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FISHERY ECOLOGY OF THE POKAI ARTIFICIAL REEF

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PLATE 1. Mulloidichthys samoensis (goatfish) on the Pokai Artificial Reef.

ABSTRACT

The ecology of biota found on an artificial reef in Hawaii was studied for a period of 30 months. The reef, located near Pokai Bay off the leeward Oahu shore, covers approximately 25 acres and is composed of 4,000 tons of concrete pipe. The pipes lie in water 45 to 90 feet deep about one mile offshore.

The standing crop of marine biota on the reef study sites increased significantly during the course of study. Fish biomass increased 25 times or more, while invertebrate and algal abundance also increased as evidenced by observations within quadrats placed on pipe surfaces.

Reef complexity (density and variety of shelters) appeared to be the most important parameter responsible for increasing the marine fauna. Availability of food and orientation to topographical relief were also important in attraction of fishes to the artificial reef.

Recruitment of adult fishes onto the artificial reef was studied by tagging 902 fishes of 49 species in four quadrants surrounding a proposed reef increment. The movement of fishes onto the reef was entirely random with no particular area contributing more fishes than another. Territorial fishes in natural areas adjacent to the reef increment tended to stay on location, while itinerant species were first to arrive on the reef.

The succession of fishes, invertebrates and algae was followed on three study sites established on pipes deposited at different times. Seventeen species of fishes were chosen to represent a cross section of the more important species found on the reef. Regressions on total number, biomass and average weight of a fish against time were run for each of these species. Data for delayed-colonizing species tended to cluster around straight line regressions, while data for early-colonizing species appeared widely scattered around the straight line regression. The delayed-colonizing species were composed primarily of resident fishes.

Important invertebrates were followed from the time of their settlement on pipe surfaces until the climax community condition was reached after approximately 18 months. Oysters, Bryozoa and tunicates were predominant on the inside roofs of pipes, while vermetids, limpets, corals and algae were the main life forms on the top surfaces of pipes.

A study of grazing herbivores indicated that herbivorous fishes utilize the algae growing on the pipes and determine through selective grazing, the observable algal species on the pipe.

The artificial reef was a central orientation and shelter point from which both diurnal and nocturnal fishes radiated into the surrounding areas in search of food.

Comparisons of natural reef areas with the artificial reef showed that there were more fishes of larger size on the artificial reef. There also appeared to be fewer juveniles on the artificial reef when compared with nearby natural areas.

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CHAPTER I

INTRODUCTION

With the present logarithmic expansion of world population and the projected increase in the near future (Ehrlich, 1968), the importance of the ocean as a source of food for man is also increasing. Commercial catches of fishes and other aquatic life has risen 200% since 1950 (Riley, 1969), while aquaculture annually furnishes the world with over two million metric tons of food (Bardach, 1968). Artificial reefs have been and are being used as a means of increasing the yield of fishes in natural areas (Unger, 1966).

The concept of establishing artificial reefs probably is derived from observations that natural benthic areas differ in their capacity to provide food and shelter required by fishes. There are more species of fishes associated with rocky areas of the ocean floor (Carlisle, et al., 1964).

Certain stable substrates have been occasionally provided by accidents such as shipwrecks. During the First and Second World Wars large number of ships were sunk, many within sight of land. Stephens (1969) pointed out that such wrecks are a new resource to animals in an area. Many large wrecks have become the sites of flourishing marine communities that provide both food and habitat for important sport and commercial fish (Walford and Clark, 1967). Some of these, such as the cruiser San Diego located off Long Island, have become the favorite locations for charter and private fishing boats (Walford and Clark, 1967).

Shipwrecks are not the only man-derived structures that may improve the habitat for marine fauna. Piers, jetties, marker buoys and offshore oil rigs for years have been known to attract fishes. However, this was not their intended function. Not until man had depleted the inshore fish population in areas close to human population centers did the idea of purposeful improvement of the marine environment receive concentrated attention.

The Japanese experimented for centuries with artificial structures as fish attractors, but widescale testing of various materials and methods did not begin until after World War II. Ogawa (1966-67), Ogawa and Onoda (1966), and Ogawa and Takemura (1966a, b, c) experimented with different substrates, varying in shape and color, under controlled laboratory conditions. According to their studies, color was not as important a parameter as shape in attracting or deterring marine animals to or from the substrates. Invertebrates, such as crustaceans (e.g., lobster), were attracted to structures with many holes and crevices, while fishes were attracted to the higher reef structure. The two principal types of artificial reefs built by the Japanese worked to promote growth of attaching organisms and to attract fishes and invertebrates. The first of these was called _tsukiiso_ or "constructed beach" and the second, the higher structure was referred to as gyosho or "fish reef" (Oren, 1968). Other scientific investigations of fish behavior relative to artificial reefs were conducted by Toshiwata and Tanaka (1966) and Oshima (1964).

Federal, state and local fishery agencies in the United States have initiated artificial reef projects utilizing a variety of artificial substrates. The most ambitious program was in California where old streetcars, automobiles, quarry rock and specially designed concrete shelters were used for the artificial substrates (Carlisle, *et al.*, 1964). Artificial reefs were also built in Alabama, Florida, Maryland, New Jersey, New York, Virginia, Texas, Hawaii and the Virgin Islands. The construction material varied depending upon what was the most abundant in the specific areas where the reefs were built. Ship hulls, old barges, tires, broken culvert pipe, building rubble, oyster shells, concrete blocks, as well as the car bodies and constructed fish shelters previously mentioned, were used as the artificial substrate.

In California and the Virgin Islands artificial reefs received comprehensive scientific study, whereas in almost all other areas, little scientific study was made. The general pattern for construction has been to collect the substrate material and then to deposit it in an area that appeared optimum for both fish production and access by small boat. Favorable catches by sportfishermen have been the main measure of success for these reefs.

In studies by the California State Department of Fish and Game (Carlisle, 1962; Carlisle et al., 1964; Carlisle, 1963; Turner, 1961, 1962a, 1962b), selected fish species were counted at intervals to determine the rate and time of their appearance. The most common fishes and invertebrates were catalogued to obtain an idea of community structure. However, little was done with the succession of invertebrates and the interrelationships among the fish, algal and invertebrate communities.

In the Virgin Island study (Randall, 1963), an artificial reef was constructed of approximately 800 concrete blocks. A rotenone recovery after 28 months revealed a standing crop of fishes 11 times greater than on the natural reef areas along the adjacent shore. Visual censuses documented the succession of fishes attracted to the reef. The succession of algae and invertebrates was not studied but a check-list was assembled of the most common biota. Stomach analyses were made to determine dietary habits of important fishes.

