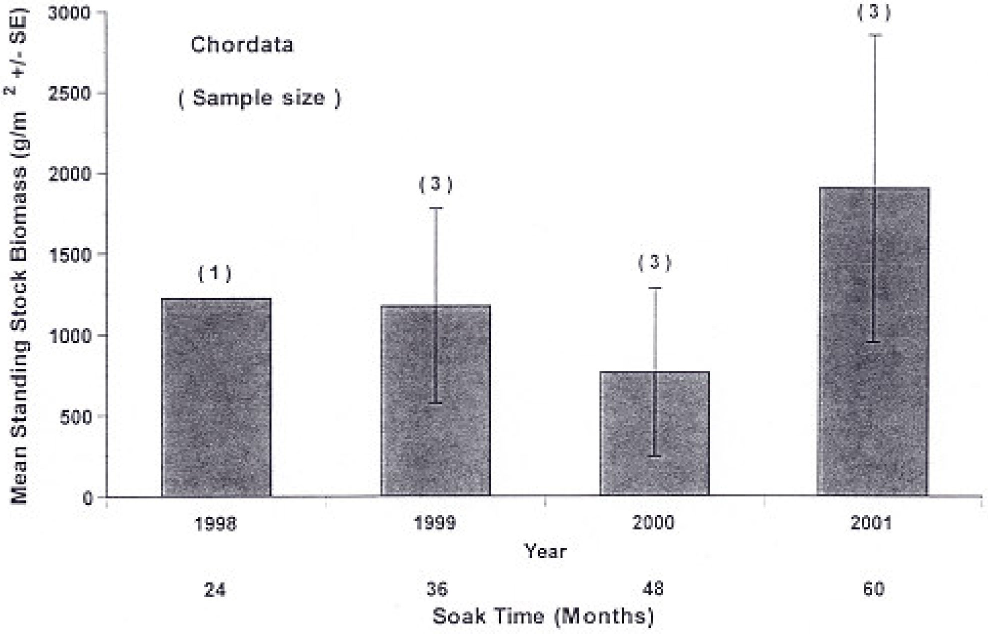

Figure 32. Mean standing stock biomass (g\m^2) of chordata on experimental reef habitats over time.

