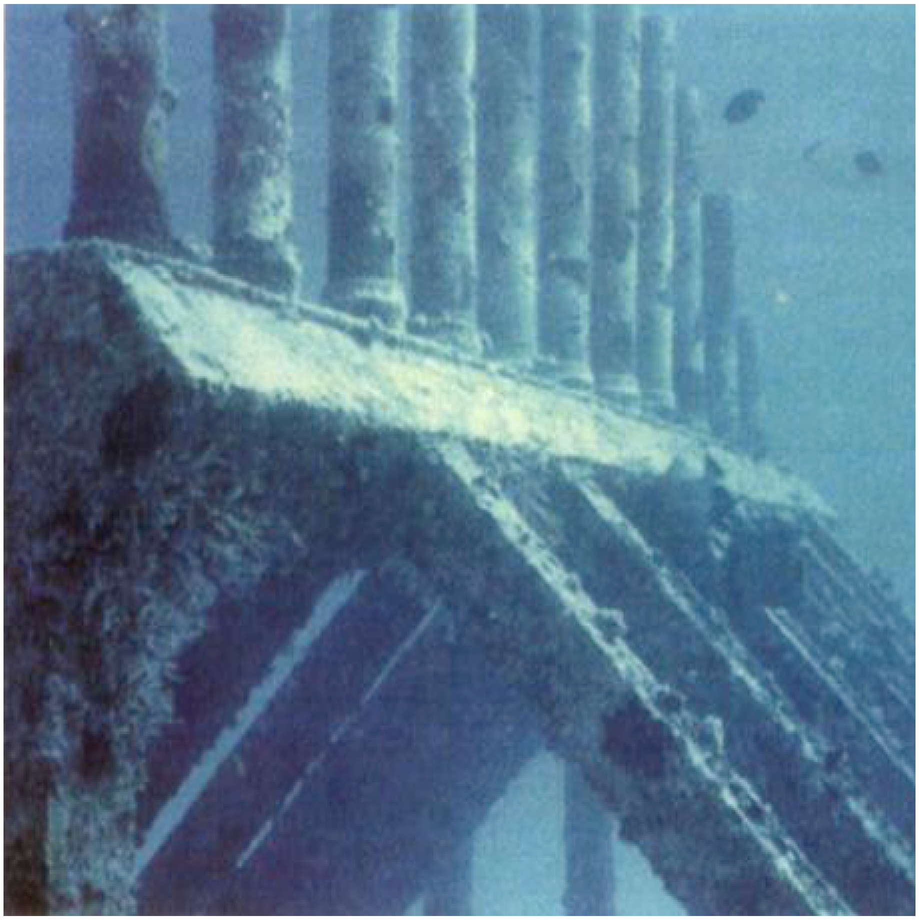
NOAA Technical Memorandum NOS NCCOS 16

Coastal and Estuarine Data Archaeology and Rescue Program

THE USE OF LARGE ARTIFICIAL REEFS TO ENHANCE FISH POPULATIONS AT DIFFERENT DEPTHS IN THE FLORIDA KEYS



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THE USE OF LARGE ARTIFICIAL REEFS TO ENHANCE FISH POPULATIONS AT DIFFERENT DEPTHS IN THE FLORIDA KEYS

by

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Cover photograph: Underwater view of a mid-water prefabricated unit 17 months after placement.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

SAR - Shallow prefabricated unit

SARC - Shallow prefabricated units combined

SNR - Shallow natural reef

MAR - Mid-depth prefabricated unit

MARC - Mid-depth prefabricated units combined

MNR - Mid-depth natural reef

DAR - Deep prefabricated unit

DARC - Deep prefabricated units combined

DNR - Deep natural reef

BH - Bahia Honda bridge rubble reef

AS - American Shoal bridge rubble reef

HAWKC - BR and MIS combined

N - Number of samples

PREFACE
[PREPARED IN 2005]

There are a significant number of documents and data related to the marine environment of South Florida that have never been published, and are thus not used by scientific community and academia. These documents and data are important because they can help characterize the state of the coastal environment in the past, and thus are essential when evaluating the current state of degradation and setting restoration goals. Due to the nature of the paper and electronic media on which they exist, and in some cases the conditions in which they are housed, the data and documents are in jeopardy of being irretrievably lost. These materials cannot be located using electronic and manual bibliographic searches because they have not been catalogued or archived in libraries.

The purpose of the Coastal and Estuarine Data Document Archeology and Rescue (CEDAR) for South Florida is to collect unpublished data and documents on the South Florida coastal and estuarine ecosystem; convert and restore information judged valuable to the South Florida restoration effort into electronic and printed form, and distribute it electronically to the scientific community, academia and the public. "Data Archaeology" is used to describe the process of seeking out, restoring, evaluating, correcting, and interpreting historical data sets. "Data Rescue" refers to the effort to save data at risk of being lost to the science community.

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THE USE OF LARGE ARTIFICIAL REEFS TO ENHANCE FISH POPULATIONS AT DIFFERENT DEPTHS IN THE FLORIDA KEYS

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Abstract [PREPARED IN 2005]

This study showed that large prefabricated units and concrete rubble patch reefs, placed as artificial marine habitats on sand bottom, greatly enhance the abundance, diversity, and biomass of fish in an area. Densities of individuals and biomass were found considerably higher at artificial reefs than at nearby, natural, bank reefs, a result consistent with other studies. Location, depth, and vertical profile are important factors determining fish assemblages at artificial habitats in the Keys. Fishes were both produced at artificial reefs and attracted from the surrounding area. Fish assemblages at the Hawk Channel artificial reefs were considerably different from those on the offshore reef tract, particularly in terms of dominant species. Rescue of the original 1992 work in 2005 was funded by the South Florida Ecosystem Restoration Prediction and Modeling Program.

1. Introduction

The use of artificial reefs as fishing sites is well established in the Florida Keys. Early residents knew that wrecks, sunk accidentally or deliberately, often produced concentrations of fish. In recent years, artificial "patch reefs" have been created with large concrete slabs, boulders and rubble from bridge removal projects, and large steel vessels have been intentionally sunk. The main purpose of artificial reef construction is to enhance, supplement, or mimic natural reef habitats by providing relief on flat, featureless ocean bottom (Seaman and Sprague, 1991). Artificial reef construction increases habitat diversity, vertical relief, and "hard bottom", creating new fishing and diving opportunities.

Florida's coral reef ecosystem supports extensive recreational and commercial fisheries for species dependent on complex reef habitats during some all stages of their life cycles. Of particular importance are fisheries for snapper, grouper, grunt, and porgy on natural hard bottom and reef habitats. Mid-water species such as mackerel, jack, cobia, and barracuda are often caught near habitats with high vertical relief. The marine life industry collects reef fishes and invertebrates for aquariums; fishes targeted include angelfish, butterflyfish, damselfish, wrasse, parrotfish and goby. Expansion of boating and fishing activity in South Florida and much improved technology have increased pressure on most reef species with fishery value.

Fishing and diving industries in the Keys have benefited greatly from the sinking of large vessels and rubble reefs. The marine life industry collects live specimens on rubble reefs. Artificial habitats can reduce user conflicts, increase fishing and boating efficiency, make fishing and diving more predictable, increase public access to fishery resources, and enhance fish abundance through attraction and production (Bohnsack, 1989). Milon (1991) reported that

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about 28% of anglers and 14% of divers use artificial habitats in the Dade County (Miami), Florida area.

As habitat for fish, artificial reefs provide food resources, shelter from predation, and sites for orientation and reproduction (Bohnsack and Sutherland, 1985). Shulman (1984) concluded that shelter from predation may be more important to fish recruitment than food availability, but some species may be limited more by supply of larval recruits (Bohnsack, 1990). Observations of higher fish densities at artificial reefs than at nearby natural reefs are common, although community structures are usually similar (Bohnsack, 1990). Research has shown that, although the fish assemblages vary at different artificial reefs because of different physical conditions, increasing habitat complexity increases abundance and diversity (Alevizon and Gorham, 1989; Bohnsack and Sutherland, 1985; Bohnsack *et al.,* 1989; Bohnsack, 1990).

Like many other non-profit and governmental artificial reef programs around the Gulf of Mexico, the Florida Keys Artificial Reef Association (FKARA), organized in 1980, has functioned mainly as an opportunistic builder of reefs when suitable material or vessels were available. From 1981 to 1987, FKARA supervised the placement of 35,000 tons of bridge rubble at six permitted sites, and the sinking of five vessels from 187' to 327' long from Key Largo to Key West (FKARA, 1990). All materials were placed onto sandy bottoms. Although fish surveys have been conducted on several of these shallower rubble reef sites for years, available information is limited to relative abundance, general patterns of succession, and, to some degree, recruitment.

The use of prefabricated reef structures in the eastern United States is not common, but as the uses of artificial reefs evolve from exploitation towards resource conservation and management, assessment of their value is taking place (Seaman *et al.,* 1989). In 1987 and 1988, FKARA obtained donated materials, labor, and work space, funds through fund raising, and a state grant for transportation that allowed construction and placement of seven prefabricated concrete units of two different designs. The largest (27 m^2 bottom area, 5 m high with PVC, 7 mt) are believed to be the largest prefabricated units ever used in south Florida as artificial marine habitats.

A NOAA grant through the National Marine Fisheries Service (NMFS), Marine Fisheries Initiative (MARFIN) program funded the two-year monitoring project that followed unit placement in June of 1988 and the preparation of this descriptive report. The purpose of this study was to evaluate the potential for fishery enhancement of placing large prefabricated units and concrete rubble in different depths and locations off the Lower Florida Keys. The project was designed to produce useful information on the responses of fish to the introduction of specific types and profiles of large structures. Examined were production potential, locational differences, fishery value, and economics of two different types of artificial reef construction projects. Censusing adjacent natural bank reefs using standard methods allowed comparisons of community structure. Fishes were censused on 15 bridge rubble "patch reefs" placed from 1983 to 1987 at two locations in Hawk Channel for additional comparisons. The study's original objectives were:

1. Quantify the species composition, biomass and seasonality of fishes attracted and produced on large fabricated artificial habitats over a 24-month period.

2. Compare the colonization and community structure of reef fishes on the fabricated habitats to nearby natural reefs.

3. Evaluate the effects of reef sitting at different water depths on species composition, recruitment, and biomass.

4. Separate fish communities into trophic levels to assess location of food source (e.g. water column, surrounding bottom, structure fouling community, etc.)

5. Through standard photographic techniques, document and quantify plant and invertebrate fouling communities as a function of substrate and water depth.

6. Determine if large, fabricated habitats can provide significant fishing opportunities.

7. Evaluate the economics of construction, transportation, and placement of artificial habitats to enhance fishery resources and fishing opportunities.

Understanding how much artificial reefs increase fish numbers and biomass is important to wise fishery management and to the proper construction and deployment of artificial reefs (Bohnsack, 1989). Basic knowledge of the results of reef building is critical to measure their value in a region as unique and significant as the Florida Keys, where future efforts could include additional concrete rubble reefs, clean steel vessels, and prefabricated concrete units. How artificial reefs should be used in a comprehensive fisheries (and people) management program in the Florida Keys National Marine Sanctuary will be resolved only through continued accumulation of ecological information on fish assemblages associated with reef habitats and documentation of various human uses. The use of structured, consistent methods for assessment of artificial habitats and the collection of long term population data on natural reef communities will facilitate important management decisions. As well, the ability to provide alternative fishing and diving sites through the creation of productive artificial reefs could assist in the management of people in one of the most popular fishing and diving locations in the United States and the world.

2. Methods

2.1. Overview

Project design was based on recommendations of Bohnsack and Sutherland (1985) in regard to the need for experimentation with large, inexpensive, long lasting, easily handled, and easily transportable, artificial reefs. Efforts were made to collect quantitative data on the short and long-term physical, biological, and economic aspects of artificial reef projects as well as to establish baselines for future comparisons.

Seven prefabricated structures were placed in 1988 in three depths on the Florida reef tract near Big Pine Shoal. Of these, three low profile concrete units were placed in the shallowest depth (7 m), and two high profile concrete and PVC units were placed at mid-depth (14 m) and deep (24 m) sites. Fish assemblages on the units and nearby natural reefs were censused for two years following unit placement. Rubble reefs, placed from 1983 to 1987, were censused in mid 1989. Assemblages were compared by species composition, frequency-of-occurrence, abundance, and biomass. Species at each artificial reef were classified as settler or colonizer species for indications of production potential. Fishery values, if any, and trophic group were determined for each species.

2.2. Artificial Reef Construction and Placement

The prefabricated units were designed by FKARA in collaboration with a structural engineer and built at a construction yard on Big Pine Key in late 1987 and early 1988. Pre stressed concrete (6,000 PSI) beams (15 cm x 20 cm) were used for diagonal and vertical members of the high profile units and for horizontal beams in the low units (Figs. 1 and 2, Plate 1). The units were structurally unified with tied, reinforcing steel in the poured concrete (4,000 PSI) base and upper beams. They are designed to last indefinitely and survive severe storms. Grove *et al.* (1991) note that shapes and dimensions of fabricated reefs with desirable structural integrity and durability are best developed based on knowledge of the "environmental loading" anticipated and the strength of the materials used. Important structural characteristics for artificial habitats include profile, shadow, vertical relief, surface area, substrate, holes, voids, and interstices that provide cover for fishes (Bohnsack, 1990). Japanese experiences using large prefabricated reefs to enhance fish populations suggest that maximum horizontal spread profile should be emphasized and that vertical profile probably need not be more than about 5 m high (Grove *et al.,* 1991).

The four high profile units were fabricated with identical square (5.15 m x 5.15 m) bases (Plate 1) to prevent toppling and open sides to minimize effects of wave surge during storms. The wide base beams were designed to minimize sinking into sand substrates. The concrete portion of the structure was 2.8 m high. Total height, including the PVC "stacks", ranged from 4.6 to 5.4 m (Fig. 1, Plates 2 and 3). The top PVC pieces were seated in a PVC base embedded in the poured concrete top beam and were held in place by large galvanized pins in holes drilled through both pieces. Each high unit covered about 27 m^2 of bottom, had a volume of 40 m^3, a surface area of about 66 m^2 (43 m^2 concrete and 23 m^2 PVC), and weighed approximately 7,300 kg. Structural variation between high units was limited to the eight vertical concrete end pieces (0.9 to 2.0 m tall) and the PVC tubes, thick walled (15 cm diameter, 0.7 to 2.5 m tall) at the top and thin walled at the bottom of the units (11 cm diameter, 0.1 to 0.4 m tall). High units had 5-cm diameter holes drilled in all top PVC pieces and smaller holes drilled in most bottom PVC pieces. Upper surfaces of the pre stressed beams were rough, while the surface of poured concrete was smooth. Most pre stressed beams had lengths of 0.5-cm diameter steel wire attached by 5-cm steel pegs along the upright edge (Plate 1), further diversifying the structures' surfaces. Bohnsack (1990) reports that the surface of material used can influence food availability through differences in fouling community development.

Three low profile units were created by fabricating two separate table-like structures (3.1 m long and 7.0 m long) and placing the shortest structure over the other (Fig. 2, Plate 4). Pre stressed beams were used for cross members, and formed and poured concrete with reinforcing steel was used to tie beams together on each end and to form the legs. The three structures had nearly identical dimensions. The horizontal portions of the structures were elevated from 0.5 m to 1.2 m above the bottom. The upright surfaces of the pre stressed beams were rough and included a strip of steel wire on small pegs as on high profile units. Loops of reinforcing steel were placed in the top of the poured concrete as lifting rings. Each unit covered about 29 m^2 of bottom, had a volume of 20.4 m^3, and weighed about 2,300 kg (2 sections). One small unit (SAR3) had two flat concrete plates installed on the upper surface to hold inserts of several surfaces.