Some of the reefs mentioned above were placed in poor locations, and after a few years, they became covered with shifting sands or disappeared in soft sediments. Others, such as those off New York and Hawaii, maintained high levels of productivity (Walford and Clark, 1967). Mathews (1966) found on a Florida artificial reef between May and August that 13 to 207 mg of carbon per hour were fixed in one cubic meter of sea water, in comparison with 9 to 34 mg outside the reef. A summary of most artificial reef projects in the United States is given by Unger (1966).

These failures and successes have improved our knowledge concerning the selection of an optimum artificial reef site. Stroud (1961a, 1961b, 1964), Stroud and Jenkins (1961a, 1961b) and Stroud and Massmann (1966) have published papers concerning the basic criteria for the construction of a hard natural substrate where water depth is shallow enough to permit good photosynthetic activity but deep enough to avoid wave damage during severe storms. Good water circulation and water rich in plankton are essential for the success of the benthic invertebrates as well as some fishes. Other important considerations are proximity to construction materials and easy accessibility for fishermen.

Prior to the placement of full-scale artificial reefs in Hawaii, a pilot study by the Hawaii Division of Fish and Game was conducted using concrete fish shelters placed at three locations around the island of Oahu. The information gained from this study indicated that addition of habitat to a fish-poor area could significantly increase the standing crop of fishes (Kami, 1960). Subsequently, three sites were picked for the establishment of artificial reefs. On Oahu, 829 car bodies were placed in 80 feet (24 m) of water at Maunalua Bay. A second reef, consisting of 94 car bodies and over 4,000 tons of damaged concrete pipe, was deposited in 80 feet of water near Pokai Bay off the Waianae Coast. A third reef at Keawakapu, Maui, consisted of 150 car bodies placed in 80 feet of water. Funds for these projects came in part from the Fish Restoration Act and in part from State appropriations. All three areas showed significant increases in the standing crops of fishes (Morris, 1965).

This paper is concerned only with the ecological development of the Pokai Artificial Reef and specifically with the concrete pipe increments of the past 3 years. The Pokai Artificial Reef was chosen because of the year-round diving accessibility, proximity to a small boat harbor and suitability of the concrete substrates for long-term succession studies.

The Hawaii Division of Fish and Game followed the development of the Pokai Artificial Reef prior to the present study. Visual fish censuses were made three or four times a year by the Division to ascertain the standing crop of fishes. The actual succession of fishes onto the reef was not followed as the censuses were done too infrequently and not soon enough after the pipes were deposited to discern many of the faunal changes. The censuses were conducted by swimming along a transect line and recording all the fishes in a designated area on underwater writing slates. All estimates were in pounds per acre. A fish census over the pipe section in June 1965, showed a standing crop of 662 pounds per acre (735 kg/ha), while another census over the car body section in March 1965 showed a standing crop of 1,084 pounds per acre (1,204 kg/ha). A section of bottom without pipes had a standing crop of only 47 pounds per acre (52.24 kg/ha) (Morris, 1965).

The investigation with which this dissertation is concerned was begun in June of 1967 when the reef consisted of 2,850 tons of pipe, and was continued through January of 1970, when deposits exceeded 4,000 tons. The author spent approximately 150 hours of SCUBA time in making underwater observations, representing approximately one-tenth of the actual man hours spent over the reef on the various projects. Field assistants spent an additional 300 SCUBA hours collecting specimens, water, and setting up grids, transects, etc. for study.

This study differs from previous ones in that an attempt was made to look at the total ecology of an artificial reef rather than limiting the studies to the fish fauna. The primary problem has been to follow the succession of fishes, invertebrates and algae at close enough census intervals to pick up the majority of the biotic changes on the reef. Wherever possible, interactions among the biotic elements and their relationships to physical and chemical parameters were examined by experiment and direct observation in order to gain insight into such questions as:

1. How do artificial reefs increase marine biota in otherwise barren areas?
2. What are the characteristics of a successful artificial reef?
3. What sequence, if any, is there to the appearances of marine forms on an artificial reef?
4. What effect does an artificial reef have on the biota of adjacent natural areas?
5. What role does an artificial reef play in the life and daily cycles of important sport and commercial fishes?

CHAPTER II

DESCRIPTION AND LOCATION OF THE POKAI ARTIFICIAL REEF

Natural Areas.

Observations of the natural substrate in the Pokai Artificial Reef area indicated that ledges, located on the inner and outer margins of the site, were the only notable topographic relief. The inner ledge marks a contour break where the water depth decreases from 60 to 50 feet (18.2 to 15.2 m). The outer ledge is larger and marks a contour break between 85 and 120 feet (25.9 and 36.5 m) of water (Fig. I). Coral grows well along the rim of the outer ledge, and a significant fish population is associated with this area. The natural bottom between the ledges is basaltic rock overlain with dead coral, sand, coral rubble and coralline algae (Plate 2). Isolated patches of live coral (*Porites lobata*, *Porites pukoensis* and *Pocillopora meandrina*) are intermixed with the sand and rubble. Random ring tosses (Plates 3 and 4, Appendix Table Va) revealed that 30% of the bottom was occupied by coralline algae, while corals were found to occupy only 2 to 3% of the bottom. These figures were obtained by brushing the substrate within a 30 cm ring free of sand and loose rubble and then photographing the area within the ring. From the developed print, areas covered by coral and coralline algae were determined with a planimeter. Gastropod mollusks, annelids, the enteropneust *Ptychodera*

FIGURE I

Location map showing the site of the Pokai Artificial Reef in relation to the small boat harbor at Pokai Bay and to Maile Point. Scale: One inch = approximately 2,000 feet.

