A Comparison of Fish Populations on an Artificial and Natural Reef in the Florida Keys

R. B. STONE, H. L. PRATT,
R. O. PARKER, Jr., and G. E. DAVIS

Introduction

Various states and local groups are building reefs to develop or improve fishing grounds in response to increasing fishing pressure; however, little effort has been spent on using artificial reefs to expand or rehabilitate natural reef areas. We believe that artificial reefs could be used to effectively expand the amount of reef fish stocks. Ogawa (1973) stated that properly constructed artificial reefs or submarine forests could increase survival, growth levels, and feeding efficiency of certain juvenile fishes. This suggests that building reefs close to other artificial or natural reefs, could be a useful fishery management practice to increase total biomass of reef fishes.

ABSTRACT—An artificial reef was placed adjacent to a natural coral patch reef of similar size to study the feasibility of increasing fish carrying capacity and total biomass within a given area by augmenting natural reef habitat. After the artificial reef had been in place 7 months, visual observations indicated about equal numbers of fishes and similar species composition on both the artificial reef and the natural patch reef. Although the artificial reef was less than 25 m from the natural reef, it did not diminish the resident populations of the natural reef but doubled the carrying capacity and fish biomass in the immediate vicinity of the two reefs. For the remaining 2 years of this study, the fish populations on both reefs showed similar seasonal fluctuations.

R. B. Stone is with the Office of Marine Recreational Fisheries, NMFS, NOAA, Washington, DC 20235. H. L. Pratt is with the Narragansett Laboratory, Northeast Fisheries Center, NMFS, NOAA, South Ferry Road, Narragansett, RI 02882. R. D. Parker, Jr., is with the Beaufort Laboratory, Southeast Fisheries Center, NMFS, NOAA, Beaufort, NC 28516. G. E. Davis is with the South Florida Research Center, Everglades National Park, P.O. Box 279, Homestead, FL 33030.

This concept is accepted and has been used successfully by the Japanese (Ogawa, 1973) in their commercial fisheries, but had not been demonstrated for either commercial or recreational fisheries in the United States. Our study was designed to investigate the feasibility of using artificial reefs to increase fish carrying capacity and total biomass within a given area by augmenting natural reef habitat. We also compared the populations of our artificial reef with the fish populations on a nearby natural patch reef to determine if a tire reef is selective for or against any fish species.

Study Area Description

The study area is located northwest of Pacific Reef Light, in Biscayne National Monument, 50 km south of Miami, Fla. (Fig. 1). At lat. 25°22′35″N, it is near the northern limit of living reef corals in North America with annual water temperatures ranging from 16° to 31°C (Vaughn, 1918). This is reflected by low species diversity and small growth forms of hermatypic corals.

The specific area within the Monument that we selected is 274 m northwest of the Pacific Reef Light in 14 m of water. It is a back reef area, a few hundred meters behind the outer barrier ridge, and is subjected to east-west tidal currents. The bottom is coral sand inhabited by a moderate growth of manatee grass, *Syringodium filiforme,* and some turtle grass, *Thalassia testudinium*. The common algae are *Udotea* spp., *Penicillus* spp., and *Rhipocephalus* spp. The area is dotted with coral patch reefs. Except for the depth, these patch reefs are typical of the lagoonal patch reefs described by Hoffmeister (1974) for the entire Florida reef tract. The principal hermatypes are *Montastraea annularis, M. cavernosa, Diploria clivosa, D. labyrinthiformis,* and *Siderastrea siderea*. In the square kilometer we surveyed during the study, there were a dozen distinct reefs ranging from 10 to 30 m in diameter. One of these was chosen as our natural study reef (Fig. 2) and an artificial reef was placed adjacent to it, 21 m to the northwest.

We built the artificial patch reef on 21 January 1972, with 500 automobile tires to approximate the size and relief of the adjacent natural patch reef. Six months after emplacement, the tire reef had slumped and spread from its initial 12 m diameter and 2 m profile to almost a 20 m diameter with only 1 m of vertical relief. A few peripheral tires were moved back into the main body of the reef, and it remained stable in that configuration until its removal 24 months later (Fig. 3)

Materials and Methods

We used scrap automobile tires to construct the artificial reef since they are one of the most popular reef building materials in use (Stone, 1975). A 13-mm hole was punched through the tread of each tire to allow air to escape. Then a cylinder of waste concrete (road test core) was levered into the casing opposite the punched hole. We assembled the 500 tires into three different types of units: 250 single-tire units (23-28 cm high), 30 triple-tire units (51-61 cm high), and 20 multi-tire units (7-9 tires high, 1.8 to 2.1 m).

Our observations of fishes on the reefs started immediately following the tire drop. We also trapped and tagged 14 fish on the natural reef the same day. Divers counted fishes on the site the

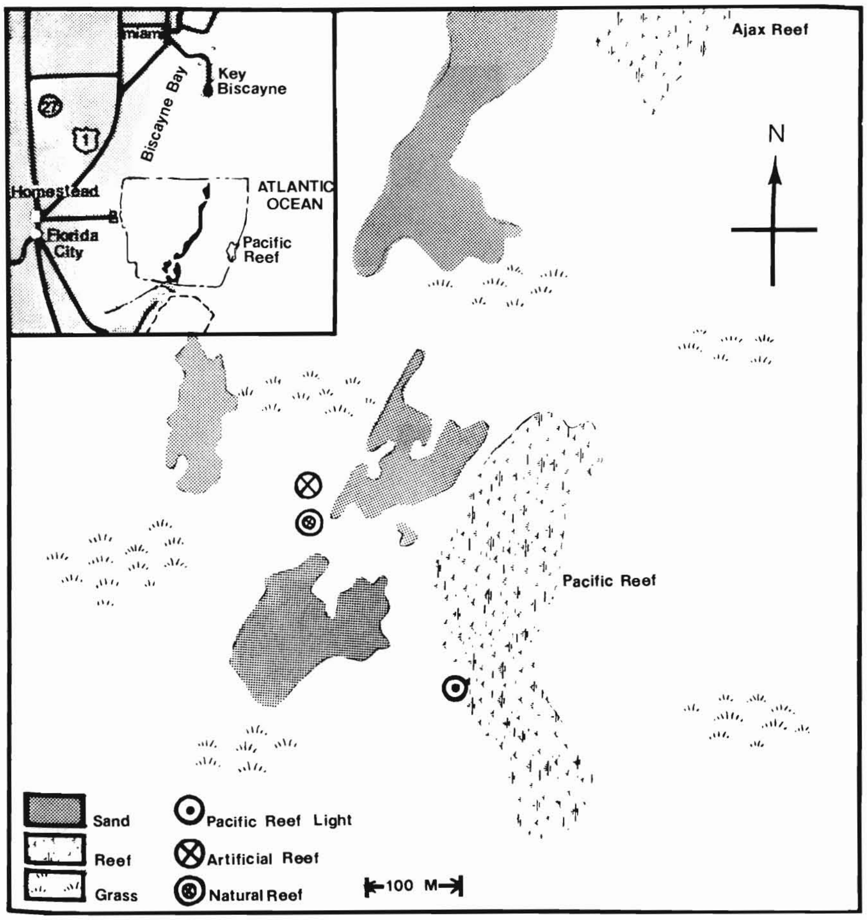

Figure 1.—Pacific Reef study area.