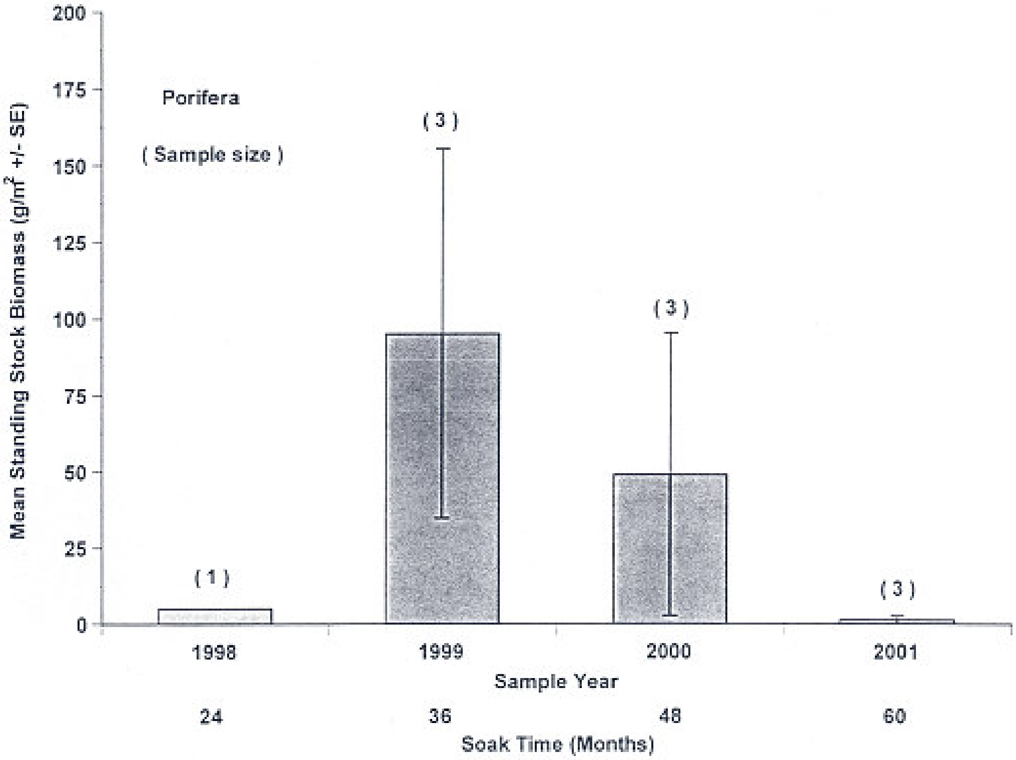

Figure 33. Mean standing stock biomass (g/m^2) of porifera on experimental reef habitats over time.

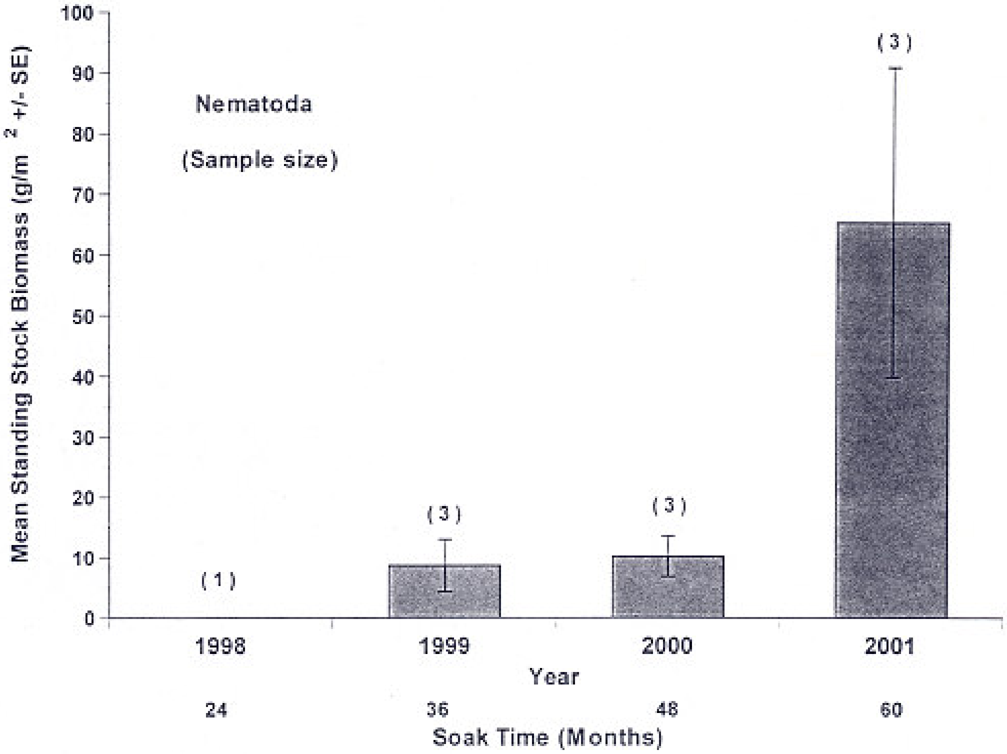

Figure 30. Mean standing stock biomass (g\m^2) of nematoda on experimental reef habitats over time.