FIGURE 1

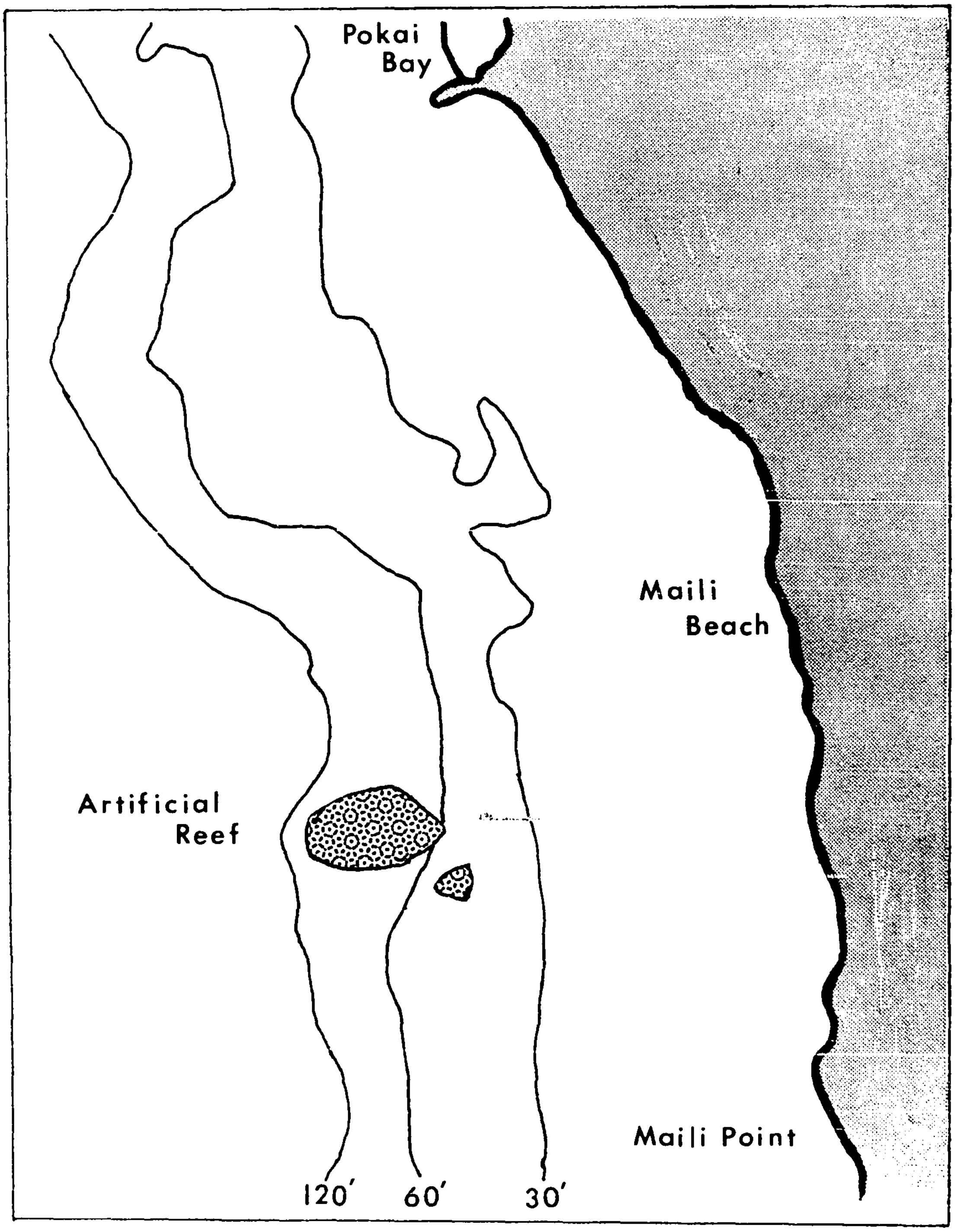


Plate 2

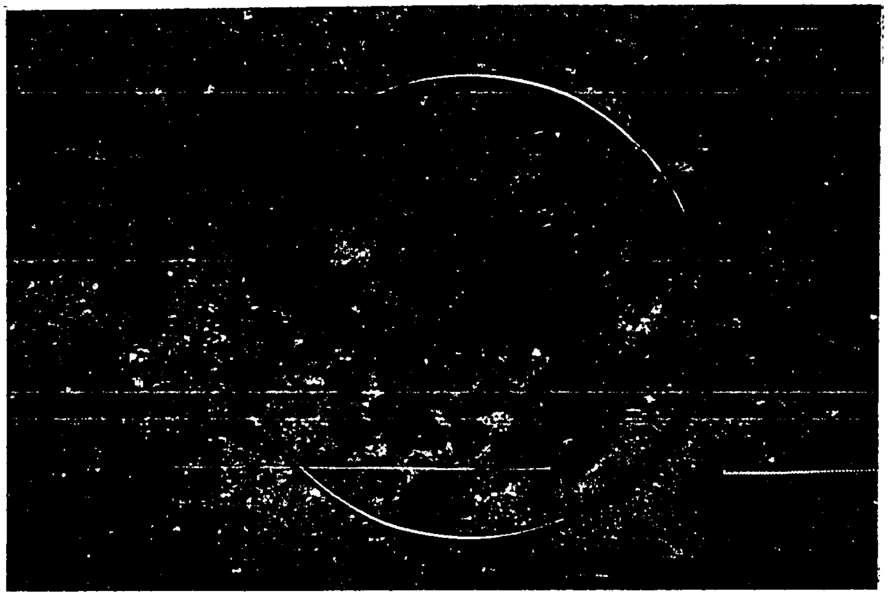
Natural substrate at the Pokai Artificial Reef site prior to the deposit of pipes. Brushed substrate within a steel ring is being photographed.

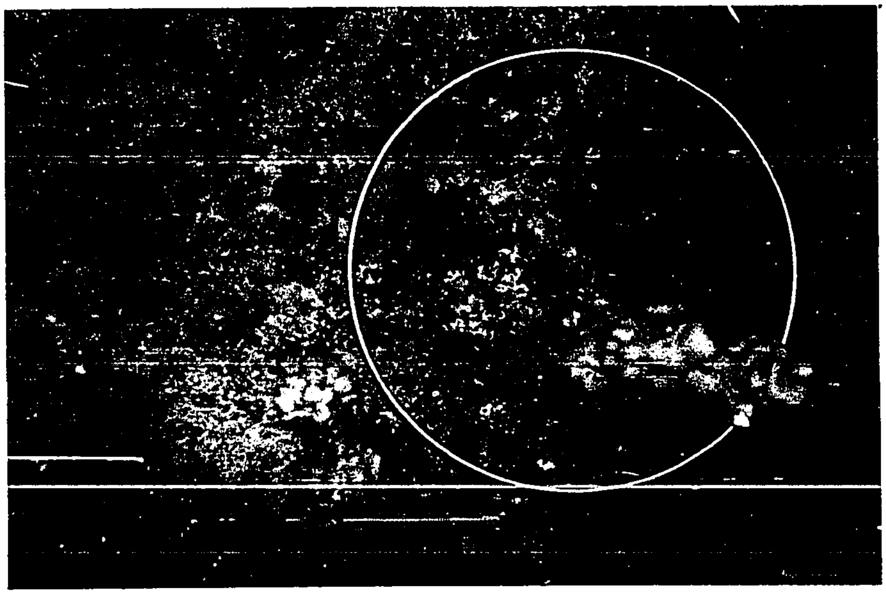
Plate 3

Coralline algae within a ring tossed randomly on the natural substrate at Pokai Artificial Reef.