Figure 2.—Natural patch reef used for comparison study.

next day for 1 man-hour. Successive counts and observations of fish behavior on both reefs were made from 26 February to 2 March 1972 for 26 man-hours and from 12 to 17 April 1972 for 30 man-hours from an underwater habitat, EDALHAB II (Weeks, 1972). The habitat was located 46 m northwest of the tire reef and allowed teams of three divers to live and work in 14 m of water for up to 5 days. The team members, all from the National Marine Fisheries Service, were Wes Pratt, Narragansett, R.I.; Frank Steimle, Highlands, N.J.; and Clifford Newell, Roger Clifford, and Kenneth Pecci from Woods Hole, Mass. We

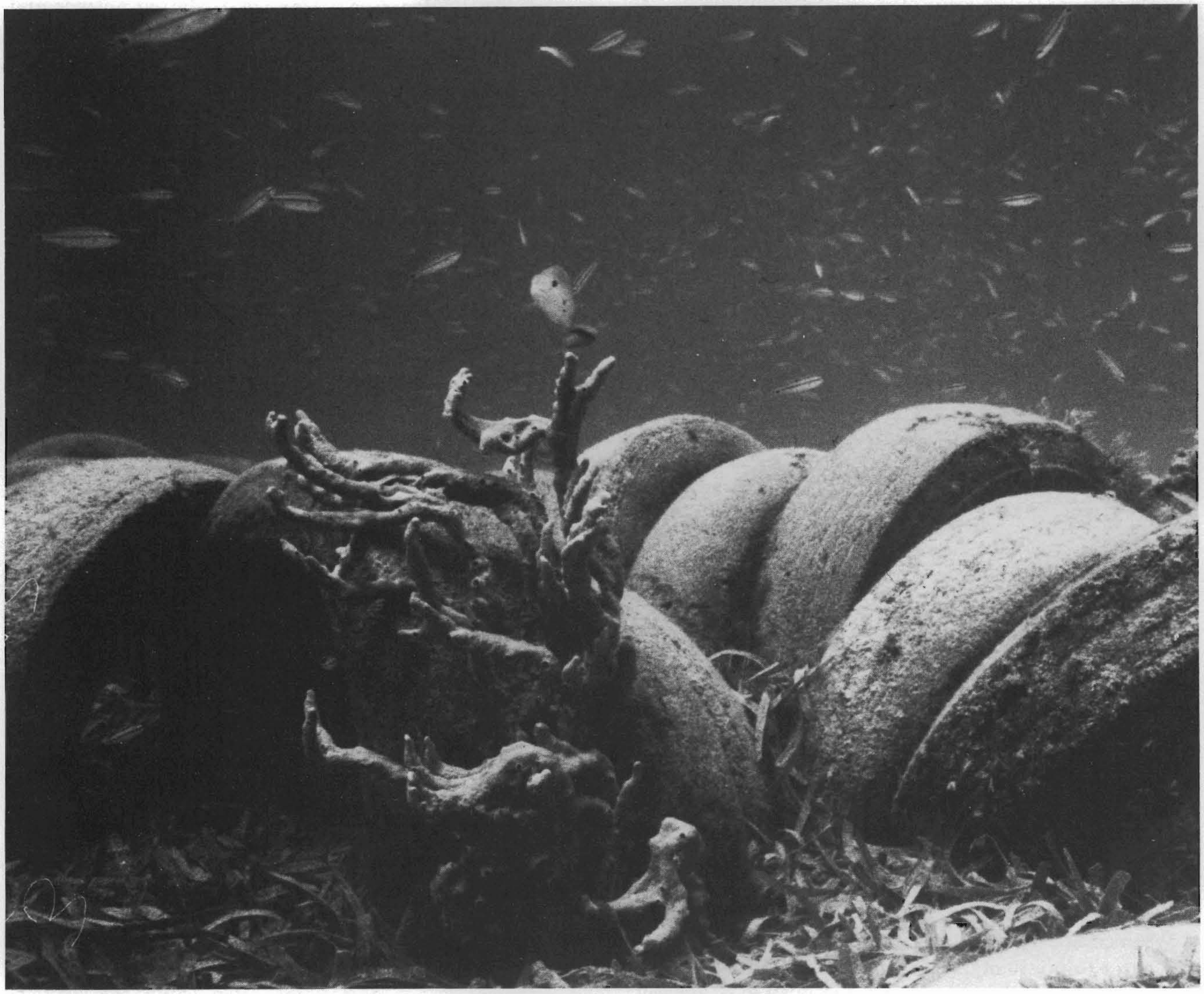

Figure 3.—Artificial reef used for comparison study in its stable configuration as of August 1974.

conducted six seasonal follow-up studies at the site diving from boats over a 28-month period using the same observation techniques developed during the habitat studies.

Seventy independent fish population estimates were made on both reefs. Two or three divers counted fish on each reef from four locations at the edges of the reef (Fig. 4) and then from an area above the reef. This procedure took about an hour for each reef. Both reefs were counted between mid-morning and mid-afternoon and additional, but less regular counts, were made at dawn, dusk, and midnight. Species, number of individuals, mean lengths, and behavioral observations were recorded on waterproof data sheets, held by a clipboard or embedded in fiber glass resin over plywood. We transcribed the information from the data boards onto a matching data form and erased the boards or replaced the data sheets after each count. Lengths of fishes were estimated primarily to separate juveniles from adults.

Several individuals followed us from reef to reef. These and wider ranging fish seen occasionally were considered visitors and distinguished from residents in the data. Approximately 2,000 underwater photographs were taken to aid in species identification and population estimates. The reefs were measured to obtain surface areas for standing crop estimates.

In August 1974, we completed our

Figure 4.—Biologist/diver enumerating fish species on resin.

study by counting both reefs and quantitatively harvesting the fishes on the artificial reef with rotenone. This enabled us to determine the standing crop on the artificial reef and provided a standard with which to evaluate our visual counts on both reefs. After harvesting the fishes, we removed all artificial reef materials from the study site and left the area as it was prior to the construction of the reef.