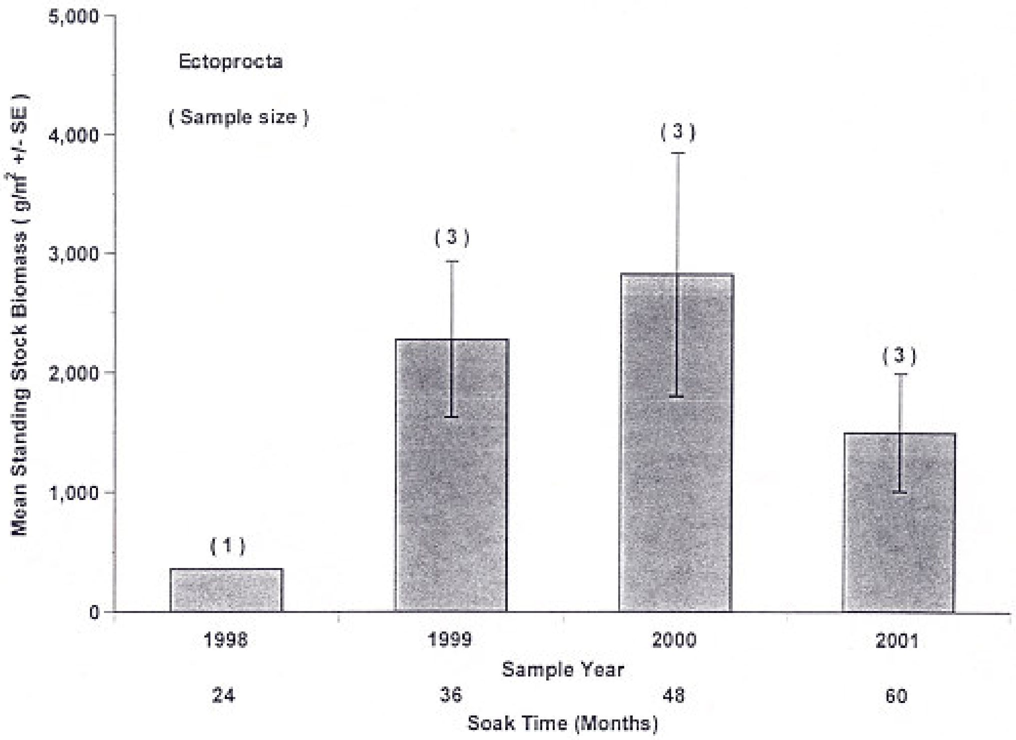

Figure 34. Mean standing stock biomass (g/m^2) of ectoprocta on experimental reef habitats over time.

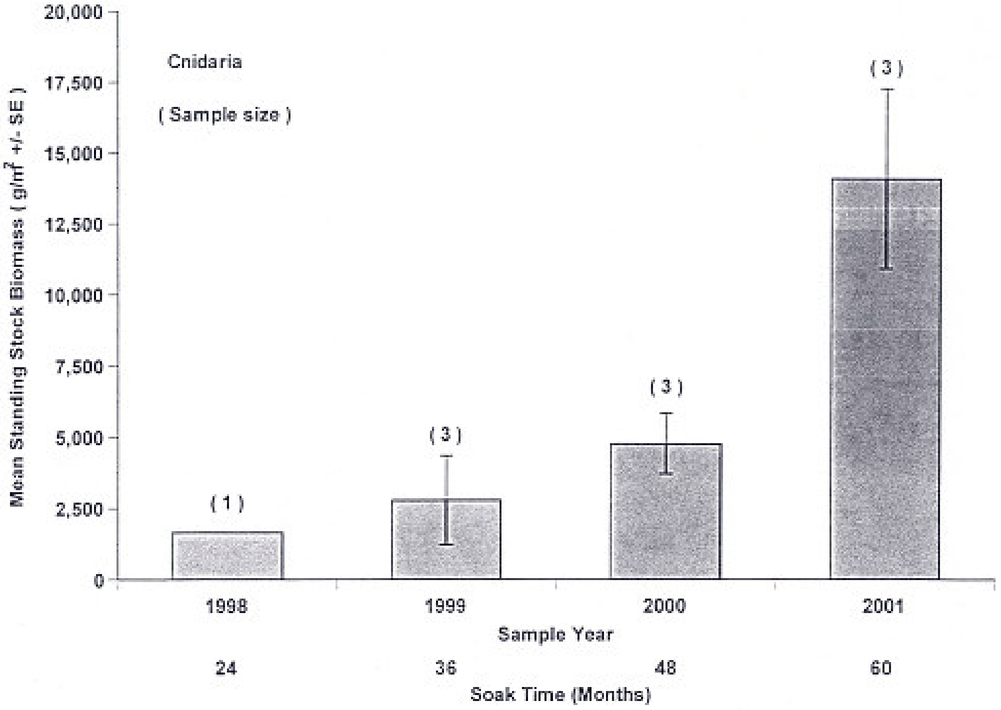

Figure 35. Mean standing stock biomass (g/m^2) of cnidaria on experimental reef habitats over time.