Plate 4

A colony of *Porites lobata* within a ring tossed randomly on the natural substrate at Pokai Artificial Reef.





and other invertebrates were associated with the sand and rubble areas.

Artificial Reef Area.

The Pokai Artificial Reef, consisting primarily of 4,000 tons of damaged concrete pipes, is located in 45 to 95 feet (13.7 to 28.9 m) of water about one mile (1.6 km) off the leeward Oahu shore. The pipes have been deposited since 1964 in yearly increments providing ideal substrates for studying biotic succession. They were carried by barge and unloaded as the barge drifted over the area. Since 1967, attempts were made to place as many pipes as possible at the same location. The exact location of the reef in reference to the small boat harbor at Pokai Bay and Maile Point is shown in Fig. I.

In July of 1969, points on the reef perimeter were marked with buoys. Their positions were plotted by triangulation from a shore baseline 7,706 feet (2.34 km) long. Divers then swam in a direct line between selected pairs of buoys and recorded the relative numbers of pipes within the transect distance. In this way, the location of the reef (Fig. I), as well as its area and pipe concentration (Fig. II), were mapped. The concrete pipes presently cover about 25 acres (10.1 ha) of bottom with a considerable variance in density.

In areas of highest concentration (Plate 5), pipes

FIGURE II

A schematic showing the relative density of pipes and the location of the three fish transects (A-1964, D-1966, M-1968) on the Pokai Artificial Reef. Transect lines are 145 feet (44.2 m) long.

FIGURE II

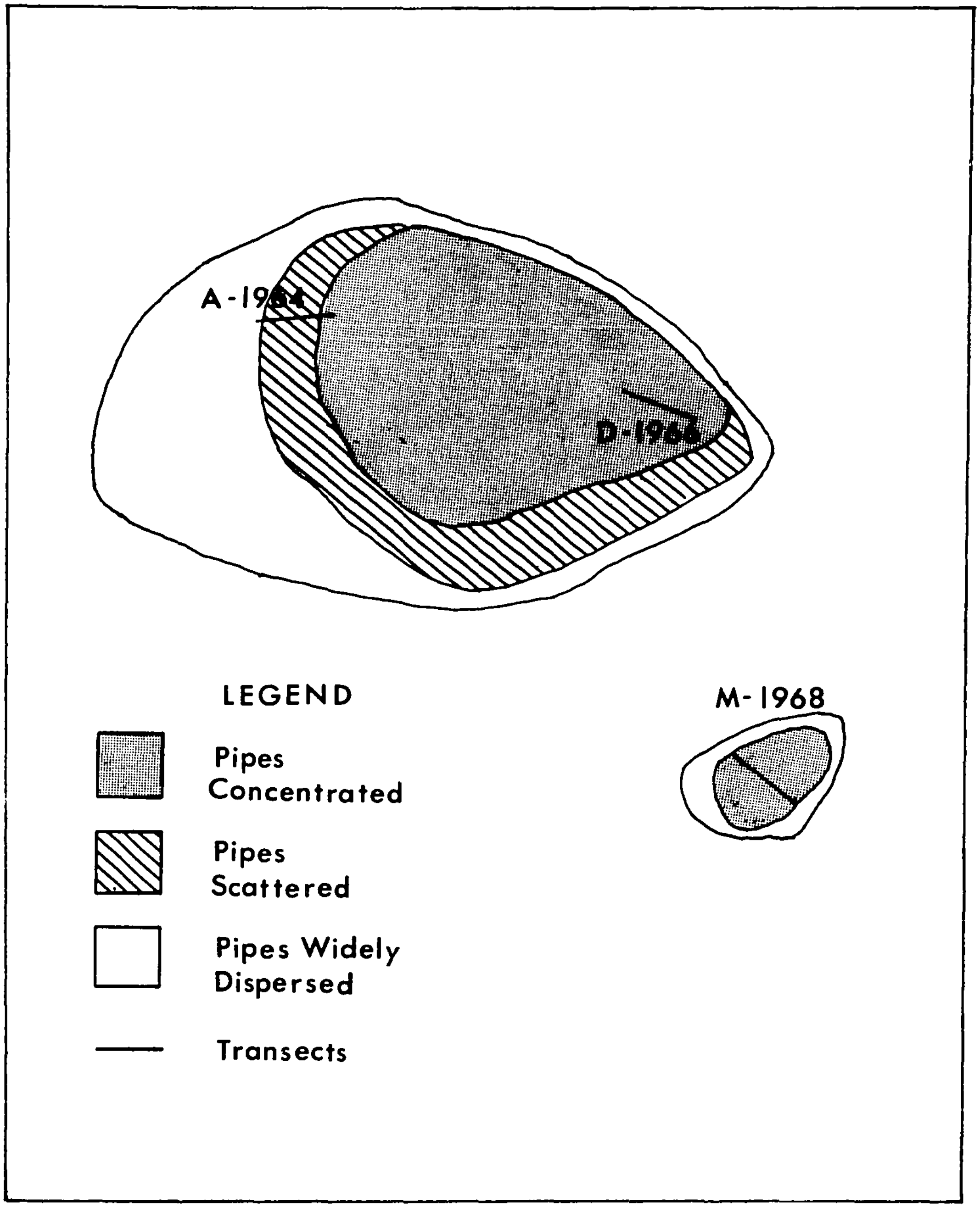

A-1964
D-1966
M-1968
LEGEND
Pipes Concentrated
Pipes Scattered
Pipes Widely Dispersed
Transects

Plate 5

Concentrated pipe arrangement at Pokai Artificial Reef. Fish transect line extends from right foreground.

usually adjoined but only occasionally did they actually rest upon one another. Assemblages of pipe rubble existed in these areas due to violent collision during periods of storm-generated waves. Open areas, 25 to 50 feet (7.6 to 15.2 m) wide, existed between groups of pipes. In the area labeled as scattered, the distance between groups of pipes sometimes approached 100 feet (30.5 m). Fewer pipes occurred in these groups, and single pipes were common. In the dispersed area, pipes were almost always solitary and separated by distances exceeding 100 feet.

Pipe diameters ranged from 6 inches (15.8 cm) to 5 feet (1.5 m). In many cases, exposed steel reinforcing rods offered metallic substrates on which organisms could settle.

Study Areas.

Three permanent study areas were set up in locations representing different ages of pipes (Fig. II). The first was established on pipes that were immersed in April 1964. This, the deepest and oldest area, is located in 85 feet (25.9 m) of water on the outer margin of the reef. The second was located on pipes deposited in December 1966, immediately adjacent to the ledge on the inner margin of the reef at a depth of 60 feet (18.3 m). The third was positioned on pipes that were placed in 50 feet (15.2 m) of water in March 1968. This last area is separated 600 feet

(183 m) from the main reef complex and lies to the southeast of the 1966 study area. Hereafter these study areas will be referred to as A-1964, D-1966 and M-1968, respectively.