We encircled the 152.9 m^2 artificial reef, prior to poisoning, with a 26 mm bar mesh seine, 49.2 m long and 6.1 m high, to reduce the chance of fishes escaping the rotenone. On the day of treatment, 21 August 1974, 27 people using 5 boats participated in poisoning the artificial reef, collecting the fishes and removing the reef material. Five liters of Chem Fish Collector[1], the brand of rotenone selected, were divided equally among five 3.8-l squeeze bottles that were then filled with seawater. This provided a concentration of about 4 ppm of 5 percent rotenone on the tire reef. We divided the reef into a pentagon and assigned each section to a diver for treatment and collection of fish. Sections were treated simultaneously from the outside to the center. Four other divers took photographs, herded fish, and helped collect stunned and dead fish. The divers dispersed the rotenone in 5 minutes and finished collecting the dead fish 70 minutes later. The only dead fish observed outside the treated area, during post-poisoning surveys, were small fish that swam through the mesh during treatment and died within 10 m of the net.

The participants cooperating in this study came from the NOAA Atlantic Oceanographic Laboratories in Miami, Fla.; NMFS Laboratories in Beaufort, N.C.; Narragansett, R.I.; Highlands, N.J.; Woods Hole, Mass.; and Miami, Fla.; National Park Service personnel from Biscayne National Monument and Everglades National Park; U.S. Geological Survey personnel from the Fisher Island Station Miami, Fla.; Department of Natural Resources biologists from the States of Georgia and South Carolina; University of Miami graduate students; local contractors; and the Miami Sport Fishing Club. The project was partially supported by the National Oceanic and Atmospheric Administration's Manned Undersea Science and Technology Office as part of their Project FLARE.

Open circuit, self-contained underwater breathing apparatus (scuba) was used in all phases of the study. Diver propulsion vehicles (DPV) were used to survey the surrounding patch reefs but not for the counting excursions.

Results and Discussion

On 22 January 1972, the day after the artificial reef was installed, we finished arranging tires on the reef and made a quick survey of less than 1 hour of both the natural and artificial reef. We observed three species of fish which usually feed near sand bottom or grass beds, hogfish, *Lachnolaimus maximus;* spotted goatfish, *Pseudupeneus maculatus*; and trunkfish, *Lactophrys* sp., foraging in the disturbed sediments around the artificial reef and a school of juvenile fish using the tires for shelter that appeared to be grunts, *Haemulon* sp., but were too small for positive identification. During the limited time available, about 250 individuals of 24 species were seen or photographed on the natural reef with the pomadasyids and the labrids accounting for most of the fishes. Obviously overlooked were the more secretive fishes such as the cardinal fishes, Apogonidae.

The first extensive survey of both reefs started on 26 February 1972, 37 days after establishing the artificial reef. The EDALHAB II habitat was deployed on the study site and three biologists spent 4.5 days in the habitat, each averaging 6 hours a day working on the reefs. We found 128 individuals of 28 species residing on the artificial reef. Most of the fishes were juveniles or subadults.

Young tomtates, *Haemulon aurolineatum*, and French grunts, *H. flavolineatum*, accounted for over half of the individuals. The young tomtates swam in schools slightly above the artificial reef and would retreat to the shelter of the tires when approached. The French grunts stayed near the bottom of the reef, much closer to the reef material than the tomtates. Other species occurring in abundance on the

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

artificial reef were parrotfishes, including *Scarus taeniopterus, Sparisoma viride,* and *S. aurofrenatum,* surgeonfish, and goatfishes. The rest of the fishes occurred as one or two individuals of each species (Table 1). Several of these were juvenile fishes, spotfin butterfly fish, *Chaetodon ocellatus*; highhat, *Equetus acuminatus*; jackknifefish, *E. lanceolatus*; and the bicolor damselfish, *Pomacentrus partitus*, which had apparently established territories on the new habitat created by the artificial reef.

The natural reef contained 387 individuals of 37 species (Fig. 2). The species composition was similar with tomtates most numerous; however, the natural reef did have more species of pomacentrids and greater numbers of both pomacentrids and pomadasyids.

On 12 April 1972, the habitat was repositioned near the study area. Although a few tires had "bedded" into the sand, the position of the reef material was virtually unchanged. The population of the tire reef had increased to 573 individuals of 53 species (Fig. 5). A number of motile invertebrates were seen on the artificial reef in April including two spiny lobsters, *Panulirus argus*. The natural patch reef community included 866 individuals of 58 species of fish (Fig. 5).

The dominant species on both reefs was the tomtate with about 300 occurring on the natural reef and about 70 on the artificial reef. The difference in the number of individuals between the two reefs is largely attributable to greater numbers of tomtates, bicolor damselfish, and bluehead wrasse on the natural reef (Table 1).

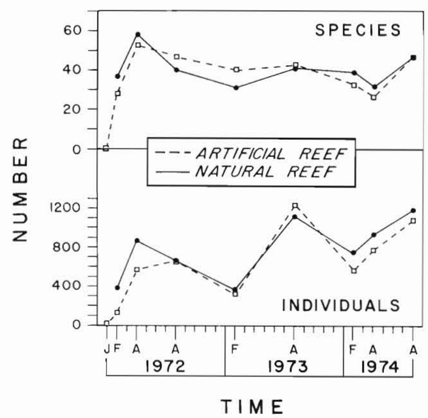

Figure 5.—Occurrence of fish species and individuals on the artificial and natural reef by date.

The new artificial reef continued to be attractive to juvenile fishes, probably because of reduced competition for unclaimed territories. Species diversity equaled that of the natural reef by April (Fig. 5). Two 2.5-cm bicolor damselfish had established territories on tires and three 5-cm yellowhead wrasse, *Halichoeres garnoti*, were associated with a juvenile doctorfish, *Acanthurus chirurgus*, and several unidentified juveniles on an outlaying single tire unit. A juvenile French angelfish, *Pomacanthus paru*, took up residence in an upright single tire and a juvenile jackknife-fish was seen inside the same tire in which it was observed during the February mission. Assuming it was the same fish, it had grown about 1.5 cm.

Large (72-cm) rainbow parrotfish, *Scarus guacamaia*, used the multitire units and the natural study reef for shelter at night. Two or three were

Table 1.—Comparison of populations by reef and sampling date.