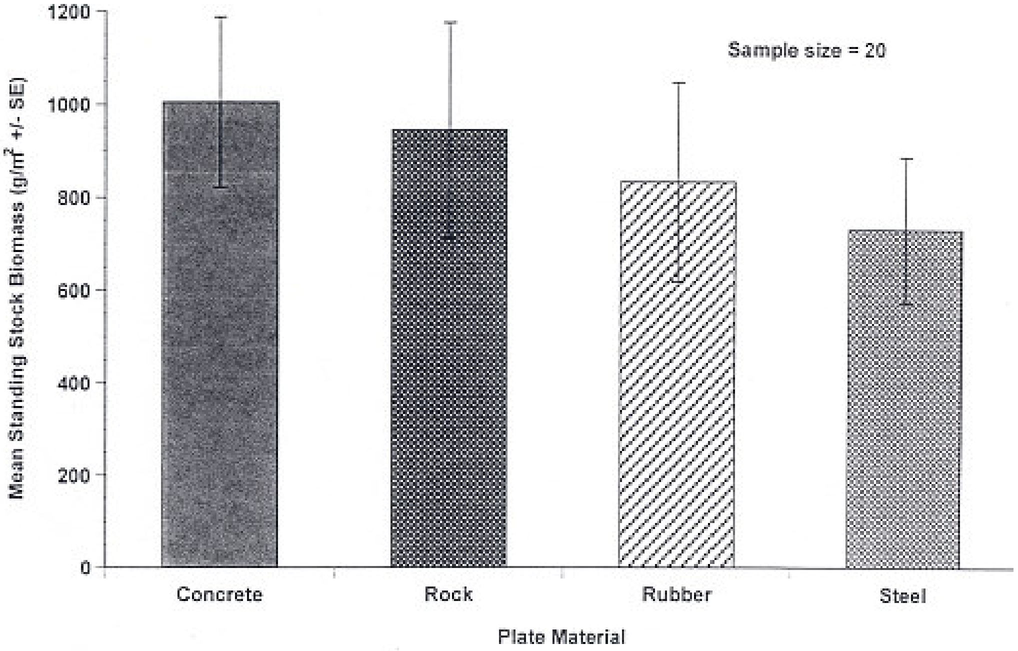

Figure 36. Mean standing stock biomass (g/m^2) of all attached epibenthic invertebrates inhabiting colonization plates by plate material for sampling years 1998 - 2001.