Each study area consisted of a fish census quadrat 145 feet (44.2 m) long and 30 feet (9.1 m) wide or approximately one-tenth acre (0.04 ha). Each quadrat was delineated by stretching a center line along the bottom and then placing several cement blocks or other recognizable objects in parallel rows 15 feet (4.5 m) on either side. One-tenth acre quadrats were the most desirable as they reduced the error in counting fishes inherent in larger areas. In addition, visual censuses could be done on all three quadrats in one day allowing for better comparison of data.

Two pipes were selected within each quadrat, and permanent grids were affixed to three distinct life zones on the pipes. These were the exterior top surface of the pipe, the side of the pipe where it met the substrate, and the interior roof of the pipe (Plate 6). Grids were affixed to the pipes by hand-drilling corner holes in the cement with a masonry bit. Screws were then placed in the holes and nylon cord stretched between the four screws to mark the perimeter of a $\frac{1}{4}m^2$ grid (Plate 7). These three life zones were selected as representing the greatest diversity of habitat available on the pipe. This selection was based upon visible differences in community structure on the pipes.

Plate 6

Mature communities on the principal life zones of an old reef pipe.

A

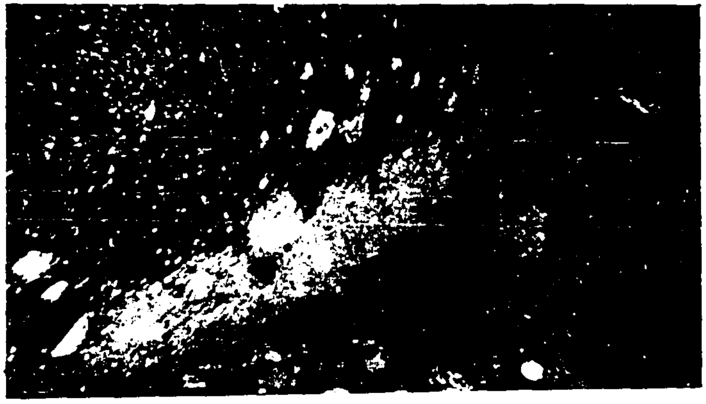
The exterior top surface of a pipe with grid, small colonies of coral and spawning *Chromis ovalis*. Most of the surface is covered with the typical algal mat.

B

The side of a pipe where it meets the substrate. Note change of biotic community.

C

Interior roof of a pipe with grid and urchin *Echinothrix calamaria*.



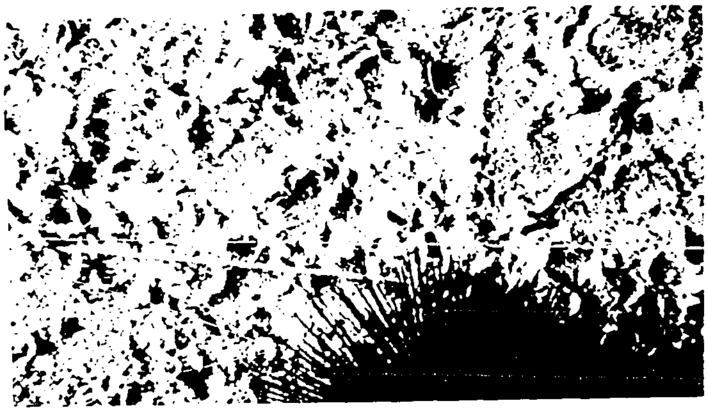


Plate 7

Method of attaching permanent grids to pipes for sessile invertebrate study.

A

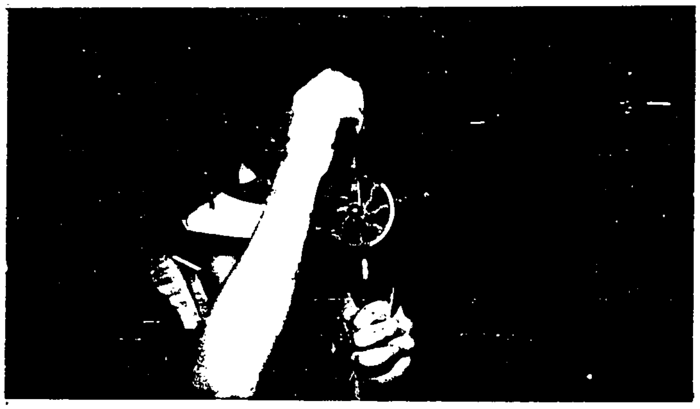
A hole is drilled into pipe roof with a masonry bit as a preliminary step in the placement of a permanent grid for sessile invertebrate study.

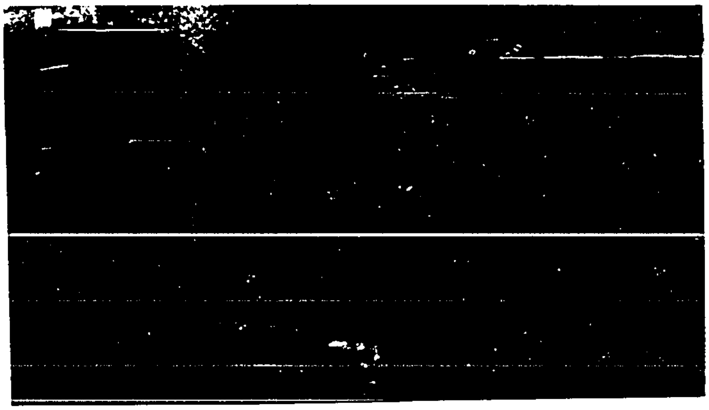
B

Screws were then attached to the pipes to mark the corners of the grid.

C

Nylon cord was secured to the four screws, and the succession of invertebrates was studied within this $\frac{1}{4}$ m^2 rectangle.





Physical and Chemical Parameters Affecting Study Areas.

In order to obtain an idea of the factors influencing biological development, several characteristics of the water mass were examined. These were tidal and surge effects, temperature and salinity.

Studies by Laevastu *et al*. (1964) and Sunn *et al*. (1962) showed a tidal current system consistent with that illustrated in Fig. III. For the present study, the velocity of tidal currents was measured by releasing fluorescein dye into the water and timing its passage along a known distance. Averages of five replicates indicated that currents varied up to 3 mph (4.8 km/hr). Falling tides flowed to the northwest and brought turbid water from the Maile Point area. Falling tides generally had less velocity than rising tides. Rising tides flowed to the southeast and usually resulted in clearer water conditions on the reef site. The importance of these tidal currents to reef ecology is discussed later.