In June 1988, the units were transported via US Highway 1 to a staging area at the southwest end of the old Bahia Honda Bridge east of Big Pine Key (Plate 2). A barge was used to transport the units offshore to the permitted sites where they were carefully placed with the assistance of divers on top of markers set in the bottom (Plate 4). Two high profile units were placed at 14 m depth on June 25, 1988, 50 m apart and 50 m south of a natural linear bank reef. The other two high units were placed at 24 m depth on June 26 and 27, 50 m apart and 50 m north of the natural deep reef. On June 27, the three low units were placed at 7 m depth, 50 m apart and 50 m from a shallow natural bank reef. Mid-depth and deep units were placed perpendicular to the prevailing east-west orientation of current flow. Stakes of reinforcing steel were driven (September 1988) into the bottom 76 cm off the corners of all except one deep unit to allow detection of any unit movement.

2.3. Site Conditions

The area chosen for placement of the units is a north-south cross section of the Florida reef tract at latitude 24° 34' N and longitude 81° 20' W, about 8 to 9 km south of Big Pine Key and about 7.5 km east of Looe Key Reef (Figs. 3 - 5). The area is in the blue water zone of the coral reef ecosystem - the outer reef slope, influenced more by the warm offshore Florida Current than by the seasonally cooler, green waters of the Gulf of Mexico. Gilbert (1974) notes that the richness of the Florida Keys fish fauna is due in large part to the mixing of continental (green water) and insular (blue water) fish faunas

Mid-depth and deep units were placed onto open, sandy bottom while the shallow (7 m) units were placed on sandy bottom with nearby patches of turtle grass (*Thalassia testudinum*) (Fig. 5, Plate 5). Mid-depth units were placed on a sandy plain with low, flat, relict rock within about 15 m of the west side of the westernmost unit (MAR2, Plate 5). The natural bank reefs at shallow and deep depths were seaward (south) of the units; at mid-depth, the natural reef was landward (north) of the units.

Currents on the reef tract were typically mild and variable in direction; the strongest were on the deep reef, nearest to deep water and the Florida Current. Winds and seas were usually from the southeast, except when fall and winter colds fronts produced strong northerly winds. Water temperature ranged from 22.0 to 30.5 °C (Table 1). Most temperature measurements were made on the bottom with a hand-held thermometer; a few were obtained from the Florida Institute of Oceanography data bank of surface water temperatures at Sombrero Reef, a few miles to the east. Visibility was affected by strong winds, the Florida Current, and tides, and varied from 7 to 18 m during census work. Visibility was lowest on the deep reefs where stratification often occurs; producing clear, warm, blue water on the surface and "dirty", often cooler water, near the bottom.

The shallow (6 to 8 m) natural reef censused was about 50 m wide and 150 m long (Fig, 5, Plates 5 and 6). This reef was an isolated section of linear bank reef (Jaap, 1984; Voss, 1988) that extended a considerable distance to the east. Overall relief was about 2 m with greatest habitat complexity on the slope along the north edge and on an elevated section to the west. Relief of individual rock outcrops, large vase sponges, and large octocorals was up to 1 m. Soft corals included *Pseudopterogorgia* sp., *Pseudoplexaura* sp., *Gorgonia* sp. and major stony corals included *Siderastrea siderea*, *Stephanocoenia michelinii*, *Porites astreoides*, *P. porites*, *Agaricia agaricites*, *Dichocoenia stellaris*, *Montastraea cavernosa*, and *Millepora alcicornis*. Of all the natural reefs censused, only this area had associated beds of seagrass.

The mid-depth (10 to 12 m) natural reef censused was about 50 m wide and part of an elongated (east-west) bank reef (Fig. 5). The homogeneous reef sloped about 20 to 30 degrees seaward, with overall relief of about 2 m, and well developed sand channels to about 0.7 m deep (Plate 5). Maximum vertical relief provided by octocorals, hard corals, rock, and sponges was about 1.4 m (Plate 6). This reef consisted of a larger proportion of hard corals than the shallow natural reef, including *Porites astreoides, Montastraea annularis, Millepora alcicornis, Siderastrea radians*, *Dichocoenia stokesii, Colcophyllia natans*, *Oculina diffusa*, *Manicina areolata*, and *Meandrina meandrites*.

The deep natural reef was censused at a depth of 26 to 31 m on a steep, seaward facing slope of about 40 to 60 degrees. Immediately south of the reef began the expanse of open sand that descends offshore into deeper waters of the Straits of Florida. At about 15 to 20 m wide, this linear reef was relatively homogeneous, smaller than the shallow and mid-depth reefs censused and somewhat discontinuous beyond the census area to the east and west. This relict reef consisted of large, eroded, rocky areas with relief up to 1.2 m (Plate 7). Exposed rock was encrusted with sponges, octocorals, bryozoans, and hard corals including *Stephanocoenia michelinii, Agaricia agaricites, Montastraea cavernosa*, and *Siderastrea siderea*.

Two additional study sites were the Bahia Honda and American Shoal rubble reefs in Hawk Channel (Fig. 4) constructed from 1983 to 1987 by placing large concrete boulders, concrete deck slabs and heavy steel from local bridge removal projects on sand bottom. The Bahia Honda site includes large steel girders from removal of the old Bahia Honda Channel bridge (Plate 8). The location in little-studied Hawk Channel (to 14 m depth), which lies between the reef tract and the island chain, influences physical parameters, particularly water clarity, and probably minimum water temperature. Proximity to tidal channels connecting to the Gulf of Mexico and the depressional nature of the area results in frequent stratification of the water column. These sites appear to be influenced more by green waters of the Gulf of Mexico than by the Florida Straits.

The Bahia Honda rubble site, in 9 to 10 m depth on the north edge of Hawk Channel about 4.5 km offshore from Bahia Honda Channel (Fig. 4), is composed of 19 "patch reefs" placed in 1985 and 1987 containing a total of about 6,000 mt of material (Plate 8). Averaging about 150 m^2 in area, but with considerable size range, the patches are separated by about 20 to 70 m and are scattered over about 2 ha. Schroeder (1987) reported that a grouping of several small reefs produces higher density and higher total number of recruits than one large reef. Patches vary somewhat in combinations of materials (concrete boulders, slabs, and rubble; steel girders, pipe and pipe hangars), size, vertical profile, and open space within the patch. The patches are just seaward of deep beds of predominantly turtle grass and shoalgrass (*Halodule wrightii*) that extend offshore to the 9-m depth contour. Vertical relief on the patches ranged to about 2.5 m. In the years between placement and the 1989 censuses, a variety of sponges and large octocorals (to 58 cm tall) have flourished on hard surfaces, along with some stony corals.

The American Shoal rubble reef consists of four patch reefs, averaging about 450 m^2, placed from 1983 to 1987 on sand bottom at a depth of 11 to 12 m on the south (seaward) edge of Hawk Channel (Fig. 4). Patches were constructed by carefully placing a total of 3,800 mt of large concrete slabs, boulders, and steel pipe from local bridge removal projects. Vertical relief ranged to about 2.5 m. The four patches vary somewhat in materials and profile: patch 1 is mostly large boulders and slabs with open space between many pieces; patch 2 is both large and small boulders in a large mound with some pipe; patch 3 is high profile large boulders, slabs and pipe; patch 4 is a mound of boulders and slabs. By 1989, octocorals had reached a height of 50 cm on the oldest material, adding appreciably to the structural complexity of the site (Plate 9). Various sponges and small stony corals were also present.

2.4. Sampling

2.4.1. Prefabricated Units

Divers listed and counted all fishes at prefabricated units and estimated the range of fork length of each species using standard visual census techniques (Bohnsack and Talbot, 1980; Bohnsack *et al.,* 1989). Large fish were recorded first from a distance, then the unit was inspected closely for small and cryptic species. A zone about 5 m wide around each unit was included to insure all fishes associated with the structure were counted. A second diver recorded cryptic and unusual fishes allowing comparisons and creation of accurate census records. The units were censused on June 30, 1988 (mid-depth units also on June 27), after placement, then monthly for the next three months, and every other month thereafter until June 1990.

2.4.2. Natural and Rubble Reefs

On natural reefs and bridge rubble reefs where total counts were not possible, a stationary sampling method developed by Bohnsack and Bannerot (1986), was used to visually sample the community structure of highly diverse and abundant reef fish populations. Stationary censuses were also taken on sand bottom at the two mid-depth sites prior to unit deployment to allow comparison of changes as a result of unit placement. A major value of the stationary sampling method is that quantitative data are collected simultaneously on species composition, abundance, frequency-of-occurrence, and lengths of all visually detectable species. This method, considered extremely effective for censuring reef fish and providing indices of abundance for comparative purposes, is simple, fast, objective, and repeatable (Bohnsack and Bannerot, 1986). Sale (1991) concludes that stationary visual censuses can have definite advantages over other census methods. As in other census methods, documentation of many crevice dwelling and cryptic species is poor. Alevizon (1990) assesses various reef fish census methods used in south Florida and reminds us that at night reef fish communities differ substantially from those observed during the day.

Two divers went to different regions of a natural or rubble reef to be censused, and each established an initial census area (177 m^2) using a 7.5-m anchored rope to delineate the sample circle's radius. Stationary at the center of the circle, the divers listed all species observed in 5 minutes within an imaginary cylinder extending from the bottom towards the water's surface. After 5 minutes, beginning at the bottom of the list, all individuals of each species within the sample area were counted and the range of fork lengths estimated using 40 cm rulers at the ends of poles carried by the divers to reduce effects of magnification. Fast moving species, such as jacks and mackerels, were counted during the initial 5 minutes. The percentage of sand and rock/coral surface in the sample area was recorded along with water depth, temperature, and visibility. After the initial census, each diver traveled to a second census site based on a predetermined, randomly derived list of compass headings and distances, and the process was repeated. Distance traveled between censuses was measured by swim kicks and was adequate to preclude overlap. Divers worked in different regions of the reef to avoid interference with the other's counts. At most, three censuses were conducted during a single dive on shallow and mid-depth reefs and two censuses on the deep reef. Project design required eight stationary samples from each the mid-depth and deep natural reefs and 12 from the shallow natural reef during months when the adjacent units were counted. All regions of the natural bank reefs near the units were censused during the two years of sampling. To insure consistency, the authors conducted all censuses.

The bridge rubble reefs in Hawk Channel were censused from June to August, 1989. A 7.5-meter radius visual census area was established on different patches after they were located with land ranges and a depth recorder. At the American Shoal site, all samples were collected on the three westernmost patches (numbers 1 - 3). At the Bahia Honda site, several censuses were made on each of the largest patches (numbers 1 and 2) which include large, piled steel girders; the remainder were made on about 10 other patches randomly sampled. Poor visibility (<7 m) precluded censuses on several occasions at both natural and rubble reefs.

2.5. Analysis

Census data from prefabricated units, natural reefs, and bridge rubble reefs were entered into a data entry template for "Reef Fish Visual Censusing Samples" provided on Lotus 1-2-3 by the Southeast Fisheries Center of the NOAA National Marine Fisheries Service (NMFS) in Miami, Florida (D. Harper, pers. comm., 1989). Multiple samples were processed into a flat data file from which a summary analysis of samples from different locations was performed by the NMFS program. Mean length was determined for each species in each sample from the range of lengths recorded in the field. Total biomass was calculated for each species at all artificial reefs and the deep natural reef using overall mean lengths and length to weight formulas in Bohnsack and Harper (1988). Density was estimated for comparative purposes by dividing the total number of fishes censused at a site by the area censused. Similarity between fish assemblages at two reefs was determined by comparing species shared to the total number of species and by comparing the 15 most frequent, abundant, and heaviest species at the two sites.

To determine which species have the potential for being produced by these types of artificial habitats, reef fishes were separated into settlers and colonizers using a modification of the following definitions by Bohnsack *et al.* (1989):

> "Settlers are defined as species that arrived at the artificial reef directly from the plankton as larvae. Colonizers are defined as species that arrive at a reef as juveniles or adults after apparently settling elsewhere and then swimming to the artificial reef."

Production and attraction at artificial reefs are not mutually exclusive and actually occur on a gradient or continuum depending on reef type and location (Bohnsack, 1989). Settler species, as defined here, are species of which at least a single young juvenile was recorded, a result of either settling directly from the plankton or moving to the artificial habitat a short time after settling in nearby sand or seagrass. Settler species have documented potential to be supported by these types of artificial habitats at a very early life stage (at least for a short period), benefitting by the food and shelter resources provided. Determination of a settler species was based on the minimum size recorded at a site, juvenile coloration, and known biology of individual species. Questionable individuals were listed as settlers. Colonizer species at a site were those never observed at a young juvenile size, and included visitors and transients. Bohnsack *et al.* (1991) note that many reef fishes initially use an intermediate habitat (e.g. sand plains, rubble zones, seagrass beds) prior to using reef habitats.

Fishes at the mid-depth and deep units, the deep natural reef, and the Bahia Honda rubble reefs were separated into trophic categories based on designations in Bohnsack *et al.* (1989) for comparison and assessment of food source.

An economic fishery value classification (commercial, recreational, marine life) was assigned to each species based on lists in Bohnsack *et al.* (1989), marine life industry lists contained in Florida Administrative Code Chap. 46-42.001 (Marine Life), and commercial experience of both investigators in the collecting and wholesale of marine life throughout Florida.

2.6. Foulinq Community Photography

Photography was conducted on a quarterly basis from September 1988 to August 1990. Six points, marked either with nails driven into the concrete or located by measured distances, were established in the same locations on the concrete surfaces of each of the low units (Fig. 6). Six points were established on each side (east and west) of each of the high units (Fig. 6) resulting quarterly in 12 images for each unit. A Nikonos V camera with a 28-mm lens, SB-103 strobe, and close-up unit with a frame measuring 12.8 cm x 18.4 (236 cm^2) cm was used with Fujichrome 50 color transparency film. Routine underwater photography of the units was conducted as well.

3. Results

Four hundred eleven visual fish censuses were conducted in 23 different months from June 1988 to June 1990 (Table 1); a total of 105,405 individuals of 179 species (Table 2) in 44 families (Table 3) was recorded from all sites. Although fishes not identified to species level represented 10% of those listed, they were minor and infrequent contributors to the total number of individuals except for unidentified juvenile grunts and scad in local abundance.

In 104 counts on the seven prefabricated units, 9,515 individuals (978 kg) of 108 species in 33 families were recorded (Table 4). Combining all 50 samples from bridge rubble reefs showed 43,289 fishes (2,345 kg) of 103 species in 34 families (Table 5). Two hundred fifty-seven censuses on the three natural reefs showed 52,601 individuals of 156 species in 39 families (Table 6). By comparison, Bohnsack *et al.* (1987), using two census methods at Looe Key Reef, reported 188 species in 48 families from 10 habitat zones (0 to 12 m depth). At Looe Key Reef, known for its high spur and groove formations, 66 species of grunts, damselfishes, wrasses, sea basses, and parrotfishes made up 35% of total species. Here these families represented 66 species, 36% of the total, with seven members not identified to species level (Table 3).

Both numbers of species (Fig. 7) and relative fish density (Fig. 8) were comparable at prefabricated units in the same depth. Highest species richness and abundance were at the mid-depth units. The numbers of species were similar at the different natural reefs, but density appeared to increase with greater depth. Fish density ranged from a low of 0.9 inds./m^2 at the shallow natural reef to 5.9/m^2 at the Bahia Honda site. Of the Hawk Channel rubble reefs, Bahia Honda had the more diverse and abundant fish assemblage. Biomass density at artificial reefs ranged from a low of 199 g/m^2 at the Bahia Honda site to a high of 483 g/m^2 at the deep units. The deep natural reef, the only natural reef for which biomass was reviewed, showed 72 g/m^2.