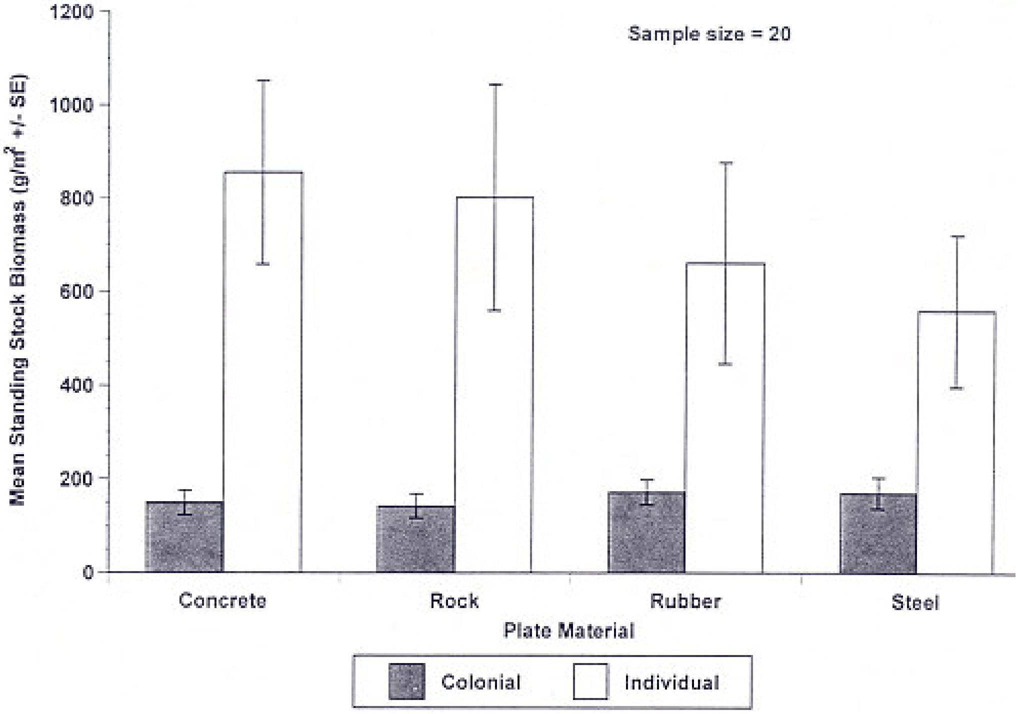

Figure 37. Mean standing stock biomass (g/m^2) of individual and colonial attached epifauna on colonization plates by plate material for sampling years 1998 - 2001.

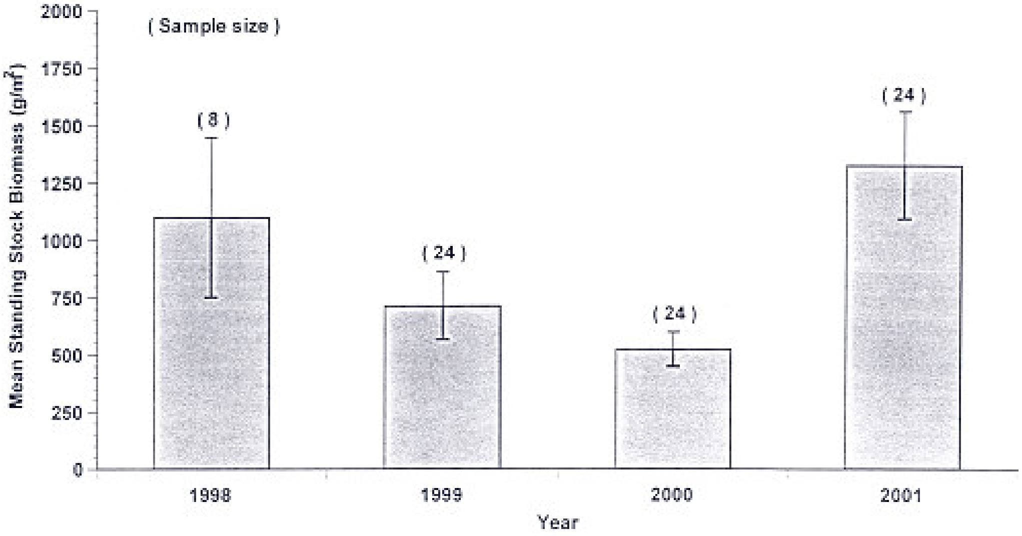

Figure 38. Mean standing stock biomass (g/m^2) of attached epibenthic invertebrates inhabiting colonization plates for sampling years 1998 - 2001.