	Artificial reef										Natural reef								
	1972			1973		1974			Rotenone		1972			1973		1974			
Species	Feb.	Apr.	Aug.	Feb.	Aug.	Feb.	Apr.	Aug.		Status[1]	Feb.	Apr.	Aug.	Feb.	Aug.	Feb.	Apr.	Aug.	Status
Acanthuridae																			
Acanthurus bahianus	0	4	6	6	8	7	8	6	10	DR	0	3	1	4	2	7	3	2	DR
A. chirurgus	4	5	5	P	0	0	0	3	2	DR	3	4	4	0	0	0	0	3	DR
A. coeruleus	0	0	7	0	0	0	0	4	2	DR	0	1	2	0	0	0	6	4	DR
Antennariidae																			
Antennarius multiocellatus	0	0	0	0	0	0	0	0	1	C									
Apogonidae																			
Apogon binotatus	3	10	0	P	0	0	0	0	2	NR	15	10	4	5	6	2	0	7	NR
A. maculatus	2	20	2	0	1	0	0	6	0	NR	10	9	4	2	13	1	0	1	NR
A. pseudomaculatus	0	0	0	0	0	0	0	0	53	NR	0	0	0	0	0	0	0	0	—
A. quadrisquamatus	0	1	0	0	0	0	0	0	0	NR	0	0	0	0	0	0	0	0	—
Phaeoptyx pigmentaria	0	0	0	0	0	0	0	0	9	NR	0	0	0	0	0	0	0	0	—
Atherinidae																			
Allanetta harringtonensis	0	0	0	0	0	0	0	1	0	D	0	0	0	0	0	0	0	100	D
Aulostomidae																			
Aulostomus maculatus	0	0	0	0	0	0	0	0	0	—	0	1	0	0	0	0	0	0	DV
Balistidae																			
Aluterus schoepfi	0	2	1	0	0	0	0	0	2	DV	1	0	0	0	0	0	0	0	DV
A. scriptus	0	1	0	P	0	0	0	0	0	DV	0	1	0	P	0	0	0	0	DV
Monacanthus ciliatus	0	0	0	0	0	0	0	0	0	—	0	4	0	0	0	0	0	1	DR

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Table 1.—Continued.

Species	Artificial reef 1972 Feb.	1972 Apr.	1972 Aug.	1973 Feb.	1973 Aug.	1974 Feb	1974 Apr	1974 Aug	Rote-none	Status[1]	Natural reef 1972 Feb.	1972 Apr.	1972 Aug.	1973 Feb.	1973 Aug.	1974 Feb.	1974 Apr.	1974 Aug.	Status
Bothidae																			
Syacium micrurum	0	0	0	0	0	0	0	0	1	C	0	0	0	0	0	0	0	0	—
Carangidae																			
Caranx bartholomaei	0	2	0	1	2	0	0	0	0	DV	0	2	0	0	0	0	0	13	DV
C. crysos		0	0	0	0	0	0	0	1	DV	0	0	0	0	0	0	0	0	—
C. ruber	7	7	7	3	3	14	7	13	0	DV	7	6	4	2	7	4	10	10	DV
Unidentified	0	0	7	0	0	0	0	0	0	?	0	0	12	0	0	0	0	0	?
Chaetodontidae																			
Chaetodon ocellatus	2	1	0	P	0	0	2	2	2	DR	0	2	0	P	0	0	2	2	DR
C. sedentarius	0	4	2	0	0	0	0	0	0	DR	0	1	3	0	0	0	0	0	DR
Holacanthus bermudensis	0	0	0	0	0	0	0	0	0	—	1	0	1	0	0	0	0	0	DV
H. ciliaris	0	0	0	P	1	1	1	0	1	DR	2	4	2	0	1	1	1	0	DR
H. tricolor	0	0	0	0	0	0	0	0	0	—	0	0	1	1	1	1	1	2	DR
Pomacanthus arcuatus	0	2	0	0	2	1	1	1	0	DV	0	2	0	0	2	0	2	1	DV
P. paru	0	1	0	0	0	0	0	2	0	DR	1	1	0	0	0	0	0	2	DR
Cirrhitidae																			
Amblycirrhitus pinos	0	0	0	0	0	0	0	0	0	—	1	1	0	0	0	0	0	0	DRC
Dasyatidae																			
Urolophus jamaicensis	0	0	0	0	0	0	0	0	0	—	0	1	0	0	0	0	0	0	DV
Gobiidae																			
Coryphopterus dicrus	0	0	0	0	0	0	0	0	1	C	0	0	0	0	0	0	0	0	—
C. glaucofraenum	0	300	0	P	225	P	P	300	90	DR	35	100	P	0	P	P	P	300	DR
C. hyalinus	0	0	0	P	1	P	0	50	0	DC	0	20	0	0	75	P	0	65	DC
Gnatholepis thompsoni	0	0	0	0	0	0	0	4	0	DR	0	0	0	0	0	0	0	8	DR
Gobiosoma evelynae	0	25	0	0	0	0	0	0	0	DC	0	0	0	0	0	0	0	0	—
G. oceanops	0	1	0	P	2	P	0	1	0	DR	2	1	2	0	4	P	P	6	DR
Ioglossus helenae	0	0	0	0	0	0	0	2	0	DR	2	3	0	0	0	0	0	0	DR
Gerreidae																			
Eucinostomus gula	0	4	0	0	0	0	0	0	0	NV	0	0	0	0	0	0	0	0	—
Holocentridae																			
Unidentified	0	0	0	0	0	0	0	0	1	C	0	0	0	0	0	0	0	0	—
Labridae																			
Halichoeres bivittatus	0	0	36	48	44	22	15	25	39	DR	0	0	18	8	15	11	7	25	DR
H. garnoti	1	3	2	5	4	4	4	20	2	DR	0	6	8	6	5	6	3	15	DR
H. maculipinna	2	2	18	16	7	4	3	3	2	DR	10	53	10	5	4	5	2	2	DR
H. Pictus	0	14	1	0	0	1	0	0	0	DR	0	0	0	0	0	0	0	0	—
H. poeyi	0	0	1	0	1	1	1	0	0	DR	0	0	2	0	2	1	0	0	DR
Hemipteronotus splendens	0	2	0	0	0	0	0	0	0	C	0	0	0	0	0	0	0	0	—
Lachnolaimus maximus	1	3	2	1	1	0	0	2	0	DR	2	4	1	2	2	1	3	1	DR
Thalassoma bifasciatum	2	3	13	10	19	15	11	11	9	DR	25	116	9	19	20	35	10	12	DR
Unidentified	0	7	12	4	0	0	0	0	1	?	0	0	0	2	0	0	0	0	—
Lutjanidae																			
Lutjanus analis	0	0	0	1	0	0	0	0	0	DV	0	0	0	1	1	1	1	0	DV
L. buccanella	0	0	17	2	1	1	0	11	10	R	0	0	15	2	0	0	0	0	R
L. griseus	1	0	0	0	0	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
L. mahogoni	0	1	0	0	0	0	0	1	0	DV	0	1	0	0	0	0	0	1	DV
L. synagris	0	0	0	0	0	0	0	0	0	—	1	0	0	0	0	0	0	0	DV
Ocyurus chrysurus	0	1	2	0	1	0	0	0	0	DV	0	3	1	0	1	4	0	0	DV
Unidentified	0	0	0	0	5	0	0	0	0	?	0	0	0	0	10	0	0	0	?
Mullidae																			
Mulloidichthys martinicus	0	0	1	0	2	2	1	0	0	D	0	0	1	0	1	0	0	0	D
Pseudupeneus maculatus	3	4	16	9	7	3	3	6	8	DNV	7	4	8	6	1	2	3	5	DNV
Muraenidae																			
Gymnothorax moringa	0	1	0	0	0	0	0	1	0	DNR	1	2	0	0	1	1	0	0	DNR
Opistognathidae																			
Unidentified	0	0	1	0	0	2	1	0	0	?	0	0	1	0	0	0	0	0	?
Ostraciidae																			
Lactophrys triqueter	0	1	1	1	0	1	2	1	0	DV	1	1	1	1	0	1	1	1	DV
Pempheridae																			
Pempheris schomburgki	0	1	0	0	0	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
Pomacentridae																			
Chromis cyaneus	0	0	1	0	2	1	0	0	1	DR	0	1	6	4	29	5	1	8	DR
C. insolatus	0	0	0	0	0	0	0	0	0	—	1	3	0	0	0	0	0	0	DR
Microspathodon chrysurus	0	0	0	0	0	0	0	0	0	—	0	1	3	0	0	0	6	5	DR