The prefabricated units proved to be very stable on the bottom even during high seas (9 - 11 feet) resulting from the passage of several tropical storms and severe cold fronts during the study period. Monitoring at the end of two years revealed that movement was limited to a few centimeters at the westernmost mid-depth unit (MAR2), the other units appeared not to move at all. Several of the top PVC stacks were removed during the study, possibly due to vandalism.

3.1. Shallow reefs

3.1.1. Prefabricated Units

Fourteen counts were made on each of the three low profile shallow units from June 1988 to June 1990 (Table 1); summaries are in Table 7 (SAR1), Table 8 (SAR2), and Table 9 (SAR3). All units were censused during the same dive. The number of species recorded at a unit ranged from 38 (SAR1) to 45 (SAR3), and total individuals ranged from 638 (SAR1) to 683 (SAR3). Maximums of 19 species and 89 individuals were recorded in a single unit count. Combining all counts of the three shallow units revealed 67 species and 2,002 individuals (Table 10).

The average number of species per census of each unit ranged from 9.6 to 12.3, and the average number of fishes per census ranged from 45.6 to 48.8 (Fig. 9). Trends in numbers of species (Fig. 10) and individuals (Fig. 11) showed rapid increases the first few months, declines the first winter, and increases again the following June. The average number of species increased considerably by the second summer, but the number of individuals increased only slightly and peaked in October. Similarity of species between units ranged 40% (SAR2 and SAR3) to 53% (SAR1 and SAR2) (Table 11). Twenty-two species (33%) were recorded at all three units.

3.1.2. Natural Reef

One hundred eleven stationary visual samples were collected at the shallow (6 to 8 m) natural reef in ten different months from July 1988 to April 1990 (Table 1). Combining all samples showed 107 species and 17,038 total individuals (Table 12). Maximums of 30 species and 335 individuals were recorded in a single census. The number of species, 104, was the lowest of the natural reefs censused (Fig. 7), and fish density (0.9/ m^2) the lowest of all reefs, including the units (Fig. 8).

3.2. Mid-Depth Reefs

3.2.1. Prefabricated Units

Sixteen counts were conducted on each of the two high profile mid-depth units from June, 1988 to June, 1990 (Table 1); summaries are at Table 13 (MAR1) and Table 14 (MAR2). Both units were censused on the same dive. MAR1 showed totals of 55 species and 2,395 individuals, MAR2 had 58 species and 2,036 individuals. Maximums of 25 species and 873 individuals (800 juvenile grunts) were recorded in a single unit count. Combining counts at both units showed 73 species, 4,421 individuals (Table 15), and an estimated density of 4.2 inds./m^2 when the 800 grunts are excluded (Fig 8). Total biomass was 335 kg (738 lbs.).

The mid-depth units had the highest mean number of species per census (16.5) and the most individuals per sample (113.5) of all units (Fig. 9). An additional count at each MAR unit only several days after placement, and not made at other units, was included in the data base and slightly lowered mean values. The mean number of species in the second year was 19.3. The number of individuals per sample was more than double that at the shallow units and about two-thirds greater than at the deep units. The average number of species per census was about the same for each of the two units, 16 to 17 species, but the average number of individuals was about 27% higher at MAR2 (excluding 800 grunts at MAR1) (Fig. 9). The location of MAR2, within about 15 m of an area of flat, hard bottom with some sponges and gorgonians extending from the bank reef may have accelerated colonization at this unit.

Trends in the fish populations on the MAR units were similar the first year but varied somewhat the second (Figs. 12 and 13). Little seasonality was seen in the bimonthly number of censused species, and near average numbers was reached a few months after placement. The overall number of fishes peaked the first fall, declined substantially the first winter, and increased the second year.

June, 1989 was a month of considerable difference between the units, particularly in grunts. MAR1 (14 total species, 48 inds.) had a single cottonwick grunt (14 cm) while MAR2 (20 species and 270 inds.) showed 211 grunts of four species (2 - 10 cm). Small ledges under the base beams of the units caused by wave surge during windy periods, contributed to the diversity and abundance of crepuscular and juvenile bottom dwelling fishes by providing shelter from predators and probably accounted for these differences. Bohnsack *et al.* (1989) concluded that fish assemblages were influenced by microhabitat modifications at reefs including sand chambers opening and closing under concrete modules. The temporal variation in grunts at the mid-depth units, illustrates the highly changeable nature of many fish populations. In a census in August, 1988, 802 grunts (2 - 8 cm long) were recorded, five weeks later there were only 30 (2 - 8 cm). In October, 1988, 60 tomtates (2 - 8 cm long) were noted at a unit, 2 days later there were only 5.

The two mid-depth units shared 40 species, 55% of their combined total (Table 11). Comparison of the 15 most frequent and abundant species on each unit revealed 72% similarity of frequent species and 67% similarity of abundant species, the second highest of any comparison after the deep units (Table 16). Shared of the 15 most frequent species were blue tang, ocean surgeon, doctorfish, sharpnose puffer, reef butterflyfish, slippery dick, bluehead wrasse, gray angelfish, hogfish, porkfish, masked goby, twospot cardinalfish, and yellowtail snapper (Table 17). Shared of the most abundant were tomtate, bluehead wrasse, yellowtail snapper, mackerel scad, ocean surgeon, masked goby, blue tang, yellowhead wrasse, slippery dick, unidentified scad, twospot cardinalfish, and doctorfish.

In early June, 1988, five stationary censuses taken on the open bottom before placement of the mid-depth units showed 11 species and 62 individuals (12.4/census), mostly wrasses, bottom dwelling gobies, sand perch, and sand tilefish. Pre-project density of fishes at these sites was $0.07/m^2$. Bohnsack *et al.* (1989) in 98 predeployment and sand control samples found 27 species and density of 0.09 inds./m^2. The two-year mid-depth unit mean fish density of $4.2/m^2$ excluding 800 juveniles grunts in one sample, reflects about a 6,000% post-placement increase in fish density. Including all grunts reflects about a 7,300% increase.

3.2.2. Natural Reef

Seventy-eight stationary samples were collected at the mid-depth (10 to 12 m) natural reef in ten different months from September, 1988 to May, 1990 (Table 1). Combining all samples showed 114 species and 17,106 individuals (Table 18). Maximums of 33 species and 2,633 individuals (2,500 unid. juvenile grunts) were recorded in a single census. The greatest number of species of all reefs sampled was recorded here, but density, 1.2 inds./m^2, was the second lowest of all sites (Figs. 7 and 8).

3.3. Deep Reefs

3.3.1. Prefabricated Units

Fifteen counts were made on each of the two high profile deep units from June, 1988 to June, 1990 (Table 1). Summaries are at Table 19 (DAR1) and Table 20 (DAR2). Both units were counted on the same dive. Fifty-three species and 1,029 individuals were recorded at DAR1 and 57 species and 2,063 individuals (1,000 round scad in one count) at DAR2. Maximums of 23 species and 1,145 individuals were recorded in a single census. Combining units revealed 69 species and 3,092 individuals (Table 21) and a density of 2.6 inds./m^2 (excluding 1,000 scad) (Fig. 8). Total biomass was 389 kg (852 lbs.).

The two deep units were similar in mean numbers of species and individuals, which were greater than the numbers on the shallow units and less than those on the mid-depth units (Fig. 9). The development of the fish populations on each of the deep units was similar. The number of species increased gradually the first year and leveled off thereafter (Fig. 14). The number of individuals increased gradually most of the first year with a slight decline the first winter and a variable but increasing trend thereafter (Fig. 15). The number of fishes was considerably higher at the end of 24 months than after 12 months.

Comparison of species found on the two deep units showed 59% similarity with 41 shared species, the highest similarity of all unit comparisons (Table 11). Comparison of the 15 most frequent and abundant species at each unit showed 88% and 76% similarity, respectively (Table 16). Frequent species found at both units were graysby, bluehead wrasse, hogfish, sharpnose puffer, bicolor damselfish, masked goby, slippery dick, gray snapper, yellowhead wrasse, yellowtail snapper, twospot cardinalfish, spotfin butterflyfish, and doctorfish (Table 21a). Abundant species shared were bluehead wrasse, bicolor damselfish, masked goby, twospot cardinalfish, gray snapper, yellowtail snapper, yellowhead wrasse, slippery dick, graysby, sharpnose puffer, doctorfish, spotfin butterflyfish, and hogfish.

3.3.2. Natural Reef

Sixty-eight stationary surveys were made at the deep (26 to 31 m) natural reef in ten different months from September, 1988 to May, 1990 (Table 1). Total samples showed 109 species and 18,457 fishes (Table 22). There were maximums of 39 species and 791 individuals in a single count. The mean density of fishes (1.5/m^2) was the highest of all natural reefs, about 66% higher than the shallow natural reef, and 25% higher than the mid-depth natural reef (Fig. 8).

3.4. Bahia Honda Rubble Reefs

Twenty-six stationary censuses were made at the Bahia Honda site from June to August 1989; 7 on patch reefs created in 1985 and 19 on patches created in 1987. Of the 19 patch reefs at the site, 13 were sampled. Water temperature ranged from 27 to 30.5 °C. Visibility, typically poor on the bottom of Hawk Channel, ranged from about 7 to 12 m during censuses. Due to irregular edges and the small size of some patches, six samples included from 25% to 50% sand. The combination of poor visibility during nearly half of the counts and a high percentage of open bottom in many samples may have resulted in low abundance and density estimates for these habitats. Conducting censuses at times of high visibility would allow total counts to be made on at least the smaller patches. Sixteen qualitative fish surveys made at the site by the principal investigator during nine different months July, 1985 to May, 1989, were reviewed for documentation of juveniles (settlers) of species recorded here.

Ninety species were recorded at the Bahia Honda reefs representing 27,151 individuals, of which 73% were tomtate grunts with a mean length of 9 cm (Table 23). Maximums of 32 species and 4,666 individuals were recorded in a single sample. Fish density was estimated at 5.9 inds./m^2, the highest of all reefs sampled (Fig. 8). Total biomass censused was 915 kg (2,018 lbs.). The Bahia Honda site shared 59 species (57% similarity) with the American Shoal rubble site (Table 11). Of the 15 most frequent, abundant, and heaviest species at each site, Bahia Honda and American Shoal shared 30%, 50%, and 50%, respectively (Tables 16 and 34).

Grunts (4.5/m^2) of seven species comprised 76% of fishes (Table 23). Lane and gray snapper totaled 253 individuals, but only 10 yellowtail snapper were recorded. There were 115 *Mycteroperca* groupers from 6 to 100 cm long and 23 *Epinephelus* groupers to 60 cm, with several species occurring in most samples. Seventy-six snook (in 30.8% of samples) averaged 76 cm long, with 35 recorded in a single census.

3.5. American Shoal Bridge Rubble Reefs

Twenty-four stationary censuses were made in July and August 1989 at this site. Of the four patch reefs, six counts were made on patch 1 (1983 placement) , 11 at patch 2 (1985), and seven at patch 3 (1987). Water temperature was 30 to 31 °C and visibility poor, usually about 7 to 8 m during censuses, near the minimum required. Ten of the counts included 25% to 50% sand. As at Bahia Honda, the combination of poor visibility and a high percentage of sand in some census areas may have caused an underestimation of the abundance and density of fishes on the reefs. Eleven fish surveys made by the principal investigator in seven different months July, 1985 to July, 1988 were reviewed for occurrences of juveniles (settlers) of species recorded here.

Seventy-two species and 16,138 individual fishes were recorded; 63% were tomtate with a mean length of 16 cm (Table 24). Thirty-two species were the most recorded in a single sample and 2,402 the maximum number of individuals. (See Bahia Honda above for species similarity). Estimated density of fishes was 3.8 inds./m^2, the third highest of all sites following the Bahia

Honda rubble reefs and the mid-depth units (Fig. 8). Total biomass censused was 1,430 kg (3,153 lbs.).

Six species of grunts, at a density of 3.4/m^2, comprised 89% of fishes censused. Also included were 305 lane and gray snappers, and 34 yellowtail snappers. There were 16 *Mycteroperca* groupers from 6 to 50 cm long and 12 *Epinephelus* groupers. Eight snook (in 25% of samples) averaged 63 cm long.

3.6. Hawk Channel Rubble Reefs Combined

Combining the two Hawk Channel sites (Tables 5 and 25) showed 103 species, nearly 50% more species than any set of units but slightly fewer than the 108 species from all units combined. Species on rubble reefs in Hawk Channel were compared to those on the mid-depth natural reef at about the same depth. Three-quarters of rubble reef species were also found on the natural reef, corresponding to the percentage of similarity found between units and adjacent natural reefs (Table 11). However, there was a higher percentage of species shared (55%), more artificial reef species compared to total species (74%), and a higher percentage of natural reef species found at the rubble reefs (68%). The structural complexity of the rubble reefs that resembles natural reefs may account for higher levels of similarity with MNR. Comparison of the mid-depth units to the Hawk Channel reefs showed similarity consistent with comparisons of each set of units to the adjacent natural reefs (Table 11).

Comparison of the 15 most frequent and abundant species at Hawk Channel sites to those at natural reefs showed greatest similarity (33% and 25%) with the shallow natural reef, the closest natural reef censused, and least with the deep natural reef (7% and 20%) (Table 16). Comparisons with the mid-depth natural reef, showed only 20% similarity in most frequent species and 15% similarity in most abundant (Table 35). Of the 9 most frequent species in Hawk Channel, only striped parrotfish and cocoa damselfish were recorded in the top 15 species by frequency at the mid-depth natural reef (Table 35). Comparing the 15 most abundant species showed only tomtate and striped parrotfish shared with MNR, along with unidentified grunts and unidentified scad. Although overall species lists of the Hawk Channel sites and the mid-depth natural reef were somewhat alike, the substantially different physical conditions between the two areas appear to result in less similarity of dominant species.

4. Discussion of Objectives

4.1. Objective 1. Quantify the species composition, biomass, and seasonality of fishes attracted and produced on large fabricated artificial habitats over a 24 month period.

On several occasions at the shallow and mid-depth units mixed schools of blue tang, ocean surgeon, doctorfish, angelfish, butterflyfish, and hogfish were observed moving between the units and the natural reef. The relatively close proximity, 50 m, of units to well-developed natural reefs confused the question of attraction or production. Regular observations of these species, and others, browsing on plants, sponges, and invertebrates on the units made it apparent that additional food sources and the structural diversity necessary for protection from predators have been made available to both settlers and colonizers. Although this data has limited usefulness in determining fish production at the artificial reefs during the two-year period, the derived lists of settlers and colonizers point out species and species groups with potential to be produced by these types of habitats, as well as those species that increase their biomass by consuming reef resources and benefit by the new shelter provided.

The degree of fishery production at an artificial reef appears to be a function of location (isolation reduces attraction), structural complexity, and requirements and sizes of individual species at different life stages. Bohnsack (1989) predicts that production should be more important for reef dependent, habitat limited species at artificial reefs in isolated locations. In this study only the rubble reefs could be considered isolated. Impacts to natural reefs in the Keys through the attraction of fish to relatively small artificial reefs is considered minimal in light of an annual harvest of about 4,000,000 pounds of reef fishes in the Keys (F. Little, pers. comm., 1992) and many thousands of aquarium fishes.

Typically, settlers were smaller species valued as primary marine life fishes, and colonizer species were larger with importance to commercial and recreational fisheries. Generally, settler species outnumbered colonizers (Figs. 16 and 17), but only at the shallow units did settler biomass exceed colonizer biomass excluding three large nurse sharks). Both the mid-depth and deep units averaged about 10 kg of colonizer species biomass in each sample, representing most of the biomass at these sites. Overall at the units, settler species represented about 66% of individuals but only 9% of total biomass.