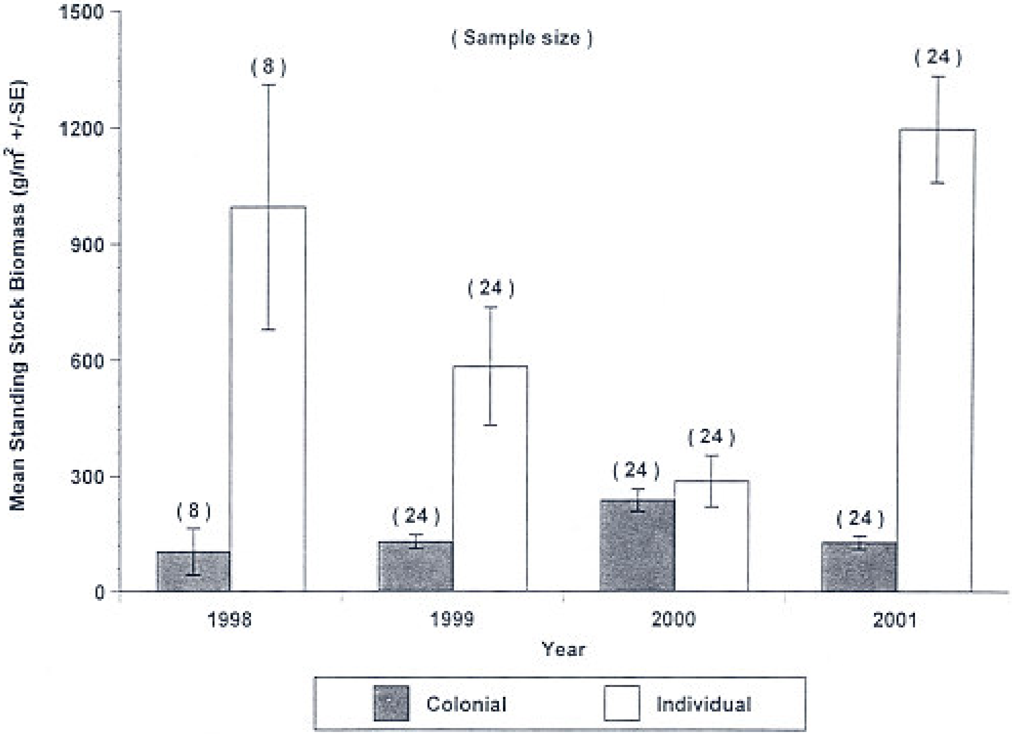

Figure 39. Mean standing stock biomass (g/m^2) of individual and colonial attached epifauna on colonization plates by sampling year (1998 - 2001).

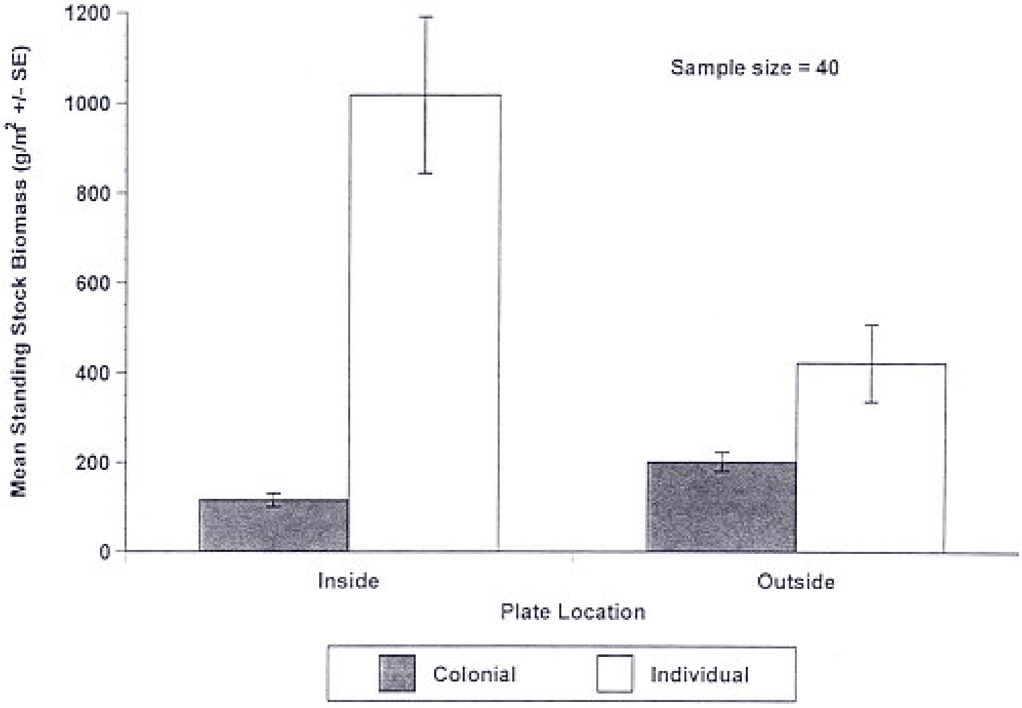

Figure 40. Mean standing stock biomass (g/m^2) of individual and colonial attached epifauna on colonization plates by plate location for sampling years 1998 - 2001.

APPENDIX

Data tables supporting figures.

Figure 21.
Mean standing stock biomass (g/m^2) of marine life colonizing experimental reef habitats by phyla, 1998 – 2001.