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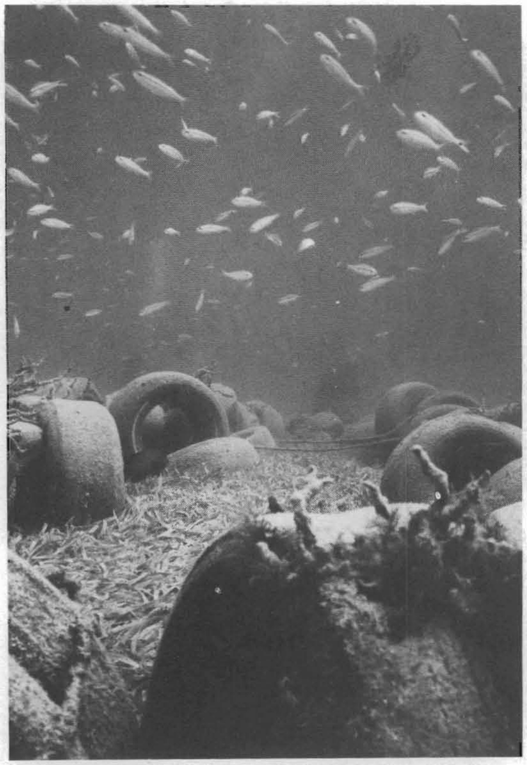
Table 1.—Continued.