The proportions of settler species to total species at mid-depth and deep units, with few exceptions, showed comparable seasonal trends (Fig. 18). The percentage of settler species was highest (60% to 80%) the first few months, lowest the first winter (March), and about 50% to 60% thereafter at both sites. The relative abundance of settlers was high (60% to 90%) the first few months, low (40% to 50%) the first winter, and elevated again the second summer (Fig. 19). General decreases in the numbers of species and individuals on artificial reefs in the winter in south Florida are also reported by Bohnsack and Talbot (1980) and Bohnsack *et al.* (1989).

4.1.1. Shallow Prefabricated Units

Settler species accounted for 90% of individuals at the shallow units, but only one-half (34/67) of species (Table 26), Gray angelfish (44 kg) represented 85% of settler biomass, while bluehead wrasse and slippery dick were the most abundant and most frequent settlers. Of the 34 settler species, one was primary commercial, three secondary commercial, three recreational, 17 primary marine life, ten secondary marine life, and three had no value designation.

Most abundant and frequent colonizers were doctorfish, hogfish, and spotfin butterflyfish (Table 26). Three large nurse sharks represented 80% of total biomass for the shallow units. Colonizers included four primary commercial species, four secondary commercial, seven recreational, seven primary marine life, and eleven secondary marine life. Seven colonizers had no fishery value designation.

4.1.2. Mid-Depth Prefabricated Units

About 65% of individuals and 31 of 73 species recorded at the mid-depth units were considered settlers, but settlers comprised only 9% of total biomass (Table 27). The most abundant settlers were bluehead wrasse, tomtate, striped grunt, and bridled goby; the most frequent were blue tang, bluehead wrasse, sharpnose puffer, and porkfish. All but one settler species had a value designation; three were primary commercial species, five secondary commercial, four recreational, 17 primary marine life, and six secondary marine life.

Yellowtail snapper, mackerel scad, and ocean surgeon were the most abundant colonizers. Ocean surgeon, slippery dick, doctorfish, hogfish, and gray angelfish were the most frequent. Yellowtail snapper represented 28% of total biomass for the two units and reached a high of 98 individuals in a single unit count (MAR1 in November 1989). Large but infrequent visitors were greater amberjack and barracuda. Seven primary commercial species, two secondary commercial, nine recreational, seven primary marine life, and 19 secondary marine life were colonizers. Seven colonizers had no designated economic value.

4.1.3. Deep Prefabricated Units

About 42% of the fishes and half of the species (34/69) at the deep units were settler species, but settlers made up only 0.4% of the total biomass of 389 kg (Table 28). The most abundant settlers were bluehead wrasse, bridled goby, and bicolor damselfish; the most frequent were graysby, bluehead wrasse, sharpnose puffer, and yellowhead wrasse. Settlers included three primary commercial species, three secondary commercial, four recreational, 21 primary marine life, and 10 secondary marine life. All settler species had a designated economic value.

The most abundant colonizers were yellowtail snapper, gray snapper, slippery dick, doctorfish, and 1,000 round scad on one occasion; the most frequent were hogfish, slippery dick, yellowtail snapper, gray snapper, and spotfin butterflyfish. Yellowtail and gray snapper represented 14% and 18%, respectively, of the total biomass on the two units. Maximums of 26 gray snapper (March 1990) and 49 yellowtail (June 1990) were recorded in a single unit count. Large but infrequent visitors were greater amberjack, mutton snapper, barracuda, permit, and cubera snapper. Colonizers included eight primary commercial species, two secondary commercial, 13 recreational, five primary marine life, and ten secondary marine life. Six colonizer species had no value designation.

4.1.4. Bahia Honda Rubble Reefs

Settler species made up 93% of fishes counted on patch reefs at Bahia Honda, a result of recording 19,955 tomtate, and represented nearly half (43/90) of all species (Table 29). Excluding tomtate, settler species accounted for three-quarters of the remainder. Reef croaker, unidentified juvenile grunts, cocoa damselfish, bridled goby, and gray snapper were other abundant settlers; the most frequent were tomtate, cocoa damselfish, porkfish, blue tang, and striped parrotfish. Settlers represented one-third of total biomass (915 kg) with tomtate, black grouper, and gray snapper making up three-quarters. Settler species included six primary commercial species, three secondary commercial, seven recreational, 21 primary marine life, and 12 secondary marine life. Only two species had no designated value.

Sixty-nine percent of colonizers were in infrequent schools of clupeids and scad. Other abundant colonizers included bluestriped grunt, white grunt, and snook (Table 29). The most frequent colonizers were white grunt, bluestriped grunt, butter hamlet, snook, and rainbow parrotfish. Seventy-eight percent of colonizer biomass was in 76 snook estimated to weigh 453 kg (1,000 lbs.). Colonizers included eight primary commercial species, nine secondary commercial, 16 recreational, five primary marine life, and 14 secondary marine life. Nine colonizer species had no economic value.

4.1.5. American Shoal Rubble Reefs

Settler species represented 71% of the individuals and 42% of the species (30/72) at the American Shoal rubble reefs (Table 30). Tomtate (10,207) accounted for 89% of settlers; excluding tomtate showed settlers comprising 26%. Other abundant settlers were lane snapper, striped parrotfish, and porkfish. The most frequent were striped parrotfish, tomtate, redband parrotfish, cocoa damselfish, lane snapper, porkfish, and slippery dick. As a result of 736 kg of tomtate, settler species represented 51% of total biomass (1,430 kg), and lane snapper, gray angelfish, and porkfish also contributed. Settlers included three primary commercial species, three secondary commercial, four recreational, 17 primary marine life, and ten secondary marine life. All settlers had an economic value.

White grunt accounted for 69% of colonizers with bluestriped grunt, bigeye, gray snapper, and yellowfin mojarra also common. The most frequent colonizers were white grunt, bluestriped grunt, spotfin butterflyfish, spotted goatfish, ocean surgeon, and yellowfin mojarra. White grunt accounted for 57% of total colonizer biomass (630 kg) with bluestriped grunt, snook, bigeye, permit, and barracuda also important. Colonizers included four primary commercial species, seven secondary commercial, ten recreational, five primary marine life, and 14 secondary marine life. Nine species had no attributed economic value.

4.2. Objective 2. Compare the community structure of reef fishes on prefabricated habitats to nearby natural reefs.

The effectiveness of efforts to create artificial habitats to mimic and supplement natural reefs may best be measured by comparing the fish communities that develop with those on natural reefs in similar depths. The length of time required for artificial habitats to become relatively stable in terms of fish community structure appears to be primarily functions of location, reef type and size, and the rate of fouling community development. At the end of two years of monitoring, numbers of species and individuals at the shallow (Figs. 10 and 11) and mid-depth units (Figs. 12 and 13), although variable, seemed to have stabilized while at the deep units there was a gradual increasing trend in abundance (Figs. 14 and 15).

Data for artificial and natural reefs are often not precisely comparable due to different census methods used and because the stationary census method may underestimate fish abundance (Bohnsack and Bannerot, 1986; Bohnsack *et al.,* 1989). As well, density estimates for the units based on total counts may overestimate true density because the area of sand surrounding the units is not included in density calculations. Most fishes censused at the units, however, are structure oriented species present as a direct result of the unit placement. The large number of year-round stationary censuses over sizeable areas of the natural reefs should insure relatively accurate estimates of fish abundance for these habitats. Even with the different methods used, relative abundance estimates should be comparable (Bohnsack *et al.,* 1989). Bohnsack *et al.* (1991) report that most comparative studies of artificial and natural reef fish communities show considerable similarity in species composition although abundance and biomass may vary.

A comparison of the number of species (Fig. 7) and density (Fig. 8) for all sites studied reflects greater species richness on natural reefs but higher density on artificial habitats. On average, the units showed only about 62% as many species as the adjacent natural reefs. About half of the species at the natural reefs were also recorded at the nearby units (Table 11).

4.2.1. Similarity of Units to Natural Reefs

Comparison of species lists for each depth revealed similar percentages of unit species shared with the nearby natural reefs, ranging from 75% to 78% (Table 11). Small cryptic species often appeared in total counts of the units but were usually missed in stationary censuses on adjacent natural reefs. For example, twospot cardinalfish and seaweed blenny were important constituents of fish populations at the shallow units but were not recorded at the adjacent natural reef, although they undoubtedly occur there. Other than infrequent schooling scad, every species with more than eight individuals recorded at the mid-depth units was also found at the adjacent natural reef. At the deep units, other than twospot cardinalfish, every species with more than seven individuals was also recorded at the deep natural reef.

The number of species on each set of units was only 55% to 56% of the total species at each depth (Table 11). The percentages of the pool the units shared with nearby natural reefs, 42% to 44%, were also low and very similar.

Sixty-seven species were recorded at the shallow units and 104 at the shallow natural reef. In decreasing order, wrasses, grunts, surgeonfishes, combtooth blennies, and cardinalfishes were the most abundant families at the units and damselfishes, wrasses, grunts, surgeonfishes, and parrotfishes the most abundant at the natural reef. Density of fishes was 1.6 inds./m^2 at the shallow units and 0.9/m^2 at the adjacent natural reef.

Seventy-six species occurred at the mid-depth units and 114 species at the mid-depth natural reef. Grunts, wrasses, jacks, snappers, and surgeonfishes were most abundant at the units and grunts, damselfishes, wrasses, jacks, and parrotfishes the most abundant at the natural reef. Fish density at the mid-depth units was 4.2 inds./m^2; at the adjacent natural reef density was 1.2/m^2.

Sixty-nine species were found at the deep units and 109 species at the deep natural reef. Wrasses, snappers, gobies, damselfishes, and jacks were the most abundant groups on the units, and grunts, damselfishes, jacks, snappers, and gobies the most abundant on the natural reef. In terms of biomass, snappers, jacks, surgeonfishes, barracuda, and angelfishes were the most abundant on the most important at the units and grunts, jacks, snappers, angelfishes, and sea basses most important at the natural reef. Mean fish was 2.6 times greater on the deep units (126 g) compared to the adjacent natural reef (48 g).

4.2.2. Similarity of Rubble Reefs to Other Reefs

Combined Hawk Channel rubble reefs produced a species total (103) close to that of all prefabricated units (108) and fish density (4.9/m^2) slightly higher than the mid-depth units, nearly double that of the deep units, and three times that of the low shallow units (Figs. 7 and 8). Even with sizeable areas of sand included in many censuses, fish density was three to five times higher at rubble reefs than at the natural reefs. Mean fish size at Hawk Channel reefs (55 g) was smaller than that at the mid-depth (76 g) and deep units (126 g) and close to that of the deep natural reef (48 g).

The greater number of species and higher density at Bahia Honda (90 species, 5.9 inds./m^2) than at American Shoal (72 species, 3.8/m^2) may result from its location, directly offshore from and within the influence of Bahia Honda Channel, a deep, active channel that connects the Gulf of Mexico to the Atlantic. The Bahia Honda site is also in close proximity (50 m) to seagrass beds that extend offshore to the 9 m contour along the north edge of Hawk Channel. The American Shoal reefs are the most isolated from seagrass or hardbottom habitats of all sites studied. The most abundant families at Bahia Honda reefs were, in decreasing order, grunts, drums, herrings, jacks, and damselfishes, and at the American Shoal site the most abundant were grunts, snappers, parrotfishes, damselfishes, and wrasses. Based on biomass, the most important families at Bahia Honda were snook, grunts, sea basses, parrotfishes, and snappers, and at American Shoal the most important were grunts, snook, snappers, bigeyes, and jacks. Mean fish size was nearly 3 times larger at American Shoal (90 g) than at Bahia Honda (33 g), mainly as a result of larger tomtates at American Shoal.

Comparison of the Hawk Channel sites (9 to 12 m depth) to the mid-depth natural reef (10 to 12 m depth) showed that 75% of artificial reef species were shared with the natural reef, a percentage similar to the relationship between units and natural reefs (Table 11). However, a somewhat higher proportion (55%) of the species pool was shared and a higher percentage (74%) of the pool was found at the rubble sites. About half of the bridge rubble at the Hawk Channel reefs was placed in 1983 and 1985, the remainder in 1987.

4.2.3. Comparison of Top 15 Species

To measure similarity between sites, comparisons were made of the 15 most frequently occurring and abundant, and in some cases, heaviest species. The number of top 15 species in common to two sites was divided by the total number of top 15 species at the two sites to obtain an index of similarity. Various comparisons between artificial and natural reefs are at Table 16.

Assessment of the similarity of dominant species on artificial and natural habitats indicates substantial variation in fish populations between units and natural reefs but high similarity among prefabricated units of the same depth. Comparison of sets of prefabricated units to the adjacent natural reefs showed highest similarity (33%) of the 15 most frequent species at the shallow reefs (Table 31) and lowest (22%) at the deep reef (Table 33). Of the 15 most abundant fishes, similarity was greatest (30%) at the mid-depth reefs (Table 32) and lowest (15%) on the deep reefs. Biomass was compared only between the 15 heaviest species on the deep reefs. Thirty percent similarity occurred with scad and snapper, the heaviest fishes on the deep units, and scad and grunts, the heaviest on the deep natural reef.

Although low similarity was recorded between dominant species at the units and natural reefs, the nearly identical high units placed in deep water showed the highest similarity of all reef comparisons with 88% of the 15 most frequent species and 76% of the 15 most abundant species common to both units (Table 21a). The two high units placed at the mid-depth site showed 72% similarity of the 15 most frequent species and 67% similarity of the 15 most abundant species (Table 17). Although comparisons were not made for the low shallow units, review of data indicates relatively high similarity, with bluehead wrasse, slippery dick, seaweed blenny, sharpnose puffer, porkfish, small grunts, and 3 species of surgeonfish as common elements.

4.2.4. Length-Frequency Comparisons

Based on mean lengths it appears that artificial habitats studied here may have provided shelter and protective cover useful to small individuals of some species. Comparisons between the units and nearby natural reefs showed many species with similar mean length, but a few common species with apparent differences. Assessment of length data must take into account the probability that the total count method used on units is biased towards recording more small fish than the stationary sampling method used on natural reefs.

At mid-depth reefs (Tables 15 and 18), common species with shorter mean length at units included bicolor damselfish (32% smaller), bluehead wrasse (-32%), yellowhead wrasse (-34%), graysby (-38%), and cottonwick (-46%). Doctorfish and ocean surgeon were both 26% larger on the units than at the mid-depth natural reef. At the deep reefs (Tables 21 and 22), smaller species on the deep units included bicolor damselfish (25% smaller), bluehead wrasse (-28%) reef butterflyfish (-31%), graysby (-48%), spotfin hogfish (-57%), yellowhead wrasse (-59%), and blackfin snapper (-68%). Doctorfish and ocean surgeon were 34% larger on the deep units than on the deep natural reef.

Mean length data from the Hawk Channel sites (Table 25) were compared with the mid-depth natural reef. Hawk Channel data were all collected in the summer, possibly resulting in more juveniles recorded, while natural reef censuses were made over two years. Common fishes with substantially smaller mean length at the rubble habitats than at MNR were queen angelfish (36% smaller), sharpnose puffer (-38%), porkfish (-38%), and blue angelfish (-43%). Fishes larger on rubble reefs were spotted goatfish (29% larger) and tomtate (+57%). *Acanthurus* surgeonfishes (251 inds.) averaged 14.6 cm long on the Hawk Channel rubble reefs and 15.0 cm on the mid-depth natural reef (398 inds.).

4.3. Objective Number 3. Evaluate the effects of reef siting at different water depths on species composition, recruitment and biomass.

Water depth appears to be an important factor affecting fish assemblages that develop on artificial habitats, although little information is available on the placement of similar structures or materials at different depths. Here, due to structural differences between the low profile shallow units and the high profile mid-depth and deep units, direct comparisons are made only between the latter two depths. Data from the shallow units provide information on species that could be expected on artificial habitats in this depth on the reef tract.