Stevenson (1963) found that surge action was of ecological importance in determining the distribution of *Dascyllus* in Hawaii. Gosline (1965) indicated that surge may have greater influence than tide on the zonation of Hawaiian biota. Grigg (1964) hypothesized that surge might limit black coral distribution in Hawaii to depths below 20 m. Pipe movement observed in this study suggests that

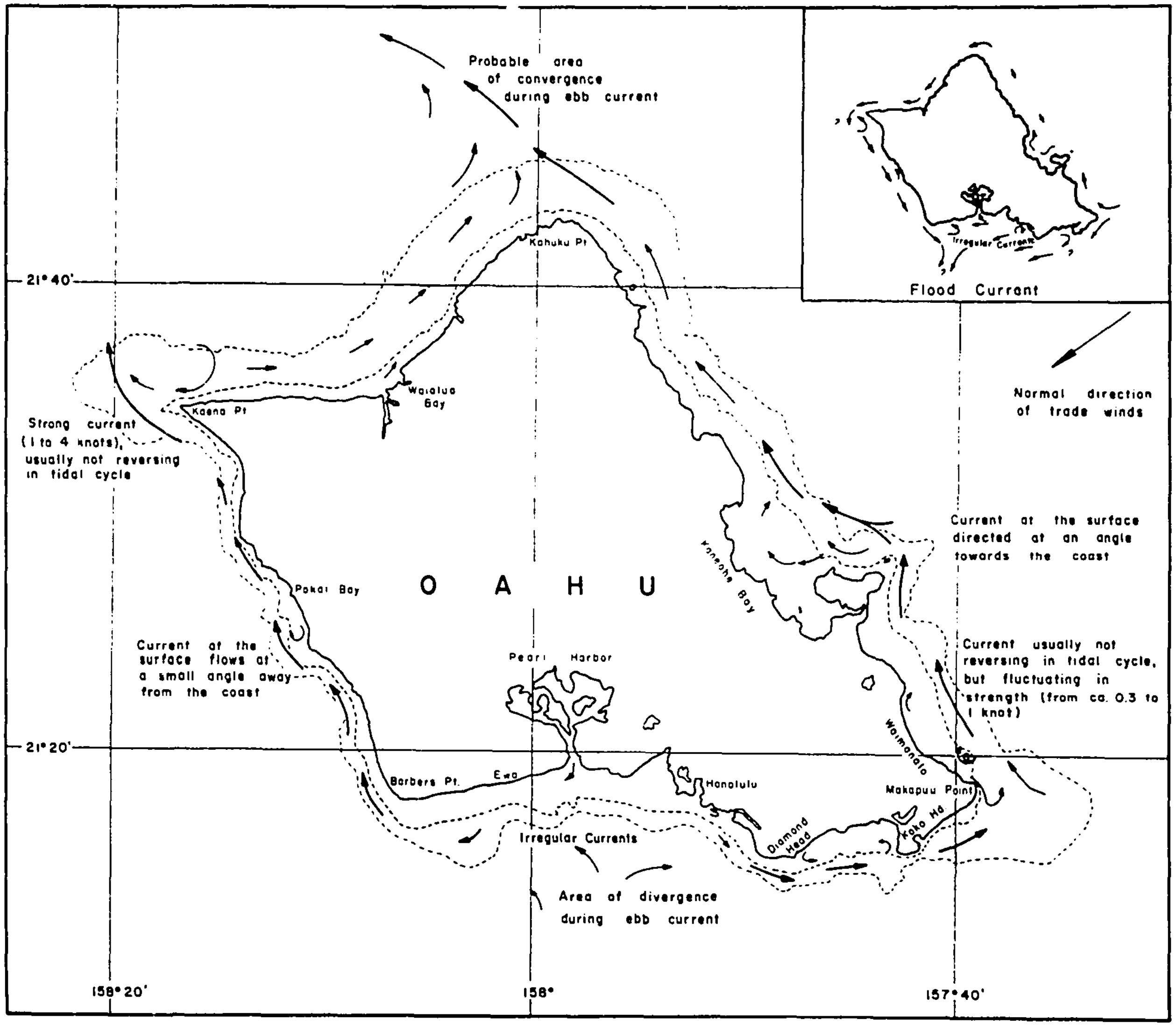


Fig. 111. Generalized ebb current pattern around Oahu during trade wind season. Inset shows generalized flood current pattern. (From Laevastu, Avery, and Cox, 1964)

significant bottom surge action occurs to a depth of 30 m along the Waianae Coast. Winter storm swells actively moved many pipes, smashing some by violent contact (Plate 8) and scouring the exterior sessile communities from others. Even in calm weather, bottom surge was evident at 85 feet (28 m) where certain pipes rolled slowly but continuously in an inshore-offshore path (Plate 9).

Temperatures were measured to within 0.5°C with a mercurial thermometer. Figure IV shows the temperature fluctuations encountered 5 feet (1.6 m) above the substrate on the D-1966 study site. Each value represents the average of three readings taken at intervals during the course of a single dive. The temperature variation between winter and summer was only 3°C, and lowest temperatures occurred immediately after winter storms. No pronounced thermoclines were noted during the study. This agrees with the data of Leipper and Anderson (1950) who found an isothermal layer extending down 262 feet (90 m) in March and 164 feet (50 m) in September.

All salinity samples were taken within 5 feet of the bottom on the D-1966 study area. Salinity, determined primarily by refractometry (American Optical Co., Model 10402), fluctuated very little from the mean of 34.5 ‰ for the year ending in March 1969 (see Appendix Table IVa). This mean was obtained from 27 determinations with a range of 33.9 to 35.2 ‰. The oceanic salinities encountered

Plate 8

Pipe damage after winter storm on the M-1968 site.

Plate 9

Pipe rolling due to force exerted by surface swells at a depth of approximately 85 feet (28 m).