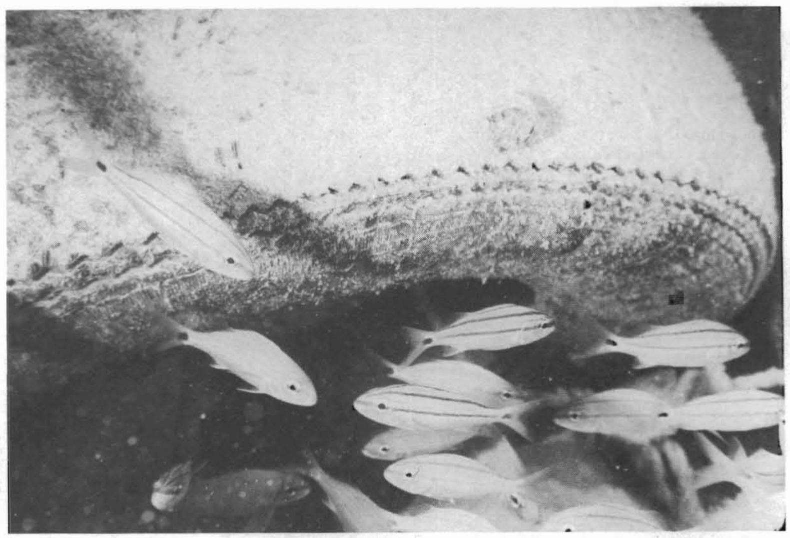
Species	Artificial reef								Rote-none	Status[1]	Natural reef								Status
	1972			1973		1974					1972			1973		1974			
	Feb.	Apr.	Aug.	Feb.	Aug.	Feb.	Apr.	Aug.			Feb.	Apr.	Aug.	Feb.	Aug.	Feb.	Apr.	Aug.	
Pomacentrus fuscus	0	1	2	2	0	0	0	1	3	DR	0	3	10	P	0	0	0	3	DR
P. partitus	1	2	1	P	3	0	0	15	3	DR	48	80	18	47	31	18	12	50	DR
P. planifrons	2	1	0	2	0	1	0	1	0	DR	32	5	2	7	5	2	1	4	DR
P. variabilis	1	2	2	6	4	2	2	2	1	DR	3	2	6	10	6	8	2	6	DR
Priacanthidae																			
Priacanthus arenatus	0	0	0	0	0	0	0	0	0	—	0	1	0	0	0	0	0	0	NV
Pomadasyidae																			
Anisotremus virginicus	0	1	1	1	1	0	0	0	1	DNV	0	1	0	0	0	0	0	0	DNV
Haemulon album	0	0	0	0	2	3	3	1	0	D	0	0	0	0	0	3	1	1	D
H. aurolineatum	50	73	450	100	805	400	675	500	760	DNR	100	312	500	220	800	453	725	400	DNR
H. carbonarium	0	0	0	0	1	0	0	0	0	D	0	0	0	0	0	0	0	0	—
H. chrysargyreum	0	1	2	0	1	0	0	0	0	D	0	3	1	0	1	4	0	0	D
H. flavolineatum	25	26	7	73	7	42	15	14	4	DNR	25	35	0	P	16	151	113	50	DNR
H. melanurum	0	0	1	1	0	0	0	1	2	D	0	0	1	0	0	3	0	0	D
H. plumieri	2	1	2	3	1	15	5	0	2	DNR	3	1	0	2	1	4	0	0	DR
H. sciurus	1	2	3	0	1	0	0	0	0	DR	2	5	0	0	0	0	0	0	DR
H. striatum	0	0	0	0	0	0	0	0	412	DR	0	0	0	0	0	0	0	1	DR
Unidentified	0	0	0	0	0	0	0	0	2	?	0	0	0	0	0	0	0	0	—
Scaridae																			
Scarus coeruleus	0	2	0	0	0	0	0	2	0	DV	0	1	0	0	0	0	0	0	DV
S. croicensis	0	0	1	4	17	5	6	1	1	D	0	0	0	1	12	5	3	0	D
S. guacamaia	0	4	0	0	0	0	0	0	0	NV	2	2	0	0	0	0	0	0	NV
S. taeniopterus	2	7	5	11	10	2	0	5	0	DR	4	4	6	3	8	0	0	6	DR
Sparisoma aurofrenatum	3	2	5	3	0	1	1	6	2	DR	2	8	3	4	0	3	1	6	DR
S. chrysopterum	0	0	0	0	3	2	1	0	0	D	0	0	0	0	2	0	3	0	D
S. radians	0	0	0	0	0	0	0	25	0	D	0	0	0	0	0	0	0	25	D
S. rubripinne	0	0	0	0	0	0	0	2	4	D	0	0	0	0	0	0	0	12	D
S. viride	4	1	1	0	0	0	0	1	1	D	10	3	2	0	0	1	1	1	D
Unidentified	0	0	0	0	0	0	0	0	10	?	0	0	0	0	0	0	0	0	—
Sciaenidae																			
Equetus acuminatus	1	0	1	1	0	0	0	0	0	D	0	0	0	0	0	0	0	0	—
E. lanceolatus	1	1	0	0	0	0	0	1	0	DR	0	0	0	0	0	0	0	0	—
Odontoscion dentex	0	1	0	0	0	0	0	0	0	NV	0	1	0	0	0	0	0	0	NV
Scombridae																			
Scomberomorus cavalla	0	0	0	0	1	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
S. maculatus	0	0	1	0	0	0	0	0	0	DV	0	0	0	0	1	0	0	0	DV
Scorpaenidae																			
Scorpaena plumieri	0	0	0	0	0	0	0	0	0	—	0	0	0	0	0	0	0	1	D
Serranidae																			
Epinephelus morio	0	0	0	0	0	0	0	1	0	D	0	0	0	0	0	0	0	1	D
E. striatus	0	0	0	0	0	0	0	0	0	—	0	0	0	0	1	0	0	0	D
Hypoplectrus indigo	0	0	0	0	1	1	0	0	0	D	0	0	0	0	4	1	0	0	D
H. nigricans	0	0	2	0	0	0	0	0	0	D	0	0	0	0	0	0	0	0	—
H. puella	0	2	3	5	2	0	0	0	0	DR	0	2	0	0	1	0	0	0	DR
H. unicolor	1	3	0	1	3	1	1	3	2	DR	3	1	0	0	1	1	0	0	DR
Petrometopon cruentatum	0	0	4	2	4	1	2	3	6	DR	1	2	2	2	2	2	2	4	DR
Serranus baldwini	0	0	0	0	0	0	0	0	1	D	0	0	0	0	0	0	0	0	—
S. tabacarius	0	0	0	0	1	0	0	1	0	D	0	0	0	0	0	0	0	0	—
S. tigrinus	0	0	2	3	2	1	2	5	5	DR	2	1	0	0	3	3	2	3	DR
Sparidae																			
Calamus calamus	2	2	1	1	0	0	0	1	0	DV	0	3	0	1	0	1	1	2	DV
Sphyraenidae																			
Sphyraena barracuda	0	0	1	0	2	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
Synodontidae																			
Synodus foetens	1	1	0	0	0	0	0	0	0	DR	1	1	0	0	0	0	0	0	DR
S. synodus	1	2	1	0	0	0	0	0	4	DR	1	2	1	0	0	0	0	0	DR
Tetraodontidae																			
Canthigaster rostrata	2	2	3	8	6	6	3	10	17	DR	20	15	3	9	10	4	4	8	DR
Xenocongridae																			
Chilorhinus suensoni	0	0	0	0	0	0	0	0	2	C	0	0	0	0	0	0	0	0	—
Total																			
Individuals	128	573	663	334	1,217	563	776	1,078	1,495		387	866	679	376	1,108	756	933	1,186	
Species	28	53	47	40	43	34	27	47	45		37	58	40	31	41	39	33	46	DR
Summary				Total: 98 species										Total: 85 species					

[1]D=diurnal, N=nocturnal, R=resident, V=visitor, P=present, 0=no information or absent, C=cryptic.

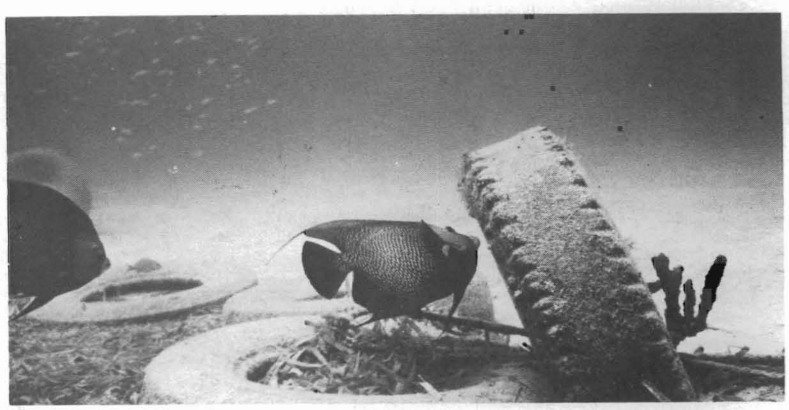


General views of the tire reef, above and top right.

Two goatfish swim past sponge and tires.



Tomtates on the tire reef (above) Below, a French angel feeds at a tire on the study reef.



discovered every night lying quietly, practically filling the tire's center with their bulk, while cleaner shrimp picked over their scales. During the day, a group of five or six of these giants could be seen from a distance grazing the surrounding grass beds.

We conducted the rest of the surveys without the EDALHAB II habitat using scuba gear from surface vessels. Our August 1972 comparisons of the two study reefs revealed about equal numbers of fishes on each reef but greater species diversity on the tire reef in daylight hours (Fig. 5). The greater species diversity on the artificial reef was a result of pelagic visitors. There were 663 individuals of 47 species on the 7-month-old artificial reef and 679 individuals of 40 species on the natural patch reef (Fig. 5).

The increase in the number of fishes on the artificial reef was attributed to the presence of about 450 juvenile grunts (probably tomtates) less than 5 cm long. There were about equal numbers of the same size juveniles on the natural study reef. The subadult tomtates (about 10 cm) that had been present on both reefs in April had disappeared on the natural reef and all but eight (about 15 cm) were absent from the artificial reef.