4.3.1. Species Composition, Frequency, and Abundance

There were some notable differences in fish assemblages on the mid-depth and deep units. For example, seven species of grunts totaled 1,335 individuals on the mid-depth units, but only two grunts of two species were recorded on the deep units. The greater abundance of large predators on the deep units probably limited utilization by juvenile and sub adult grunts, and less undermining by wave surge with increased depth resulted in fewer microhabitats. Surgeonfishes, especially ocean surgeon and blue tang, were considerably more abundant on the mid units (13.6/count) than on the deep units (3.0/count), where less food appeared available for these herbivores. Sergeant majors, water column feeders, were numerous at the mid-depth units, but virtually none were recorded in deep water. Bluehead wrasse were 75% more abundant at mid-depth, and *Chromis*, blackfin snapper, bicolor damselfish, and *Bodianus* hogfish were more abundant at the deep units. A single gray snapper and 337 yellowtail snapper (26 cm ave. length) were recorded on the mid-depth units and 154 gray snapper (31 cm) and 231 yellowtail snapper (25 cm) on the deep units. Thirty-seven hogfish were recorded from both sets of units, just over one per sample.

Species among the 15 most frequent on the mid-depth units but not on the deep units were blue tang, ocean surgeon, porkfish, gray angelfish, sergeant major, and cottonwick (Tables 32 and 33). Frequent only at the deep units were yellowtail snapper, yellowhead wrasse, gray snapper, bicolor damselfish, and greater amberjack. Frequent species common to both sets of high units were bluehead wrasse, graysby, hogfish, slippery dick, sharpnose puffer, spotfin butterflyfish, doctorfish, bridled goby, twospot cardinalfish, and reef butterflyfish.

Ranked in the 15 most abundant species at the mid-depth, but not at the deep units, were blue tang, cottonwick, and ocean surgeon; in the top 15 only at the deep units were bicolor damselfish, gray snapper, doctorfish, sharpnose puffer, graysby, greater amberjack, and hogfish (Table 32 and 33). Shared of the 15 most abundant species were bluehead wrasse, bridled goby, yellowtail snapper, twospot cardinalfish, slippery dick, and yellowhead wrasse.

Frequently occurring species common to the units in all depths were slippery dick, bluehead wrasse, sharpnose puffer, doctorfish, twospot cardinalfish, and hogfish (Tables 31, 32, and 33). Only bluehead wrasse, slippery dick, and twospot cardinalfish were included in lists of the top 15 most abundant species at all units.

Although all three sets of units had similar numbers of species, dominant species and their relative abundance differed with depth. Comparisons of the 15 most frequent and abundant species at the mid-depth and deep units showed only 48% similarity of frequent species and 25% similarity of abundant species (Table 16). The shallow units shared with the mid-depth units 50% of the 15 most frequent species and 36% of the most abundant. Shared between the shallow and deep units were 32% of the frequent species and 30% of the most abundant.

A number of species were relatively common at most depths, and several had higher mean abundance in Hawk Channel then at the units on the reef tract. Thirty six species occurred as one of the 15 most frequent at one or more artificial reefs (Table 36). Only doctorfish and slippery dick were listed for all five artificial reef sites; frequent species at three or more were hogfish, porkfish, sharpnose puffer, bicolor damselfish, blue tang, bluehead wrasse, gray angelfish, ocean surgeon, spotfin butterflyfish, and twospot cardinalfish. Frequent only at the two Hawk Channel sites were tomtate (top ranked at both), cocoa damselfish, striped parrotfish, and white grunt. Listed only at one Hawk Channel site were black grouper, blue angelfish, bluestriped grunt, lane snapper, queen angelfish, redband parrotfish, reef croaker, and spotted goatfish. Frequent only at the units were bluehead wrasse, twospot cardinalfish, graysby, reef butterflyfish, bridled goby, cottonwick, greater amberjack, puddingwife, sergeant major, seaweed blenny, yellowhead wrasse, and yellowtail snapper.

Thirty-eight species were ranked as one of the 15 most abundant at one or more artificial reefs (Table 37). In the top 15 at all artificial reefs was slippery dick; at three or more were bluehead wrasse, bridled goby, tomtate, bicolor damselfish, gray snapper, lane snapper, porkfish, twospot cardinalfish, and an unidentified grunt. In the 15 most abundant only in Hawk Channel were bluestriped grunt, cocoa damselfish, striped parrotfish, white grunt, bigeye, redband parrotfish, reef croaker, clupeids, and yellowfin mojarra. Eighteen species abundant only at prefabricated units included twospot cardinalfish, blue tang, doctorfish, ocean surgeon, sharpnose puffer, striped grunt, yellowhead wrasse, and yellowtail snapper.

4.3.2. Recruitment and Colonization

The mean number of species per census at a unit ranged from a low of ten at two of the shallow units to a high of 17 at MAR2, with deep units intermediate (Fig. 9). After excluding a single school of 1,000 round scad recorded at a deep unit and 800 juvenile grunts from a mid-depth sample, the average number of fish per census was lowest at SAR (46 - 49 fish) and highest at MAR (100 - 127), with DAR units (69 - 71) intermediate (Fig. 9). Mean species per month at the units showed comparable seasonal variation with highest numbers during warmer months (Fig. 20). Following peaks during the initial four months, total fishes declined somewhat, and then increased the second year at all units (Fig. 21).

The simple structure of the low units apparently resulted in low diversity and abundance compared to the larger units, even though census data from the shallow natural reef shows high species richness in the area. Fifteen species totaled more than 100 individuals at the mid-depth units (N = 32), seven species totaled more than 100 individuals at deep units (N = 30), but only two species (bonehead wrasse and slippery dick) showed more than 100 individuals at the shallow units (N = 42).

Settler species recruited to the units were generally the small species most valued by the marine life industry (Tables 26, 27, and 28). The number of settler individuals per census ranged from 43 (SAR) to 65 (MAR), with DAR intermediate with 44 (Fig. 16)

4.3.3. Biomass

The relatively low similarity of frequent and abundant species at different depths appeared also true in terms of the heaviest species at different depths. Although mean biomass was similar, 10.5 kg/sample and 13.0 kg/sample, at the mid-depth and deep units respectively, they shared only 43% of the 15 heaviest species (Tables 32 and 33). The shallow units (Table 31) shared 25% of the 48 heaviest species with the mid-depth units and 30% of the heaviest species with the deep units. Except at the shallow units, settler biomass represented a small portion of overall biomass (Fig. 16).

Comparison of the 15 heaviest species showed mid-depth and deep units sharing yellowtail snapper, ocean surgeon, greater amberjack, barracuda, gray angelfish, doctorfish, bar jack, hogfish, and French angelfish (Tables 32 and 33). Several scad species, blue tang, porkfish, and blue angelfish were additional important contributors of biomass at the mid-depth units, while snapper (gray, mutton, and cubera), round scad, permit, and yellow jack were additional important contributors at deep units.

Heaviest species common to the units in all depths were gray angelfish, hogfish, doctorfish, ocean surgeon, and French angelfish. Three large nurse sharks comprised 69% of the total biomass (253.91 kg) at the shallow units and gray angelfish 56% of the remainder. Yellowtail snapper made up 28% of total biomass (334.86 kg) at the mid-depth units, surgeonfish 18%, scad 14%, and other jacks 12%. One large school of round scad made up 23% of total biomass (389.37 kg) at the deep units, snappers (gray, yellowtail, cubera, mutton) 44%, other jacks 11%, and barracuda 6%.

Thirty-nine species were recorded as one of the 15 heaviest at one or more artificial reefs (Table 38). Gray angelfish and hogfish were ranked among the 15 heaviest at all five artificial reefs, and barracuda, doctorfish, porkfish, French angelfish, gray snapper, ocean surgeon, and yellowtail snapper were listed for three or more sites. Among species with greatest biomass only at Hawk Channel sites were bluestriped grunt, lane snapper, snook, tomtate, white grunt, bigeye, black grouper, rainbow parrotfish, reef croaker, yellow goatfish, and yellowfin mojarra. Listed only from the units were French angelfish, ocean surgeon, bar jack, blue angelfish, greater amberjack, yellow jack, blue tang, cero mackerel, cubera snapper, mackerel scad, margate, mutton snapper, nurse shark, round scad, saucereye porgy, slippery dick, and spotfin butterflyfish.

4.4. Objective number 4. Separate fish communities into trophic levels to assess location of food source (i.e. water column, surrounding bottom, structure fouling community, etc.).

Because many fish species are food generalists that consume a wide variety of items, separating species by trophic levels is often imprecise and somewhat arbitrary (Bohnsack *et al.* 1987). The value of the effort, however, is insight into food resource partitioning and general ecology of the fish fauna, especially where species abundance and biomass estimates are available.

Data from the mid-depth (Table 39) and deep units (Table 40), the deep natural reef (Table 41), and the Bahia Honda rubble reefs (Table 42) were assessed to determine the relative contributions to fish assemblages of five primary types of feeders: browsers (consume sessile invertebrates such as sponges, tunicates and polychaete worms attached to hard surfaces), piscivores (consume fishes on and near reefs), herbivores (consume plants from hard surfaces and surrounding bottom), invertivores (consume various size invertebrates from hard surfaces and surrounding bottom), and planktivores (consume plankton in water column).

Of the sites assessed, piscivores dominated biomass, except at the deep natural reef where invertivores dominated (Fig. 22). The proportion of browser and herbivore biomass was highest at the mid-depth units and lowest at the deep natural reef.

Planktivores dominated numbers except at Bahia Honda where invertivores were by far the most abundant (Fig. 23), The proportion of piscivore numbers was highest at the mid-depth units and comparable at the deep reefs. Browser and herbivore numbers were lowest at the deep natural reef and at Bahia Honda. Relative contributions of the 5 groups were similar at the mid-depth and deep units, the main exceptions being reduced biomass of herbivores and increased numbers of piscivores at the deep units.

4.4.1. Browsers

These omnivores obtain food directly from the hard surfaces of artificial and natural reefs, with supply on artificial habitats mostly functions of reef age, location, and substrate. The succession of the fouling community on artificial surfaces affects the relative abundance of fishes that depend on its various components.

The proportion of browser biomass was highest at the mid-depth (10%) and deep units (6%), and mainly due to gray angelfish, along with French, blue, and queen angelfish. Adult angelfish were often observed in pairs browsing on the fouling community of these units (Plate 11). The greatest proportions of browsers by abundance were also at the mid-depth (3%) and deep (3%) units. Sharpnose puffer was a frequent browser, especially at reef tract sites, while rock beauty was the most abundant browser at the deep natural reef, and adult angelfish the most abundant at Bahia Honda. Most browsers are important to the marine life industry.

4.4.2. Piscivores

Fish-eating predators use artificial reefs to capitalize on higher density of prey or as shelter for protection and orientation. They dominated total biomass at all sites except for the deep natural reef, where invertivores dominated as a result of numerous grunts (Fig. 22). Most piscivores are valued by commercial and recreational fisheries. They made up 46% of biomass at the mid-depth units, with yellowtail snapper (337 inds.), greater amberjack (22), barracuda (4), and cero (8) most important. At the deep units, 53% of total biomass was contributed by fish-eating species; the heaviest were gray snapper (154 inds.), yellowtail snapper (231), cubera snapper (1), barracuda (4), and 45 greater amberjack (Table 40). Piscivores represented only about 20% of total .biomass at the deep natural reef; most important were gray snapper (76 inds.), greater amberjack (14), yellow jack (58), and yellowtail snapper (18). The extensive use of wire fish traps in the deep reef area may have resulted in reduced numbers of predators with fishery value in censuses. Piscivores comprised the greatest proportion (63%) of biomass at the Bahia Honda reefs, with 76 snook, along with *Mycteroperca* groupers (114 inds.), gray snapper (164), and 5 barracuda (Table 42).

The proportion of piscivores ranged from a low of 1% at Bahia Honda where large numbers of grunts dominated, to a high of 15% at the deep units where yellowtail and gray snapper were common, but grunts were few (Fig. 23). At the mid-depth units the most common piscivore was yellowtail snapper, but only a single gray snapper was recorded. On the deep natural reef the most abundant piscivores were yellowtail snapper, gray snapper, and yellow jack. At Bahia Honda they were gray snapper, *Mycteroperca* groupers, and snook.

4.4.3. Herbivores

These species feed mostly on plants attached to or embedded in hard surfaces and to a lesser degree on benthic plants on surrounding bottoms. They contributed most to total biomass at the mid-depth units (18%) and Bahia Honda rubble reefs (8%) and least at the deep natural reef (3%) (Fig. 22). *Acanthurus* surgeonfishes represented 99% of herbivore biomass at the mid-depth units, where only five parrotfishes of three species were recorded, and 94% of herbivore biomass at the deep units, where only two parrotfishes were recorded. Surgeonfishes and parrotfishes dominated herbivore biomass at the deep natural reef, but mean abundance of these groups was 74% and 21% lower than on the mid-depth natural reef. On the Bahia Honda reefs, parrotfishes of nine species (principally rainbow) accounted for 82% of herbivore biomass, and surgeonfishes contributed 17%.

Ten herbivore species were recorded at both the mid-depth and deep units but herbivore biomass was nearly three times higher at mid-depth, and the number of herbivores more than

80% higher (Tables 39 and 40). Surgeonfishes, often observed feeding on algae on the units, totaled 436 individuals at the mid-depth units but only 89 at the deep units. Only doctorfish occurred at both depths in comparable numbers. Alevizon (1990) notes that as a result of reduced light penetration, primary production by plants is reduced on deep reefs as is the abundance of herbivorous species.

4.4.4. Invertivores

Some of these species consume invertebrates that attach to or use irregular hard surfaces as protective cover, others feed on surrounding bottoms, usually at night, using reefs as protective cover when not feeding. The greatest contribution by invertivores to total biomass (Fig. 22) was on the deep natural (55%) and Bahia Honda reefs (26%), and the least was on the mid-depth units (7%). At the mid-depth units, 25 species of invertivores were recorded with hogfish, porkfish, spotfin butterflyfish, and a single mutton snapper making up 81% of invertivore biomass. Five species of *Haemulon* grunts (1,299 inds., 3.65 kg) at the mid-depth units were juvenile forms listed as planktivores instead of invertivores based on observations of their feeding in schools on plankton near the top of the units. At the deep units, 25 species of invertivores were recorded but only a single porkfish and a single *Haemulon* grunt. Mutton snapper (5 inds.), hogfish (37), permit (3), and spotfin butterflyfish (35) made up 93% of invertivore biomass at the deep units. Forty-five invertivores were recorded at the deep natural reef with tomtate, white grunt, lane snapper, and bluestriped grunt making up 81% of biomass. Thirty-nine were recorded at Bahia Honda with tomtate, bluestriped grunt, white grunt, and porkfish making up 85% of biomass. Although trophic information was not reviewed at American Shoal, grunts (invertivores) alone accounted for 82% of total biomass (22% at Bahia Honda).

The mid-depth units showed 10% invertivores with the most abundant being yellowhead wrasse, slippery dick, reef butterflyfish, hogfish, graysby, and spotfin butterflyfish (Table 39, Fig. 23). Thirteen percent of deep unit species were invertivores; the most abundant were slippery dick, yellowhead wrasse, graysby, hogfish, blackfin snapper, and spotfin butterflyfish. Thirty-seven hogfish were recorded at both the mid-depth and deep units, and were often observed removing bivalve mollusks and other invertebrates from the structure's surface. The deep natural reef showed 37% invertivores; the most abundant were tomtate, white grunt, lane snapper, blackfin snapper, French grunt and yellowhead wrasse. The greatest proportion of invertivores (90%) occurred at the Bahia Honda site as a result of 19,955 tomtate (Fig. 23); removing tomtate showed 62% of the remaining number were invertivores with reef croaker, an unidentified grunt, bluestriped grunt, white grunt, slippery dick, and porkfish most abundant. Categorizing small juvenile tomtate at Bahia Honda as planktivores (as at the mid-depth units) would increase the proportion of planktivores, decrease the high proportion of invertivores, but have little effect on the overall biomass (Figs. 22 and 23).