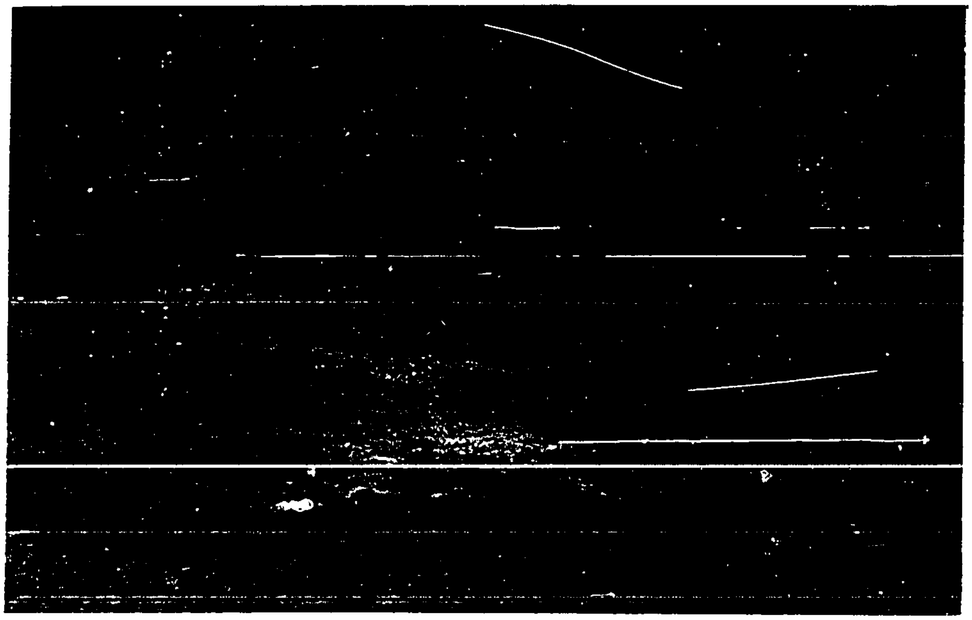
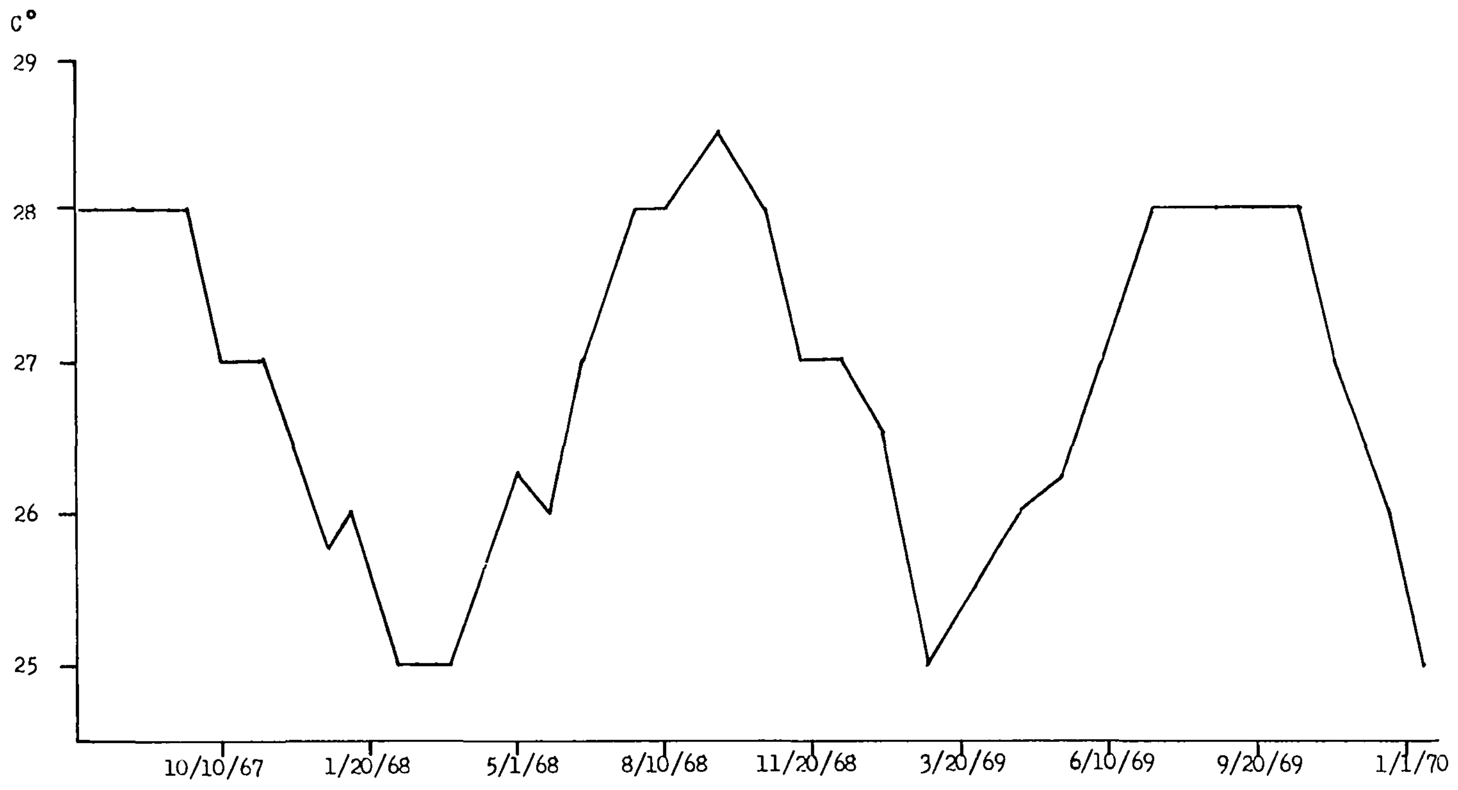


FIGURE IV

Temperatures measured 5 feet above the bottom (60 feet) on the D-1966 study site during the period July 1967 to January 1970

FIGURE IV


C°
29
28
27
26
25
10/10/67
1/20/68
5/1/68
8/10/68
11/20/68
3/20/69
6/10/69
9/20/69
1/1/70

probably did not occasion any changes in the biotic community.

CHAPTER III

COLONIZATION OF A NEW REEF (M-1968)

The M-1968 study area was the only one that could be studied both before and after pipes were deposited. As a result, the majority of the observations concerning colonization and succession were centered around this location. Comparisons were made between older study areas (D-1966 and A-1964) and the biotic communities developing on the M-1968 pipe increment. Useful information was obtained from these older areas with respect to the composition of mature communities and possible variations of biota with depth.

Pipes contained in the M-1968 study area were purposely deposited at a distance from the existing reef (cf. Fig. II) so that a study could be made of a natural area before any artificial substrates were added to the environment. This separation also provided an ideal opportunity to study the directional movement of fishes immigrating onto a new artificial reef.

Odum (1959) described a biotic community as "any assemblage of populations living in a prescribed area or physical habitat." The physical habitat available on the natural area (mainly coral rubble over rock) prior to the pipe deposit limited the existing diversity of organisms. This biota was associated either with the low relief of the natural substrate (benthos) or with the water mass (nekton and plankton).