Phylum	Mean Biomass (g/m^2)	SD	SE
Mollusca	31,990.8	20,039.4	6,337.0
Arthropoda	12,883.3	5,449.6	1,723.3
Cnidaria	6,664.0	6,045.3	1,911.7
Ectoprocta	2,017.1	1,333.6	421.7
Annelida	1,793.1	926.3	292.9
Echinodermata	1665.4	745.0	235.6
Chordata	1275.5	1,1143	352.4
Porifera	44.1	74.2	23.5
Nematoda	25.3	35.0	11.1

Figure 22.
Mean standing stock biomass (g/m^2) of molluscan species inhabiting experimental reel habitats, 1998 – 2001.

Species	Mean Biomass (g/m^2)	SD	SE
Mylilus edulis	30,016.4	19,800.7	6,261.5
Crepidula plana	1,125.5	797.4	252.2
Crepidula fornicata	615.8	490.0	154.9
Astyris lunate	144.5	104.5	33.0
Anomia simplex	53.1	62.4	19.7
All other Molluscs	35.5	30.0	9.5

Figure 23.
Mean standing stock biomass (g/m^2)of arthropod species inhabiting experimental reel habitats, 1998 – 2001.

Species	Mean Biomass (g/m^2)	SD	SE
Balanus spp.	7,343.1	3,969.7	1,255.3
Cancer borealis	4,2895	2,211.3	699.3
Xanthidae spp.	570 4	662.2	209.4
Cancer irroratus	2162	570.1	180.3
Homarus amencanus	198 0	279.3	88.3
Libinia spp.	101 8	87.7	27.7
All other Arthropods	164.3	185.0	58.5

Figure 24.
Mean standing stock biomass (g/m^2) of fish species inhabiting experimental reef habitats, 1998 – 2001.

Species	**Mean Biomass**	**SD**	**SE**
	(g/m^2)		
Tautogolabris adspersus	1,097.4	1,047.6	331.3
Conger oceanicus	133.2	421.2	133.2
Centropristis striata	17.3	32.4	10.2
Pholis gunnellus	16.9	36.6	11.6
Ulvaria subbifurcata	8.2	17.6	5.6
Macrozoarces americana	1.3	4.1	1.3
Parablennius marmoreus	1.1	3.4	1.1

Figure 25.
Mean standing stock biomass (g/m^2) of all taxa on experimental reel habitats over time.

Year	**Mean Biomass**	**SD**	**SE**
	(g/m^2)		
1998	43,0498	0.0	0.0
1999	50,397.3	15,884.2	9,170.7
2000	35,716.9	7,038.2	4,063.5
2001	94,064.6	15,692.0	9,059.8

Figure 26.
Mean standing stock biomass (g/m^2) of all organisms colonizing experimental reel habitats by organism type and sampling year, 1998 – 2001.

Year	**Colonial Biomass**	**SD**	**SE**	**Individual Biomass**	**SD**	**SE**
	(g/m^2)			(g/m^2)		
1998	1,881.4	0.0	0.0	41,168.4	0.0	0.0
1999	3,459.0	1,539.1	888.6	46,938.3	16,249.9	9,381.9
2000	7,256.7	2,798.2	1,615.5	28,460.2	6,038.5	3,486.3
2001	7,005.4	2,230.7	1,287.9	87,059.1	17,541.1	10,127.4

Figure 27.
Mean standing stock biomass (g/m^2) of molluska on experimental reef habitats over time.

Year	**Mean Biomass**	**SD**	**SE**
	(g/m^2)		
1998	26,009.4	0.0	0.0
1999	30,045.3	9,439.7	5,450.0
2000	10,912.1	4,116.6	2,376.7
2001	57,008.0	8,494.3	4,904.2

Figure 28.
Mean standing stock biomass (g/m^2) of arthropoda on experimental reel habitats over time.

Year	**Mean Biomass**	**SD**	**SE**
	(g/m^2)		
1998	11,638.7	0.0	0.0
1999	10,367.7	7,391.5	4,267.5
2000	13,975.9	2,83.8	11,638.6
2001	14,721.0	7,336.0	4,235.9

Figure 29.
Mean standing stock biomass (g/m^2) of annelida on experimental reel habitats over time.