The disappearance of the tomtates greater than 10 cm in length seems to indicate a change in habitat requirements. This agrees with the findings of Sokolova (1969). In his study of the commercial trawl fishery of the Campeche Bank, he found tomtates from 9 to 23 cm long, with predominant lengths from 17 to 19 cm, occurring in the catches. Since there were no tomtates less than 9 cm being caught, Sokolova believed that the younger age groups inhabit different areas and remain separate from the adults.

We observed a small school of juvenile blackfin snapper, *Lutjanus buccanella*, on the tire reef during the August mission. Although the adults are normally caught in water deeper than 50 m, juveniles have been seen occasionally by divers in shallower water. Stark and Davis (1966) described a 14.6-cm specimen speared west of Cat Cay, Great Bahama Bank, at a depth of 12 m.

Based on the results of the February 1972 mission, we anticipated a seasonal decline in the number of species and individuals observed on both study reefs during our February 1973 mission. This did occur with 40 species and 334 individuals counted on the artificial reef and 376 individuals of 31 species observed on the natural reef. The dominant species on both reefs were grunts, tomtate, and French grunts on the artificial reef, and tomtate on the natural reef.

The number of individuals increased considerably by our August 1973 survey (Fig. 5). Again, most of this increase was caused by the presence of juvenile grunts. We observed about 800 juveniles, predominantly tomtates, on each of the study reefs. The wrasses were next in abundance on the artificial reef with 76 individuals of 6 species and the damselfishes were second in abundance on the natural reef (Table 1).

Our counts of individuals on the study reefs were higher during the February 1974 survey than previous February missions (Fig. 5). This was attributable to the large number of subadult tomtates that remained from the influx of juveniles on both reefs prior to the August 1973 mission. We found subadult French grunts to be second in abundance on both reefs followed by bluehead wrasse on the natural reef and slippery dick, *Halichoeres bivittatus*, on the artificial reef (Table 1).

Tomtates remained the dominant species on both reefs in the April 1974 survey, but there was a difference in the size of the juvenile tomtates. The juveniles occurring on the artificial reef were about 2 cm long, while the juveniles on the natural reef were from 3.5 to 6 cm long. This may be common with juvenile tomtates. The adults are reported to spawn over a prolonged period (Sokolova, 1969) and juveniles have been observed throughout the year (Munro et al, 1973). Sokolova (1969) stated that the extended spawning period probably causes a variety of sizes within the same age groups.

Due to rough seas, we were limited to one brief count in April 1974. This probably accounts for the low number of species observed during this mission (Fig. 5).

The August 1974 mission terminated the field portion of this study. We counted both reefs and collected all the fishes on the artificial reef using rotenone. The rotenone sample consisted of 1,495 individuals of 45 species with a total weight of 10.4 kg (Table 2). Our visual estimates of fishes on the artificial reef indicated 1,078 individuals of 47 species present. The difference in the visual counts and the actual number of fishes collected was caused mainly by an underestimation of the number of juvenile grunts present on the reef.

The visual counts on the artificial and natural reefs from August 1972 through the completion of the study showed similar numbers of individuals and species living on each reef (Fig. 5). One exception that occurred throughout the study was the consistent presence of blue chromis, *Chromis cyaneus*, on the upper portion of the natural reef and only occasional occurrence on the artificial reef (Table 1). Since the blue chromis is a plankton feeder, picking individual zooplankters out of the water passing or upwelling over the reef, it frequently occurs in loose aggregations just above reefs (Bohlke and Chaplin, 1968; Randall, 1968). The higher vertical profile of the natural patch reef caused a visible upwelling effect of the current which was absent on the tire reef. This probably provided conditions better suited for blue chromis than the lower profile artificial reef.

Cleaning Stations

By 1974 the artificial reef had matured to the stage of supporting several fish cleaning stations. A juvenile French angelfish cleaned bar jacks, *Caranx ruber*. A banded coral shrimp, *Stenopus hispidus*, cleaned resident graysbys, *Petrometopon cruentatum*, and a transient red grouper, *Epinephelus morio*, from inside the casing of a tire.

During repeated observations in February and April 1972, we observed coral shrimp cleaning rainbow parrotfish at night on both reefs. Neon gobys, *Gobiosoma oceanops*, maintained a

Table 2.—Fishes collected from FLARE artificial reef at Pacific Reef study site.

Species	No.	Length (mm)	Wt. (g)
Acanthuridae			
Acanthurus bahianus	10	177-249	1,675
A. chirurgus	2	210-235	439
A. coeruleus	2	240-248	549
Antennariidae			
Antennarius multiocellatus	1	51	15
Apogonidae			
Apogon binotatus	2	42-48	3
A. pseudomaculatus	53	25-61	75
Phaeoptyx pigmentaria	9		15
Balistidae			
Aluterus schoepfi	2	355-365	825
Bothidae			
Syacium micrurum	1	123	15
Carangidae			
Caranx crysos	1	565	494
Chaetodontidae			
Chaetodon ocellatus	2	137-149	75
Holacanthus ciliaris	1		5
Gobiidae			
Coryphopterus glaucofraenum	90	31-73	89
C. dicrus	1	36	1
Holocentridae			
Unidentified	1	54	5
Labridae			
Halichoeres bivittatus	39	29-87	80
H. garnoti	2	53-56	10
H. maculipinna	2	65-72	15
Thalassoma bifasciatum	9	30-87	25
Unknown	1	68	6
Lutjanidae			
Lutjanus buccanella	10	27-95	25
Mullidae			
Pseudupeneus maculatus	8	114-162	275
Pomacentridae			
Pomacentrus fuscus	3	32-69	20
P. partitus	3	76-106	73
P. variabilis	1	86	15
Chromis cyaneus	1	97	20
Pomadasyidae			
Anisotremus virginicus	1	287	491
Haemulon aurolineatum	760	17-170	1,000
H. flavolineatum	4	109-155	175
H. melanurum	2	55-59	10
H. plumieri	2	217-277	510
H. striatum	410	30-70	875
H. striatum	2	218-250	375
Unidentified	2		10
Scaridae			
Sparisoma rubripinne	4	131-193	312
S. viride	1	88	13
S. aurofrenatum	2	97-225	240
Scarus croicensis	1	125	37
Unidentified	10		53
Serranidae			
Petrometopon cruentatum	6	157-302	1,181
Serranus tigrinus	5	46-88	25
S. baldwini	1	35	1
Hypoplectrus unicolor	2	58-73	15
Synodontidae			
Synodus synodus	4	91-133	50
Tetraodontidae			
Canthigaster rostrata	17	33-71	75
Xenocongridae			
Chilorhunus suensoni	2	109-124	8

Total specimens=1,495   Total species=45
Total weight=10,400 g

characteristic station on a patch of brain coral, *Diploria labyrinthiformis*, and cleaned smooth trunkfish, *Lactophrys triqueter*, acanthurids, and serranids. Bar jacks were cleaned daily, every few hours, by a juvenile French angelfish and on nearby patch reefs by Spanish hogfish, *Bodianus rufus*.