The foureye butterflyfish, a popular marine life species, is an example of a common reef invertivore found to be rare on artificial habitats. Five hundred twenty-six foureyes were recorded on natural reefs, but only six at the Hawk Channel rubble reefs, and none at the units. One of the most specific feeders of all common reef fish, feeding on small polychaete worms and coelenterates, the foureye's absence from the units was probably the result of food limitation or inadequate small protective cover.

4.4.5. Planktivores

These fishes feed on planktonic plants and animals over the top of hard surfaces that also serve as protective cover. They also occur in large, fast moving schools that feed over extensive areas, regardless of bottom type. It is likely that greater exposure to currents on high profile reefs favors planktivores (Bohnsack *et al.,* 1989). The contribution of planktivores to total biomass was similar at the mid-depth (19%) and deep units (24%), and deep natural reef (18%), but was low at Bahia Honda (1%), where 19,955 tomtates (ave. 9 cm length) were all considered invertivores (Fig. 22). Scad and bar jack made up 92% of planktivore biomass at the mid-depth units with minor contributions by juvenile grunts and sergeant major. At the deep units, round scad and bar jack made up over 99% of planktivore biomass; at the deep natural reef, round scad made up 96% of planktivore biomass with contributions by bicolor damselfish and bar jack. Making up most planktivore biomass at the Bahia Honda site were two unidentified clupeids, an unidentified scad, and dusky damselfish.

Sixty-one percent of the individuals at the mid-depth units were planktivores (Fig. 23) with nine species each showing more than 100 individuals (Table 39); the most common were bluehead wrasse, juvenile grunts (tomtates, striped, and cottonwick), and mackerel scad. Only three *Chromis* of two species were recorded at the mid-depth units while 783 *Chromis* of five species were recorded at the adjacent mid-depth natural reef. Since the same food source should be available at the mid-depth reefs, a greater concentration of predators, and the lack of suitable small protective cover on the units, may have precluded use by *Chromis*. Fifty-six percent of fishes at the deep units were planktivores; 1,000 were round scad and most of the rest, bluehead wrasse, bicolor damselfish and twospot cardinalfish. Only 38 *Chromis* (3 species) were recorded at the deep units, but five species of *Chromis* (2,191 inds.) made up 22% of planktivore numbers on the deep natural reef. More than half of the individuals at the deep natural reef were planktivores, dominated by round scad and juvenile grunts but with large numbers of damselfishes. Planktivores represented only 5% of total numbers at Bahia Honda with two clupeids and scad the most abundant, and dusky damselfish the most frequent. Although suitable protective cover appeared available at Hawk Channel reefs, no *Chromis* were recorded.

4.5. Objective Number 5. Document and quantify the plant and invertebrate fouling community as a function of substrate and water depth.

Artificial substrates placed in the marine environment of south Florida attract reef biota, sessile organisms including corals, and other natural reef growth (Jaap, 1984). The algae and wide variety of attached invertebrates are a source of food for many fish, both residents of the reef and visitors. About 66 m^2 of new hard surface was provided by each of the high units and several thousand square meters at each of the rubble sites. Although long term expansion of the fouling community may result in an increase in fishes dependent upon the food resources and shelter provided, infilling of cracks, crevices, and holes by encrusting organisms and sediment may act to reduce available shelter.

Fouling community photography at specific points (on concrete and PVC) on the units was initiated about 2 and 1/2 months after placement and was conducted on about a quarterly basis thereafter (Table 43). Twenty-four images (about 0.57 m^2 total area) were usually shot at each depth.

Qualitative review of chronological sequences of photographs of different substrates at different depths, along with field notes and other photography (e.g. Plate 10), revealed useful information about trends in succession of the fouling community. The color transparencies are available for possible future quantitative analysis and comparison to long term photography. Recorded as attached to the units were algae (filamentous, encrusting calcareous, frondose, etc.), encrusting and erect Porifera, Scleractinia, Octocorallia, encrusting and erect Hydrozoa, encrusting and erect Bryozoa, Ascidiacea, Annelida worms, and Mollusca (bivalves).

Within one year at MAR, unidentified hard corals measured 1 to 2 cm in diameter and encrusting *Millepora* measured 10 cm diameter on high concrete surfaces. By September, 1989, gorgonians on MAR were up to 8 cm high and *Millepora* was spreading over much of the high PVC. By January, 1990 hard corals at MAR measured 3 to 5 cm in diameter. In October, 1989, several hard corals on SAR measured 2 to 4 cm diameter.

Inspection of the units in September, 1990 (27 months after placement) showed greatest variety and extent of hard corals at MAR with SAR second and a few hard corals at DAR. A substantial variety of small hard corals up to 6 cm in diameter were recorded on MAR including *Porites astreoides*, *Montastraea annularis*, *Manicina areolata*, *Meandrina* sp., *Siderastrea radiata*, *Oculina diffusa*, and *Stephanocoenia* sp. The hydrozoan *Millepora* was common at MAR with upright growth, and octocorals were up to 20 cm tall. On SAR were the hard corals *Mycetophyllia lamarckiana, Porites astreoides*, *Dichocoenia stokesii, Siderastrea radiata, Siderastrea siderea* and *Colpophyllia natans. Millepora* formed patches up to 22 cm diameter on SAR, and octocorals were as tall as 20 cm.

Surfaces (concrete and PVC) elevated more than about 0.5 m above the bottom fouled more rapidly and densely than surfaces close to the bottom, (as an example compare lower images, Plates 10 and 11). Reduced fouling near the bottom was probably the result of sand scouring from storm-generated wave surge. For example, by early May, 1989 (about 10 months after placement), PVC on top of the mid-depth units (Fig. 6, point 2) was considerably more fouled by encrusting and erect organisms than PVC near lower edges (point 6). Feeding by benthic animals could also affect fouling near the bottom.

Point 3, smooth concrete, located 2.5 m above the bottom of the high profile units, fouled more rapidly and densely than point 5, also smooth concrete, but only 0.3 m above the bottom (Fig 6). Close-up photography showed fouling plants and animals gained a foothold on rough concrete surfaces (point 4) on high units more rapidly than on smooth concrete surfaces (point 3).

Within a year on MAR and DAR units, the small bivalve mollusk *Dendrostrea frons* (frons oyster) and the spiny oyster (*Spondylus americanus*) became common, both alive on units and as shell debris on the bottom under the unit. Hogfish were observed feeding on mollusks attached to the units, and with angelfish, surgeonfish, and butterflyfish, were common consumers of fouling resources (Plates 11 and 12).

4.6. Objective Number 6. Determine if large, fabricated habitats can provide significant fishing opportunities.

Fishing is the major direct use of artificial reefs (Bohnsack *et al.,* 1989), although diving and non-consumptive uses are gaining in popularity in the Florida Keys, especially on sunken vessels. In the past, assessment of the economic value of artificial reefs has been related to commercially or recreationally important species taken by hook and line, and to the diving community (Milon, 1991). Here assessment also includes species important to the marine life industry, a substantial fishery in south Florida regulated by the state of Florida (Chap. 46-42.001 FAC). Species were categorized as "primary" - generally targeted by a fishery with directed effort or "secondary" - of value to the fishery but generally not targeted.

Reef fish landings for the Florida Keys and their monetary value are readily available only for commercial hook and line species. Preliminary data shows nearly 4,000,000 pounds landed in 1990 worth about $5.4 million at dockside (E. Little, pers. comm, 1992). Seven species of snapper made up 54% of landings in 1990, amberjack 25%, and groupers about 11%. Overall in this study, 54% of total fish biomass at artificial reefs (3,323 kg) were commercially important species.

Rockland (1988) estimated that all recreational fishing in the Florida Keys resulted in output of about $63 million. Targeted recreational species at artificial habitats in the Keys include most commercial species as well as barracuda, permit, and snook. Recreational marine life harvest for home aquariums is a substantial activity, as well.

Fish assemblages were assessed to determine which species had commercial, recreational, or marine life value. Comparison of the relative importance of species of different fisheries at each reef habitat follows (numbers do not total 100% as some species have more than one value, the number of species are in parentheses):

VALUE	Units combined (N = 104)	Hawk Channel (N = 50)	Natural (N = 257)
Primary commercial	13.9% (15)	15.2% (16)	12.8% (20)
Secondary commercial	6.5% (7)	9.5% (10)	7.1% (11)
Recreational	18.5% (20)	21.9% (23)	17.3% (27)
Primary marine life	35.2% (38)	30.5% (32)	28.8% (45)
Secondary marine life	29.6% (32)	27.6% (29)	36.5% (57)
None established	13.9% (15)	12.4% (13)	12.2% (19)
Total species	108	103	153

Units were comparable to the natural reefs in relative proportion of valued species in all categories, with the proportion of primary marine life species slightly higher at the units. Hawk Channel rubble reefs showed a higher percentage of commercially and recreationally important species than other habitats. Species harvested by the marine life industry accounted for 65% of total species recorded at both the units (70 species) and the natural reefs (102 species), and 58% of those recorded at the Hawk Channel reefs (62).

4.6.1. Shallow Prefabricated Units

Only 22 individuals of five species of primary commercial importance were recorded at the shallow units; 15 were hogfish averaging 26 cm long. Three mutton snapper averaging 38 cm and an 80-cm black grouper were also recorded. Seven species of grunts dominated the secondary commercial category, but, with the exception of a single 40-cm margate and 61 porkfish averaging 9 cm (to 28 cm), all were juveniles, only 9% of biomass was due to species important to commercial fishing.

Ten recreational species included those important to the commercial industry along with yellow jack. The most abundant fishes at SAR were those important to the marine life fishery. Twenty-four primary marine life species were recorded, the most abundant were bluehead wrasse (724 inds.), gray angelfish (46), sharpnose puffer (59), two-spot cardinalfish (60), blue tang (42), bicolor damselfish (31), and spotfin butterflyfish (12). Common secondary marine life species (21) were slippery dick (389), doctorfish (79), ocean surgeon (68), seaweed blenny (99), and 3 nurse sharks that averaged 58 kg in weight. Only ten species and 2% of individuals at the shallow units had no economic value.

4.6.2. Mid-Depth Prefabricated Units

Ten species of primary commercial value were recorded at the mid-depth units with yellowtail snapper (337 inds.), hogfish (37), greater amberjack (22), and cero (8) the most important

(Table 39). Only one gray snapper and one mutton snapper were recorded. Beginning just over a year after placement, numbers of yellowtail snapper (ave. 26 cm) increased and ranged up to over 100 in a single combined count (Fig. 24). Yellowtail snapper were regularly seen schooling and appeared to orient to the PVC stacks on these units (Plate 12). Seven species of grunts (1,027 inds.) represented most of the secondary commercial species, but all were juveniles except for a few margate and cottonwick, and 34 porkfish averaging 18 cm. Commercial species represented 44% of total biomass on these units.

Thirteen species of recreational importance included the primary commercial species along with four barracuda averaging 6 kg, margate, and porkfish.

Twenty-four species of primary interest to the marine life industry included bluehead wrasse (659 inds.), blue tang (121), yellowhead wrasse (111), twospot cardinalfish (109), sharpnose puffer (83), bicolor damselfish (67), reef butterflyfish (37), gray angelfish (32), and spotfin butterflyfish (32). Twenty-five secondary marine life species included masked goby (273), ocean surgeon (223), slippery dick (108), doctorfish (92), sergeant major (39), graysby (37), and porkfish. Although blue chromis, brown chromis, purple reeffish, rock beauty, and foureye butterflyfish were common marine life species on the adjacent natural reef, only a single brown chromis was recorded on the units. Eight species and 19% of individuals on the mid-depth units had no economic value.

4.6.3. Deep prefabricated Units

Twelve species of primary commercial importance were recorded at the deep units with yellowtail snapper (231 inds.), gray snapper (154), greater amberjack (45), hogfish (37), and mutton snapper (5) represented by adults. A single large cubera snapper (27 kg) and one cobia were also recorded. Seventy-seven gray snapper were recorded on both DAR1 (ave. 31.5 cm) and DAR2 (ave. 30.8 cm). The number of both yellowtail and gray snapper appeared to increase in year 2 over year 1 with abundance peaks for the two species occurring in different censuses (Fig. 25) . The same number of hogfish (37) were recorded at the deep units (ave. 25.5 cm) as at the mid-depth units (ave. 23.3 cm).

Only four individuals of three species of secondary commercial value were recorded on the deep units. Although nearly 1,000 *Haemulon* grunts (secondary commercial) were recorded at the mid-depth units and 7,200 grunts of eight species were recorded at the deep natural reef, only 2 juvenile grunts occurred on the deep units.

Seventeen recreational species included the primary commercial species as well as 4 barracuda that averaged 6 kg, 3 permit, and 5 yellow jack.

Twenty-eight primary marine life species included bluehead wrasse (375 inds.), bicolor damselfish (157), twospot cardinalfish (117), yellowhead wrasse (83), sharpnose puffer (60), spotfin butterflyfish (35), yellowtail reeffish (23), and reef butterflyfish (20). Twenty secondary marine life species included masked goby (298 inds.), slippery dick (84), doctorfish (74), and graysby (54). Excluding one school of 1,000 round scad showed that only 1% of fishes (5 species) at the deep units had no economic value.

4.6.4. Hawk Channel Bridge Rubble Reefs

These sites are not "prefabricated" artificial habitats, but materials were specifically placed to form patch reefs with control over type of material, area covered, patch location, and vertical profile. The desire was to create conditions suitable to enhance the fish population of a chosen area, particularly for species valuable to commercial and recreational fishermen. A project summary (Kruer, 1985) written prior to placement of the first 11 patches at Bahia Honda predicted:

> "Species of importance expected to utilize this habitat include black, gag and red grouper, mangrove, lane, mutton, yellowtail, and schoolmaster snapper, hogfish, cobia, barracuda, Spanish and cero mackerel, porgies, permit, snook, grunts, baitfish, tropicals, spiny lobster, stone crab and others".

4.6.5. Bahia Honda Rubble Reefs

Fourteen primary commercial species were recorded at the Bahia Honda site (N = 26) with gray snapper (164 inds.), lane snapper (89), gag grouper (71), hogfish (46), and black grouper (30) occurring in half or more samples (Table 42). One hundred fifteen *Mycteroperca* groupers ranged from 5 to 100 cm in length (ave. 26 cm). Gray snapper averaged 25 cm long and ranged up to 40 cm. Other adult primary commercial species were yellowtail (10), cero (6), Nassau grouper (3), red grouper (1), and mutton snapper (1). Six species of *Epinephelus* groupers totaled 23 individuals.

Twelve secondary commercial species dominated the population as a result of 20,739 grunts of seven species, including 19,955 tomtate that averaged 9 cm long. Manooch and Barans (1982) report that tomtates are a major food source for higher trophic level fishes in the southeastern US.

The 23 recreational species included those of primary commercial value as well as 76 snook that averaged 6 kg each, porkfish (130 inds.), adult barracuda (5), and permit (1).

Twenty-six primary marine life species included cocoa damselfish (250), blue tang (79), doctorfish (75), queen angelfish (35), sharpnose puffer (35), gray angelfish (34), blue angelfish (31), and spotfin butterflyfish (23). Important secondary marine life species (26) were masked goby (174 inds.), striped parrotfish (156), slippery dick (139), porkfish (130), and dusky damselfish (42). Because of 3,276 reef croaker, along with large schools of scad and clupeids, 18% (11 species) of the total individuals had no economic value.