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	413.9	0.0	0.0
1999	1,466.3	330.8	191.0
2000	1,429.9	130.7	75.4
2001	2,942.9	664.9	383.9

Figure 30.
Mean standing stock biomass (g/m^2) of nematoda on experimental reef habitats over time.

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	0.0	0.0	0.0
1999	8.7	7.5	4.3
2000	10.2	5.8	3.4
2001	65.3	44.2	25.5

Figure 31.
Mean standing stock biomass (g/m^2) of echinodermata on experimental reef habitats over time.

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	1,7337	00	00
1999	2,176 7	841.8	4860
2000	980 8	733.0	423.2
2001	1,815.8	347.2	200.5

Figure 32.
Mean standing stock biomass (g/m^2) of chordata on experimental reef habitats over time.

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	1,227.2	0.0	0.0
1999	1,176.0	1,037.1	598.7
2000	762.6	895.7	517.2
2001	1,903.9	1,645.2	949.8

Figure 33.
Mean standing stock biomass (g/m^2) of Porifera on experimental reel habitats over time.

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	5.2	0.0	0.0
1999	95.0	104.4	60.3
2000	49.0	00 1	46.2
2001	1.3	2.3	1.3

Figure 34.
Mean standing stock biomass (g/m^2) of ectoprocta on experimental reef habitats over time

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	358.0	0.0	0.0
1999	2,278.3	1,133.3	654.3
2000	2,826.0	1,769.6	1,021.7
2001	1,499.9	852.8	492.4

Figure 35.
Mean standing stock biomass (g/m^2) of cnidaria on experimental reef habitats over time

Year	Mean Biomass	SD	SE
	(g/m^2)		
1998	1,663.0	0.0	0.0
1999	2,783.3	2,694.1	1,555.4
2000	4,770.3	1,839.1	1,061.8
2001	14,105.5	5,502.6	3,176.9

Figure 36.
Mean standing stock biomass (g/m^2) of all attached epibenthic invertebrates inhabiting colonization plates by plate material for sampling years 1998 – 2001

Material	Mean Biomass	SD	SE
	(g/m^2)		
Concrete	1004.6	821.9	183.8
Rock	943.9	1034.8	231.4
Rubber	833.2	959.5	214.6
Steel	730.5	701.1	156.8

Figure 37.
Mean standing stock biomass (g/m^2) of individual and colonial attached epifauna on colonization plates by plate material for sampling years 1998 – 2001.

Material	**Colonial Biomass**	**SD**	**SE**	**Individual Biomass**	**SD**	**SE**
	(g/m^2)			(g/m^2)		
Concrete	1495	118.7	26.5	855.1	879.9	196,8
Rock	1424	114.8	25.7	801.5	1084.0	242.4
Rubber	1718	117.9	26.4	661.4	962.0	215.1
Steel	1707	147.3	32.9	559.8	726.6	162.5

Figure 38.
Mean standing stock biomass (g/m^2) of al l attached epibenthic invertebrates inhabiting colonization plates for sampling years 1998 – 2001.

Year	**Mean Biomass**	**SD**	**SE**
	(g/m^2)		
1998	1098.4	981.4	347.0
1999	712.8	724.1	147.8
2000	522.8	368.4	75.2
2001	1325.2	1144.0	233.5

Figure 39.
Mean standing stock biomass (g/m^2) of individual and colonial attached epifauna on colonization plates by sampling year.

Year	**Colonial Biomass**	**SD**	**SE**	**Individual Biomass**	**SD**	**SE**
	(g/m^2)			(g/m^2)		
1998	103.6	169.6	60.0	994.8	894.4	316.2
1999	129.3	89.7	18.3	583.5	747.9	152.7
2000	236.7	138.1	28.2	286.1	328.8	67.1
2001	128.1	85.9	17.5	1197.0	671.7	137.1

Figure 40.
Mean standing stock biomass (g/m^2) of individual and colonial attached epifauna on colonization plates by plate location for sampling years 1998 – 2001.

Location	**Colonial Biomass**	**SD**	**SE**	**Individual Biomass**	**SD**	**SE**
	(g/m^2)			(g/m^2)		
Inside	115.9	96.0	15.2	1016.9	1098.7	173.7
Outside	201.3	134.2	21.2	422.0	544.8	86.1