Visual Counts and the Rotenone Collection

The basis for our comparison study is the ability of biologist/divers to identify and enumerate the fish populations on the two study reefs. This ability was supplemented by the extensive use of underwater photography to later confirm many identifications and, in a few cases, aid in the counts. The validity of diver estimates of fish populations was tested in August 1974 when the reef was poisoned with rotenone prior to removing the tire units from Biscayne National Monument. This operation revealed shortcomings and advantages in both techniques.

Visual counts by divers permit an uninterrupted analysis of seasonal flux and reef maturity. The fish best documented by this method are the larger and more obvious reef fishes, primarily herbivores and plankton feeders with a few opportunistic carnivores also being relatively easy to count. These fish include the acanthurids, chaetodontids, labrids, pomacentrids, pomadasyids, scarids, and some serranids. In addition, after many hours of quiet observation, we documented a population of itinerants which made rounds that included one or both of the study reefs on a daily basis. They were usually predatory species; however, the most frequently observed activity was a visit to a cleaning station. Carangids and lutjanids composed most of this group. The third group observed was the smaller or more secretive fishes. These include many diverse families with a small combined biomass. The apogonids and gobiids are the most numerous.

The rotenone method has the distinct advantage of providing an actual sample of fish which can be physically examined, counted, and identified. Its major shortcoming is that no matter how careful the investigator, some fish, notably transients like lutjanids and carangids and a few residents, flee the introduction of the poison. Others, such as the hovering goby, *Ioglossus helenae*, retreated into the sand to die, and were missed by the samplers. The loss of transients is lamentable, but does not significantly affect the standing crop estimates of the reef.

Specific comparisons of major families counted and collected in August 1974 reveal that the biologist/diver performs well as a sampler. Divers were very close in the estimate of acanthurids on the reef. They severely underestimated the apogonids, but since this is a nocturnal species, a night count would have been more successful as it was in April 1972. The school of visiting bar jacks counted by the divers avoided the poisoning of the reef. By snorkling above the reef, we discovered that some transients avoid tank divers. Resident chaetondonts and labrids compared fairly well. The larger gray angelfish, *Pomacanthus arcuatus*, and the hogfish, *Lachnolaimus maximum*, disappeared from the reef prior to the introduction of rotenone. Adult lutjanids were absent from the sample; 10 of the 11 juvenile blackfin snappers reported by divers, were collected successfully. Samples of mullids, pomacentrids, and serranids compared well.

The largest counting error involved the pomadasyids. Four hundred and twelve striped grunt, *Haemulon striatum*, were mixed with the school of 760 tomtates. In the limited time available for counts, the divers incorrectly assessed the juvenile grunts as all tomtates and then concentrated on enumerating less obvious species on the tire reef.

The composition of the rotenone sample indicates that a biologist/diver can make a fair estimate of a reef population if given enough bottom time. Identification of dominant fish species was unexpectedly accurate. Trained divers could assess seasonal flux, the role of itinerant fish, presence of cleaning stations, and the presence of a few cryptic fish that even a careful rotenone sample could not provide.

Biomass Estimates

The 10.4 kg of fishes collected from the artificial reef represented a standing crop of 680 kg/hectare. This is high compared with standing crop estimates of reef fishes on several natural reefs, but low compared with most fish biomass estimates on artificial reefs in tropical and subtropical areas (Table 3).

Although our biomass estimates appeared low compared with other artificial reef values, we estimated that the biomass values on this artificial reef approximated those of the adjacent natural patch reef. We were not able to poison the natural reef; however, through visual observations we determined that the surface areas of the two reefs and the numbers and sizes of the fishes on them were similar.

Other investigators (Randall, 1963; Wass, 1967; and McVey, 1970) have observed that fish populations are higher when rough bottom habitat is isolated from natural reef habitat. Randall (1963) attributed the much larger fish biomass per unit of area on a small artificial reef off St. John (Table 3) to the availability of additional food sources in the grass beds surrounding the reef.

Our artificial reef doubled the carrying capacity and reef fish biomass in the immediate vicinity of the natural patch reef.

Although the artificial reef was less than 25 m from the natural reef, it did not diminish the resident population of the natural reef by attracting them to the new habitat. Most of the resident species on the patch reef were recruited to the artificial reef as juveniles. Adult itinerant fishes started using the shelter the new reef afforded as soon as it was constructed. The fish biomass on the artificial reef increased through the first 7 months. Then in August 1972, the population estimates on both the natural and artificial reefs revealed about equal numbers of fishes on both reefs (Fig. 5) and similar species composition. From August 1972 through the completion of the study in August 1974, the fish populations on both reefs showed similar seasonal fluctuations.

A well planned and constructed artificial reef is a mutually beneficial enterprise for both fish and man. The construction of a reef or fish haven can change a barren, relatively unproductive substrate into a dynamic, highly productive environment. Increasing the amount of rough bottom habitat provides immediate shelter and subsequent food for a complex of organisms which may have been otherwise lost to the biota. The results of this study indicate that artificial reefs also can be used to augment productive natural reef and rough bottom areas and increase total biomass within a given area without detracting from biomass potential in other areas.

Table 3.—Comparison of fish biomass on tropical and subtropical reefs.

Reference	Location	Lb per acre	Kg per hectare
	Natural reefs		
Randall, 1963	Virgin Islands	1,420	1,590
Wass, 1967	Kaneohe Bay, Oahu	1,120	1,250
Bardach, 1959	Bermuda	440	490
Odum and Odum, 1955	Eniwetok Atoll	400	450
Brock, 1954	Average of 9 Hawaiian areas	320	360
Fast, 1974	S.W. Puerto Rico	244	270
	Average	657	735
	Artificial reefs		
Randall, 1963	Virgin Isl. (concrete blocks)	[1]6,230	[1]6,980
McVey, 1970	Pokai Artificial Reef (concrete pipes) Avg. of 16 censuses	2,340	2,620
Fast, 1974	Puerto Rico (Tires)	1,946	2,180
Morris, 1965	Pokai Artificial Reef (car bodies)	1,480	1,660
	Maunalua Bay, Oahu (car bodies)	900	1,010
Stone et al. 1979 (present study)	Florida Keys (Tires)	607	680
Morris, 1965	Keawakapu, Maui (car bodies)	230	260
	Average	1,962	2,199

[1] Figure based on roughly circular area of 125 m^2 containing interconnecting blocks and not actual area of blocks.

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