4.6.6. American Shoal Rubble Reefs

Seven primary commercial species were recorded at the American Shoal site (N = 24) including lane (249 inds.), gray (56), and yellowtail snapper (34), hogfish (18), gag grouper (15), and black grouper (1). Lane snapper averaged 17 cm long (to 22 cm), and gray snapper averaged 22 cm (to 45 cm). Ten secondary commercial species dominated numbers and biomass as a result of tomtate (10,207 inds., ave. 16 cm), white grunt (3,225), and bluestriped grunt (834). Adult bigeye (160 inds.) and porkfish (102) were other common secondary commercial species.

Fourteen recreational species included the primary commercial species along with porkfish, yellow jack (11 inds.), snook (8, ave. 4.4 kg), and permit (3, ave. 11 kg).

Twenty-two primary marine life species included cocoa damselfish (71 inds.), bluehead wrasse (57), bicolor damselfish (51), sharpnose puffer (35), spotfin butterflyfish (28) gray angelfish (22), blue angelfish (21), and high hat (21). Twenty-four secondary marine life species included striped parrotfish (190 inds.), slippery dick (97), redband parrotfish (70), masked goby (64), spotted goatfish (46), ocean surgeon (36), and doctorfish (32). Only 1% of individuals (8 species) had no economic value.

4.6.7. Fishing Activity

Although no recreational or commercial fishing or marine life collecting was observed at the units, the general area around Big Pine Shoal is heavily fished by all three industries. Considering the level of use of electronics in reef fishing, the high profile units have probably been located and fished on occasion. A recreational fishing vessel was observed attempting to anchor on a mid-depth unit, and a lost anchor was removed from a deep unit. Commercial hook and line fishing for yellowtail and gray snapper is an active fishery a short distance west of the study area. A commercial marine life collector once worked to within a few meters of the observer during a census on the mid-depth natural reef, and collectors were routinely seen in the vicinity.

Wire fish traps were extensively used seaward of the reef tract in this area for many years. Illegal usage (shallower than 30.8 m) was routine on the deep natural reef, and traps were observed within about 15 m of the deep units and as shallow as 26.2 m depth. Ten ghost traps (some open, some closed) were found in the area of the deep reef. Observed in traps were groupers, porgies, angelfishes, jacks, hogfish, gray snapper, and others (Plate 13). Based on the level and history of use of fish traps in this vicinity, it is probable that fish populations on the deep natural reef, and maybe at the deep units, were altered by this non selective harvest of larger individuals. All use of fish traps in the southeast Florida area was banned in early 1992 by the South Atlantic Fishery Management Council, about 1 1/2 years after cessation of monitoring for this study.

Recreational and commercial fishing occur on both Bahia Honda and American Shoal rubble sites. Catches of red, black, and gag groupers, mutton, lane, gray, and yellowtail snappers, permit, snook, pompano, sawfish, cobia, jacks, and grunts have been documented at the Bahia Honda reefs along with diver catches of spiny lobster (J. Lapp, pers. comm., 1992; Kruer, pers. observs.). Reported catches of *Mycteroperca* groupers over several years included roughly 80% gags and frequent black groupers under the 20 inch size limit (J. Lapp, pers. comm., 1992). Visual censuses at Bahia Honda showed about 62% of *Mycteroperca* groupers were gags and 30 black grouper with a mean length of 47 cm (19 inches), ranging 6 to 100 cm (Table 23).

Recreational and commercial catches documented at American Shoal from 1986 to 1991 included lane, yellowtail, gray, schoolmaster, and mutton snappers, gag, yellowedge, red, and black groupers, large jewfish, pompano, barracuda, cero, Spanish mackerel, large king mackerel., bluefish, tomtate, white grunt, greater amberjack, blue runner, jack crevalle, small bonefish, bigeye, and shark (J. Lapp, pers. comm., 1992; Kruer, pers. observs.). In May 1986, April and May 1987, and April 1988, sexually ripe male and female lane snapper (up to 1 kg), one of few possibly under-utilized local commercial species, were common on the American Shoal site indicating that they may aggregate and spawn there part of the year (Kruer, pers. observs.).

4.7. Objective Number 7. Evaluate the economics of constructing, transporting and placing artificial habitats to enhance fishery resources and fishing opportunities.

Although donated materials and labor made up a major portion of the cost to design and construct these prefabricated units, the commercial cost to construct such structures can be estimated. Variations in structural design to improve fishery enhancement effectiveness (i.e. add small spaces) probably would not appreciably alter the costs if similar amounts of material were used. Mass production of such units would probably result in a lower per unit construction cost. Unit transportation costs have the most potential for reduction below those paid in this project; per ton transportation costs were considerably lower for rubble. A limitation on unit size, unless constructed at a waterfront facility, is the ability to transport them via roads to a barge staging area.

Costs associated with constructing the rubble reefs are related to loading and transportation, both on land and water. Most work to date has been with rubble loaded directly onto barges at a bridge removal site, but a number of patch reefs at Bahia Honda were constructed with large concrete debris transported by truck from several Lower Key locations to the barge staging area. Similar reefs could be created in the Keys to take advantage of concrete and rubble debris routinely generated by the construction industry during reconstruction work, and by future Florida Department of Transportation bridge removal or rehabilitation projects. Suitable material can be stockpiled until several full barge loads (one load is typically 200 - 300 tons, 10 - 15 truckloads) are on hand. Eliminating high costs associated with landfill or other disposal could help offset loading and transportation costs.

Records of FKARA projects allows the following estimation of costs for the reefs censused in this study:

4.7.1. Prefabricated Units

Costs to construct 4 large units and 3 small units in 1987/88:

PVC pipe -	$ 160
poured concrete -	1,370
wood forms -	267
reinforcing steel -	1,068
equipment rental -	190
gas for torches -	85
miscellaneous materials -	457
transportation of donated material -	675
134 hours labor (paid) x $12/hour -	1,610
Subtotal -	$ 5,882

Donated - Estimated Value:

construction yard on Big Pine Key -	$ 2,000
pre-stressed beams -	10,000
225 hours labor ($15/hour) for permitting, construction, transportation, etc. -	3,375
Subtotal ($ equivalent donated) -	$ 15,375
Total estimated cost to construct 7 units -	$ 21,257
Transportation to staging area and Alexander Marine loading and barge work (3 trips) -	12,000
Total estimated cost to construct, transport and place 7 units -	$ 33,257

Cost per Unit:	High Units	Low Units
Construct	$ 3,800	$ 2,000
Transport	1,700	1,700
Total	$ 5,500	$ 3,700

4.7.2. Bahia Honda Rubble Reefs

Eleven of the 19 patches at the Bahia Honda artificial reef (6,000 mt) were placed from June to August, 1985 (2,700 mt), and eight were placed from August to October, 1987 (3,300 mt). All materials were donated; some were transported at no cost to the staging area by the Florida Keys Aqueduct Authority and the Florida Department of Transportation, other material was moved there by a contractor hired by the FKARA with state grant funds.

Costs to construct the Bahia Honda rubble reefs:

1985

Transport 90 truck loads of concrete bridge decks and rubble x $125/load -	$ 11,250
15 Misener Marine barge trips (2,700 mt) x $2,800/load -	$ 42,000
3 loads old Bahia, Honda Bridge steel girders	
3 loads steel pipe and steel hangars	
9 loads large concrete slabs/rubble	
FKARA miscellaneous expenses -	$ 750
100 hours of donated time x $15/hour -	1,500
Subtotal -	$ 55,500

1987

16 Misener Marine barge trips (3,300 mt) from partial removal of Spanish Harbor Bridge x $ 3000/load -	$ 48,000
FKARA miscellaneous expenses -	500
100 hours of donated time x $15/hour -	1,500
Subtotal -	$ 50,000
Total estimated Bahia Honda Artificial Reef cost -	$ 105,500

Cost per metric ton ($ 105,000/6,000 mt) = $ 18

4.7.3. American Shoal Rubble Reefs

Of four patch reefs at the American Shoal site (3,850 mt), patch 1 (550 mt) was placed in April, 1983; patch 2 (1,100 mt) in September, 1985; patch 3 (1,650 mt) from September to October, 1987; and patch 4 (550 mt) from October to November, 1987. Patches 1 and 2 are composed of large concrete rubble from partial removal (on two occasions) of the nearby Niles Channel Bridge and patches 3 and 4 are from the Kemp Channel Bridge.

Costs to construct the American Shoal patch reefs:

1983

3 Alexander Marine barge loads x $2,666/load -	$ 8,000
FKARA miscellaneous expenses -	300
30 hours of donated time x $15/hour -	450
Subtotal	$ 8,750

1985

11 Misener Marine barge loads x $2,800/load -	$ 30,800
FKARA miscellaneous expenses -	500
80 hours of donated time x $15/hour -	1,200
Subtotal	$ 32,500

1987

12 Misener Marine barge loads x $3,000/load -	$ 36,000
FKARA miscellaneous expenses -	500
80 hours of donated time x $15/hour -	1,200
Subtotal -	$ 37,700
Total estimated American Shoal Artificial Reef cost -	$ 78,950

Cost per metric ton ($ 78,950/3,850 nit) = $ 21

4.7.4. Cost Effectiveness of Artificial Reefs

Knowledge of the amount of concrete and steel deposited at the bridge rubble sites allows an estimation of the area this material now covers, and with estimated biomass density and construction costs, a comparison of cost effectiveness to the high profile units. Bohnsack *et al.* (1989) report that small clusters of prefabricated concrete cubes (1.75 m^2 bottom area each) placed off Key Biscayne, Florida had higher fish density than larger clusters of cubes, but found that biomass density increased with additional cubes. Multiple prefabricated units of the type used here, placed together, might alter standing stock of fishes at individual units from that found here with only two units placed 50 m apart. Multiple units might show decreased overall fish density but greater biomass density.

Short tons placed at the rubble sites were converted to cubic yardage using a factor of 0.541 based on the known weight of 3,750 pounds of a cubic yard of solid concrete aggregate. Cubic yards were then converted to cubic meters using the standard factor of 0.76. Calculating 1.2 m (4') as an approximate "average" height of the patches based on observations, and allowing 25% open space within a patch, the American Shoal reefs (4,200 short tons) are estimated to cover about 1,800 m^2 of bottom and the Bahia Honda patches (6,600 short tons) about 2,830 m^2.

Biomass density was determined for the rubble sites by dividing the total recorded biomass at each site by the total area censused at the site (N x 177 m^2) . American Shoal reefs showed a biomass density of 340 g/m^2 and Bahia Honda showed 199 g/m^2. Biomass density at the 4 high units was determined by dividing total biomass recorded (724 kg) by the total area censused in all high unit samples (62 x 27 m^2 = 1,674 m^2). Mean biomass density at the high units was therefore 432 g/m^2. In terms of the dollar cost (see estimates above) of resulting fish biomass, the American Shoal rubble reefs are about 3.6 times and the Bahia Honda reefs about 2.5 times more cost effective than the high units. The different physical influences on fish assemblages of artificial habitats in Hawk Channel and on the reef tract may also be an important factor in cost effectiveness in regard to fish biomass. Although the low units are not assessed here, their cost effectiveness when compared to the rubble reefs is considerably less than the high units.

5. Comparisons to Other Artificial and Natural Reefs

Table 44 provides a comparison of the general results from this project with studies by Bohnsack *et al.* (1989) using 50 2.3-m^3 prefabricated concrete modules arrayed in various numbers off Key Biscayne, studies of a concrete module reef in Hawaii by Brock and Grace (1987), and studies of a reef made of tires near Pacific Reef in Biscayne National Park, Florida by Stone *et al.* (1979).

This study of Keys artificial reefs showed total species ranging from 67 to 73 on the units, and 72 to 90 on the rubble reefs. On artificial habitats off Key Biscayne there were 74 (1 module reef) species to 96 species (8 module reefs); in Hawaii, 125 species; and at the tire reef in Biscayne National Park, 98 species (Table 44). Total species on natural reefs studied here ranged from 104 to 114, higher than the 81 to 85 species reported for large natural reefs in the studies compared.

Fish densities from 1.7 to 5.9 inds./m^2 on artificial reefs in this study, were higher than densities on artificial reefs in Hawaii (1.6/m^2) and Biscayne National Park (2.1/m^2), but considerably lower than densities on the concrete modules off Key Biscayne (24 - 71/m^2). Difference in sizes of artificial reefs in various projects possibly accounts for the differences in the numbers of species, total numbers, and densities (Bohnsack *et al.,* 1989; Ambrose and Swarbrick, 1989). Total counts on rubble patch reefs might reflect considerably higher fish densities than those reflected here. Fish densities on natural reefs in this study ranged 0.9 to 1.5 inds./m^2; in Hawaii density was 1.6/m^2; off Key Biscayne density ranged 1.0 to 1.5/m^2; but in Biscayne National Park density was 6.8/m^2 on natural reefs (8 samples).

In studies compared, biomass density was considerably higher on artificial reefs than on natural reefs (Table 44). On the deep natural reef studied here, biomass density was 72 g/m^2, off Key Biscayne on natural reefs it ranged from 47 to 72 g/m^2, and in Hawaii it was 46 g/m^2. On artificial reefs studied here biomass density ranged from 397 to 495 g/m^2 on the high profile units and 199 to 340 g/m^2 on bridge rubble sites, off Key Biscayne artificial reef biomass ranged 390 to 701 g/m^2, and in Hawaii it was 1267 g/m^2. Total mean biomass per sample on the high units (27 m^2) here was 10.4 kg at mid-depth and 13.0 kg at deep units, while at 8-block reefs (14 m^2) off Key Biscayne mean sample biomass was 10.2 kg. Mean fish size (biomass) was larger in the Keys (75-126 g on high units and 34 - 91 g on rubble reefs) than off Key Biscayne (6 - 29 g). It was largest in Hawaii (137 g). Commercial species composed 59% of total biomass on the artificial reefs in this study, 61% at Hawaiian artificial reefs and 61% off Key Biscayne.

Stationary visual censuses conducted in 1983 at nearby Looe Key Reef (Fig. 4) from 0 to 10 m depth on the shallow "fore reef" zone (Bohnsack *et al.,* 1987) revealed greater fish abundance and slightly greater diversity than found at the shallow bank reef sampled here. Recorded at Looe Key (N=160) were 116 species and about 250 individuals per census. Here 107 species and 153 fishes per census were recorded (N = 111). The 8 most frequent shallow natural reef species recorded here were, in decreasing order, striped parrotfish, yellowhead wrasse, bicolor damselfish, bluehead wrasse, blue tang, foureye butterflyfish, ocean surgeon, and redband parrotfish. All were listed in the 15 most frequent at Looe Key Reef. Comparing relative abundance of fishes at the shallow reef in this study to that found at Looe Key Reef showed harlequin bass, white, bluestriped, and striped grunts, porkfish, cocoa damselfish, doctorfish, hogfish, high hat, saucereye porgy, and blue angelfish more abundant at the shallow bank reef studied here. Fishes considerably more abundant at Looe Key Reef were yellowtail, schoolmaster, gray, and lane snappers, yellowtail, longspine, dusky, and threespot damselfishes, sergeant major, caeasar, French and tomtate grunts, stoplight and princess parrotfishes, spotted goatfish, bermuda chub, Spanish hogfish, masked goby, bluehead and clown wrasses, blue and brown chromis, glassy sweeper, and barracuda. The greater structural diversity of the complex spur and groove forereef at Looe Key, and its location immediately adjacent to deep waters of the Straits of Florida, probably account for differences observed.

Until now, quantitative information on deep reef fishes of south Florida was lacking, but Alevizon (1990) suggested that there should be strong similarities with insular Caribbean deep reef (>30 m) fish communities. Based on the deep natural reef (26 to 31 m) data provided here, however, there may be distinctive differences in these populations. Alevizon (1990) reports that Caribbean deep reef fishes are dominated by "strictly carnivorous, non-schooling species" including gobies, basslets, squirrelfishes, wrasses, and sea basses. Here, based on abundance and biomass, dominant families were grunts, jacks, damselfishes, wrasses, gobies, snappers, sea basses, and angelfishes, with grunts, jacks, and snappers often observed schooled.

6. Conclusions and Recommendations

This Florida Keys study showed that large prefabricated units and concrete rubble patch reefs, placed as artificial marine habitats on sand bottom, greatly enhance the abundance, diversity, and biomass of fish in an area. Densities of individuals and biomass were found considerably higher at artificial reefs than at nearby, natural, bank reefs, a result consistent with other studies. Location, depth, and vertical profile are important factors determining fish assemblages at artificial habitats in the Keys. Fishes were both produced at artificial reefs and attracted from the surrounding area. Fish assemblages at the Hawk Channel artificial reefs were considerably different from those on the offshore reef tract, particularly in terms of dominant species.

Settlers at the artificial reefs were mostly of small species important to the marine life industry, while colonizers were species important to commercial and recreational fishermen. Many settler species were demersal egg layers such as damselfishes, gobies, and blennies, or mouth brooders like cardinalfishes. The isolated rubble reefs in Hawk Channel reflected the greatest proportion (48%) of total biomass potentially produced by settler species, probably the result of their greater structural complexity, age, and large area. Abundance estimates were believed conservative at Hawk Channel sites because of poor visibility and considerable amounts of sand in census areas. Although attraction of adult fishes from the natural reef to the prefabricated units occurred, the regular movements of many browsers and herbivores back and forth appeared to be mainly for exploitation of new food resources. Large carnivores also tended to colonize these reefs temporarily, often in schools.

Doctorfish and slippery dick were ranked in the 15 most frequent species at all five artificial reef sites censused; only slippery dick was ranked as one of the most abundant at all sites, and only gray angelfish and hogfish were highly ranked at all sites based on total biomass. Duplicate high units at the same depth shared roughly three-quarters of the 15 most frequent and abundant species but only just over half of the total species, reflecting the large species pool in these areas. Sets of units and natural reefs at the same depth shared less than half of the total species, with just over half of the total found at the units. Of the 15 most frequent, abundant, and heaviest species, less than one-third were shared by the units and natural reefs, probably because of the very different structural complexity and limited food at the units.

The high profile units, and areas of high vertical relief at rubble reefs, allowed fish to partition space and food resources, increasing both diversity and abundance. Fishes benefited by the additional hard surfaces provided at all artificial reefs, both for food and cover. Planktivores dominated fish numbers at the mid-depth and deep units and the deep natural reef. Bottom feeding invertivores (especially grunts) were by far the most abundant fishes at the Hawk Channel rubble sites, indicating productive bottom feeding areas. Piscivores dominated biomass at the mid-depth and deep units and at Bahia Honda, where groupers, snappers, and snook were common. The influence of tidal currents offshore from Bahia Honda Channel may be conducive to diverse and productive benthic communities and high biomass of piscivorous fishes. The relatively low proportion of piscivore biomass at the deep natural reef may be the result of heavy use of fish traps. By the second year, the deep units appeared to be somewhat predator limited, with piscivores common (especially snappers, jacks, and barracuda), but few grunts and *Chromis* damselfish, common groups on the deep natural reef. Biomass density was nearly seven times and mean fish weight nearly three times higher at the deep units than on the deep reef. Of all artificial reefs, biomass density, was highest at the deep units.

Although fish density increased with depth on the natural reefs studied, highest density and number of species recorded on the units was at mid-depth. Frequent aggregations of yellowtail snapper around the top of the mid-depth units demonstrate the ability of high profile structures to concentrate this valuable species. Browsers and herbivores were more abundant at the mid-depth units than at other artificial reefs. Few parrotfishes occurred at any of the units. The development of hard corals, and the fouling community in general, was most rapid at mid-depth.

The simple, low, shallow units had the lowest abundance of fishes with large nurse sharks contributing most of the biomass. Most fishes recorded at the shallow units were of settler species valuable to marine life collectors, pointing to the potential of shallow artificial habitats to produce fishes for this industry.

Of all reefs studied, the rubble reefs in Hawk Channel had the highest density of fishes and the greatest proportion of species important to the commercial and recreational fishermen. Fish density was 3 to 5 times higher at rubble reefs than at natural reefs. Comparison of dominant species at rubble reefs to those at natural reefs showed highest similarity with the shallow natural reef, the closest reef to Hawk Channel. The two similar rubble sites in Hawk Channel shared only half of the 15 most abundant and heaviest species, indicating distinctive fish assemblages in different regions of Hawk Channel.

Artificial reef construction in the Keys has resulted from considerable interest by both fishermen and divers, interest that continues to grow as numbers of these users increase. This study shows the ability of rubble patch reefs and high profile units to produce and concentrate fishes economically important to fishermen and of interest to divers. In a tourist economy, the preference of many visiting divers for diving on sunken vessels and unusual structures, as an alternative to natural reefs, lends incentive to the placement of artificial reefs. Species important to the commercial hook and line fishermen comprised nearly two-thirds of total biomass at all artificial reefs combined, as found in other studies. At the American Shoal rubble reef, 99.2% of censused fishes had an economic value. Artificial reefs may take on considerable importance as people management becomes more pressing in the Florida Keys

National Marine Sanctuary, and the concept of fishery reserves is reviewed for the South Atlantic region of the United States.

Rubble reefs, built with donated materials, were roughly three to four times more cost effective than the high units in terms of biomass produced and aggregated. Large concrete rubble, similar to that used in construction of the Hawk Channel patch reefs studied here, is scattered around the Keys at various legal and illegal disposal sites and is routinely generated by the local construction industry. Additional bridge removal and reconstruction planned by the Florida Department of Transportation will also generate large quantities of concrete debris appropriate for artificial reef construction. Modification of the Keys marine environment through use of artificial habitats is already widespread, including numerous small rubble piles under private docks, thousands of bridge pilings, utility pole foundations, rip rap seawalls, rock jetties, and illegal artificial reefs composed of various items such as piles of trap debris, appliances, and steel drums. Properly placed, stable, durable, hard surfaces can be of benefit to the marine environment by providing long-term food and shelter resources; but unstable, lightweight material can be a liability.

Because of their relatively small scale, artificial reefs are minor contributors to the overall fish population of the extensive hard bottoms of the Florida Keys, but their ability to enhance fish communities in localized areas is very significant. The current high levels of use and interest in artificial reefs in the Keys requires serious consideration of the value and potential of additional reef building for future management in the Florida Keys ecosystem.

7. Recommendations for a Continuing Artificial Reef Program in the Florida Keys

1. Based on the documented biological enhancement that results from properly constructed artificial reefs, and on their value as management tools, well planned reef construction should continue as compatible with objectives of the recently designated Florida Keys National Marine Sanctuary (FKNMS). Artificial reef construction is appropriate only on stable, open, sand bottom, and under no circumstances should their placement displace or damage productive seagrass or hard bottom habitats. Large sandy areas seaward of the reef tract, on the reef tract, in Hawk Channel, and in the Gulf of Mexico offer ample suitable locations.

2. A program to build additional rubble patch reefs in the Florida Keys should be initiated. Based on data presented here reflecting high diversity and abundance of economically valuable fishes at rubble reefs, Monroe County should institute a program to collect and transport suitable concrete rubble to isolated sand bottoms in Hawk Channel, preferably in physically active settings offshore from channels. Careful handling and placement would assure valuable vertical relief and maximum benefit from creation of numerous, small patch reefs. Sources of funding include the Monroe County Boating Improvement Fund, Florida fishing license monies administered by the Florida Department of Natural Resources, and disposal fees paid by the construction industry and public utilities that generate such materials. Suitable staging areas with deep water access should be located in strategic areas of the Keys where appropriate material can be stockpiled until an adequate amount is on hand for barging to a permitted offshore site.

3. Artificial reefs should be used for management of divers and fishermen to reduce pressure on the natural reef. As a result of dive industry interest, the sinking of additional steel vessels in open, sandy areas offshore from the reef tract, and the placement of large, stable, prefabricated units in shallow, clear water zones should be considered to provide alternative diving sites. Fabricating units with both small and large interstices for fishes would more closely approximate natural conditions and result in even more diverse and interesting fish

assemblages. In addition, deep water (>45 m) wrecks could be placed for hook and line fishermen.

4. Consideration should be given to special rules for Keys artificial reefs. To avoid user conflicts, preclude possible overharvest, and possibly implement no harvest zones in some locations, consideration should be given to the concept of Special Management Zones under the SMZ program of the South Atlantic Fishery Management Council, consistent with FKNMS regulations. Review of artificial habitats (especially rubble reefs) solely to increase biological production should occur, with the idea of no harvest allowed at the site, or to the placement of such reefs within no harvest areas.

5. The artificial habitats studied here should be used for future research. The stability and durability of the prefabricated units and rubble reefs allows for long-term study of their fish assemblages. The use of the same stationary census method on large rubble reefs placed on sand on the reef tract off Long Key and in deep water off Islamorada in the mid 1980's would allow direct comparison to the similar Hawk Channel reefs studied here. The fish assemblages on the large steel vessels intentionally sunk in the Keys need to be quantified and the economic value of the vessels to the local dive industry determined.

6. Natural reef data from the three depths censused should be used as a baseline for future comparisons. The site specific quantitative information herein provides a valuable baseline for evaluation of possible changes in fish community structure over time as a result of various management efforts (i.e. fish trap prohibition, marine fishery reserves) and natural influences.

8. References

Alevizon, W. S. 1990. Fish communities. Pp. 232-245 In: N. W. Phillips and K. S. Larson, Eds. Synthesis of Available Biological, Geological, Chemical, Socioeconomic, and Cultural Resource Information for the South Florida Area. US Dept. of Mineral Managem. Serv., MNS 90-0019.

Alevizon, W. S., and J. C. Gorham. 1989. Effects of artificial reef deployment on nearby resident fishes. Bull. Mar. Sci., 44:646-661.

Ambrose, R. F., and S. L. Swarbrick. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bull. Mar. Sci., 44:718-733.

Bohnsack, J. A. 1989. Are high densities at artificial reefs the result of habitat limitation or behavioral preference. Bull. Mar. Sci., 44:631-645.

Bohnsack, J. A. 1990. Habitat structure and the design of artificial reefs. Pp. 412-426 In: S. Bell, E. McCoy, and H. Mushinsky, Eds. Habitat Structure: The Physical Arrangement of Objects in Space. Chapman and Hall, New York, NY.

Bohnsack, J. A., and S. P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41, US Dept. of Commerce, Miami, FL. 15 pp.

Bohnsack, J. A., and D. E. Harper. 1988. Length-weight relationships of selected marine reef fishes from the southeastern United States and the Caribbean. NOAA Technical Memorandum NMFS-SEFC-215, US Dept. of Commerce, Miami, FL. 31 pp.

Bohnsack, J. A., D. E. Harper, D. B. McClellan, D. L. Sutherland, and M. W. White. 1987. Resource survey of fishes within Looe Key National Marine Sanctuary. NOAA Technical Memorandum NOS MEMO 5, US Dept. of Commerce, Wash., DC. 108 pp.

Bohnsack, J. A., D. L. Johnson and R. F. Ambrose. 1991. Ecology of artificial reef habitats and fishes. Pp. 61-107 In: W. Seaman, Jr. and L. N. Spraque, Eds. Artificial Habitats for Marine and Freshwater Fisheries. Academic Press, Inc., San Diego, CA.

Bohnsack, J. A., and D. L. Sutherland. 1985. Artificial reef research: A review with recommendations for future priorities. Bull. Mar. Sci., 37:11-39.

Bohnsack, J. A., and F. H. Talbot. 1980. Species-packing by reef fishes on Australian and Caribbean reefs: an experimental approach. Bull. Mar. Sci., 30:710-723.

Bohnsack, J. A., D. E. Harper, D. B. McClellan, and M. Hulsbeck. 1989. (Draft) The relative importance of recruitment, attraction, and production of reef fishes on natural and modular artificial reefs. NOAA NMFS/SEFC, Miami, FL. 86 pp.

Brock, R. E., and R. A. Grace. 1987. Fishery enhancement through artificial reef development for nearshore Hawaiian waters. Final report for Coop. Agreem. No. NA-85-ABR-00028. Hawaii Sea Grant, 156 pp.

Florida Keys Artificial Reef Assoc., Inc. 1990. Table summary of artificial reefs in the Florida Keys. FKARA, Inc. P.O. Box 917, Big Pine Key, FL.

Grove, R. S., N. Nakamura, and C. J. Sonu. 1991. Design and engineering of manufactured habitats for fisheries enhancement. Pp. 109-152, In: W. Seaman, Jr. and L.M. Spraque, Eds. Artificial Habitats for Marine and Freshwater Fisheries. Academic Press, Inc., San Diego, CA.

Harper, D. Personal communication. NOAA National Marine Fisheries Center, Southeast Fisheries Center, 75 Rickenbacker Causeway, Miami, FL.

Jaap, W. C. 1984. The ecology of the south Florida coral reefs: a community profile. FWS/OBS-82/08, US Fish and Wildl. Serv., Off. Biol. Servs., Washington, DC.

Kruer, C. 1985. Project summary of planned Bahia Honda artificial reef project. Florida Keys Artificial Reef Assoc., Inc., Big Pine Key, FL. 10 pp.

Lapp, J. Personal communication. Rt. 5 Box 172D, Big Pine Key, FL.

Little, E. Personal communication. National Marine Fisheries Serv., Off. Fish. Stats., 301 Simonton St. Key West, FL.

Manooch, C. S., and C. A. Barans. 1982. Distribution, abundance, and age and growth of the tomtate, Haemulon aurolineatum, along the southeastern United States coast. Fish. Bull., 80:1-19.

Milon, J. W. 1991. Social and economic evaluation of artificial aquatic habitats. Pp. 237-270 In W. Seaman and L.M. Spraque, Eds. Artificial Habitats for Marine and Freshwater Fisheries. Academic Press, Inc., San Diego, CA.

Robins, C. R., R. Bailey, C. Bond, J. Brooker, E. Lachner, R. Lea, and W. Scott. 1991. Common and Scientific Names of Fishes from the United States and Canada. Comm. on Names of Fishes, Amer. Fish. Soc., Spec. Publ. No. 20, Bethesda, MD.

Rockland, D. B. 1988. The economic impact of the sport and commercial fisheries of the Florida Keys. Prep. for the Everglades Protection Assoc., Florida Conservation Assoc. and Monroe County Industrial Development Authority. F.C.A. Islamorada, FL.

Sale, P. F. 1991. Reef fish communities: open nonequilibrial systems. Pp 564-598 In: P. F. Sale, Ed. The Ecology of Fishes on Coral Reefs, Academic Press, Inc., San Diego, CA.

Schroeder, R. E. 1987. Effects of patch reef size and isolation on coral reef fish recruitment. Bull. Mar. Sci., 41:441.

Seaman, W., Jr. and L. N. Spraque. 1991. Artificial habitat practices in aquatic systems. Pp. 1-27 In: W. Seaman, Jr. and L. N. Spraque, Eds. Artificial Habitats for Marine and Freshwater Fisheries. Academic Press, Inc., San Diego, CA.

Seaman, W. Jr., R. M. Buckley and J. Polovina. 1989. Advances in knowledge and priorities for research, technology, and management related to artificial aquatic habitats. Bull. Mar. Sci., 44:527-532.

Shulman, N. J. 1984. Resource exploitation and recruitment patterns in a coral reef assemblage. J. Exp. Mar. Biol., 74:85.

Stone, R. B., H. L. Pratt, R. O. Parker, and G. E. Davis. 1979. A comparison of fish populations on an artificial and natural reef in the Florida Keys. Mar. Fish. Rev., 41:1-11.

Voss, G. 1988. Coral reefs of Florida. Pineapple Press, Sarasota, FL.

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