The benthos may be divided into three main categories (Odum, 1959): that attached to the hard substrate (sessile invertebrates and algae), that which crawled over the substrate (mobile invertebrates), and that which lived in bottom sediments (both sessile and mobile biota). Those invertebrates which lived in bottom sediments were relatively unimportant as colonizers of new reef substrates and therefore will not be considered as colonizers in this study.

Sessile invertebrates as well as most mobile invertebrates and fishes spend at least part of their life cycle as members of the plankton. The sessile biota found on the pipe surfaces of the artificial reef must originate from immature stages settling out of the plankton. The larval stages of mobile invertebrates and juveniles of fishes may also settle out of the plankton onto the artificial reef. Mature mobile invertebrates and fishes may immigrate to a new area if it provides suitable habitat.

Analyses of the natural communities of plankton, sessile invertebrates and fishes as possible sources for colonization are presented in this chapter.

Colonization by Invertebrates.

Invertebrate colonization of the new artificial substrate was inferred from indirect evidence such as plankton tows and censuses of sessile invertebrate communities in the vicinity of the reef, as well as direct observation of developing invertebrate communities on the pipe substrates. Plankton tows were made twice a month during the initial colonization time to see what invertebrates were available for colonization. Surface tows were made from a boat, and sub-surface tows were made by two divers pulling a plankton net (Plate 10).

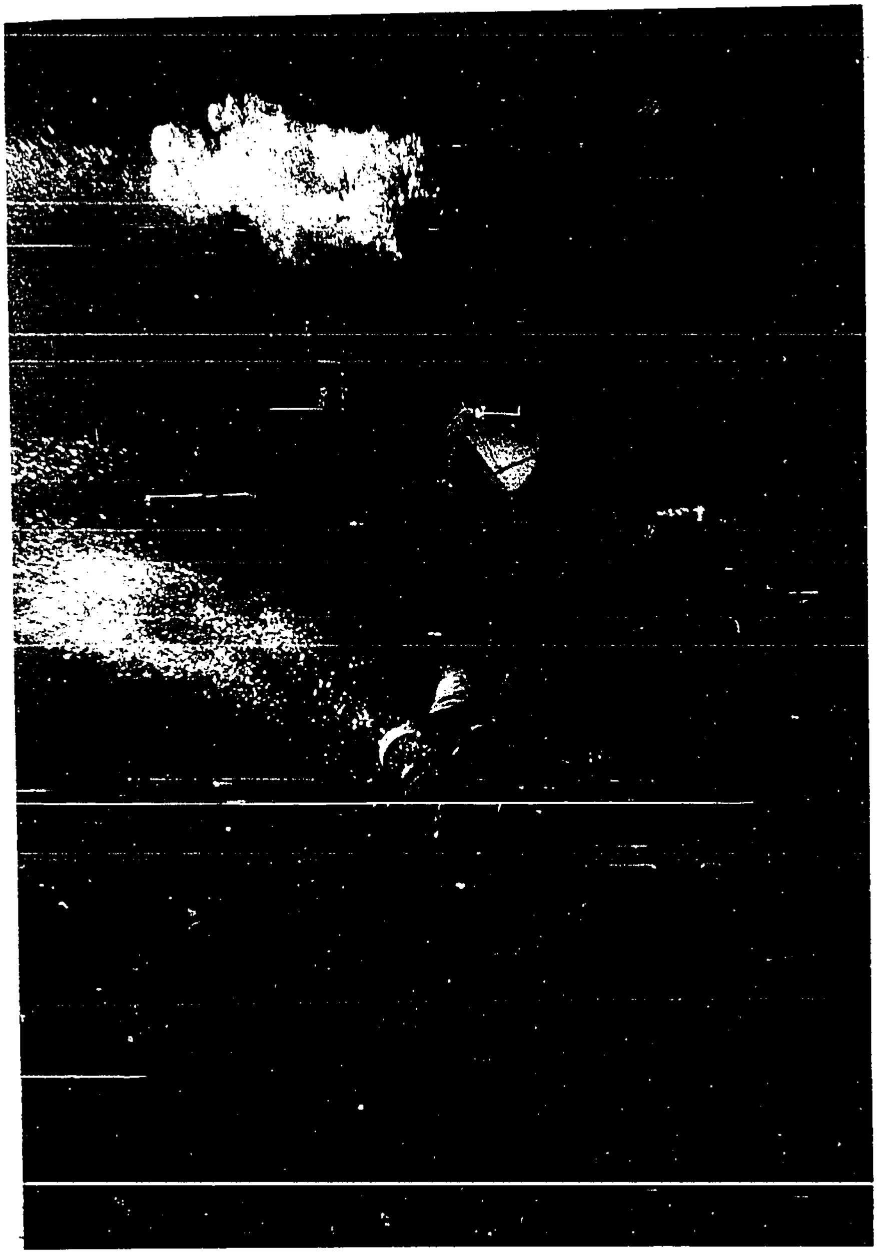
The relative abundance of plankton varied with the time of year. Copepods were the most common planktonic form in all months. Next in abundance were those appearing as follows: September and October--gastropods and bivalve veligers; November--fish and crab larvae; December--annelid larvae; January--shrimp larvae and fish eggs; February and March--gastropod and bivalve veligers; April--crab and shrimp larvae; and May through August--fish and invertebrate eggs.

The biota most often encountered, in a descending order of abundance, were: copepods, bivalve veligers, gastropod veligers and protoconchs, fish and mollusk eggs, crab megalops, shrimp mysids, annelid larvae, tunicate larvae, coral planulae, sponge gemmules, barnacle nauplii, and larval fishes as well as organisms that were not potential colonizers such as ctenophores, lucifer shrimp and chaetognaths.

The sessile invertebrate community was sampled by making ten random grid counts ($\frac{1}{4}m^2$ each) on the natural substrate

Plate 10

Hand towing a net ensures that plankton are sampled at the desired depth and locality.



of the M-1968 site before the pipe deposit. Figure V shows the average number and percentage of coverage of the most abundant organisms or colonies of animals for these grid counts. Isolated sponge and bryozoan colonies were counted as single organisms in the enumeration on the right-hand side of the figure. Organisms occupying a significant portion of the grid area are included in the estimate of per cent coverage on the left side of the figure. The annelids, occupying an average of 10% of all grid surfaces, were found after removing the thin layer of sand which covered the hard rock surfaces. These sand-tube annelids were not found on the pipe surface because it does not provide such habitat. The enteropneust, Ptychodora sp., and the majority of sponges censused were also associated with this sand layer and were not found on the elevated substrates of the artificial reef. However, the species of corals, bryozoans and algae censused in the random invertebrate counts on the natural substrate were later observed on the introduced pipe surfaces.

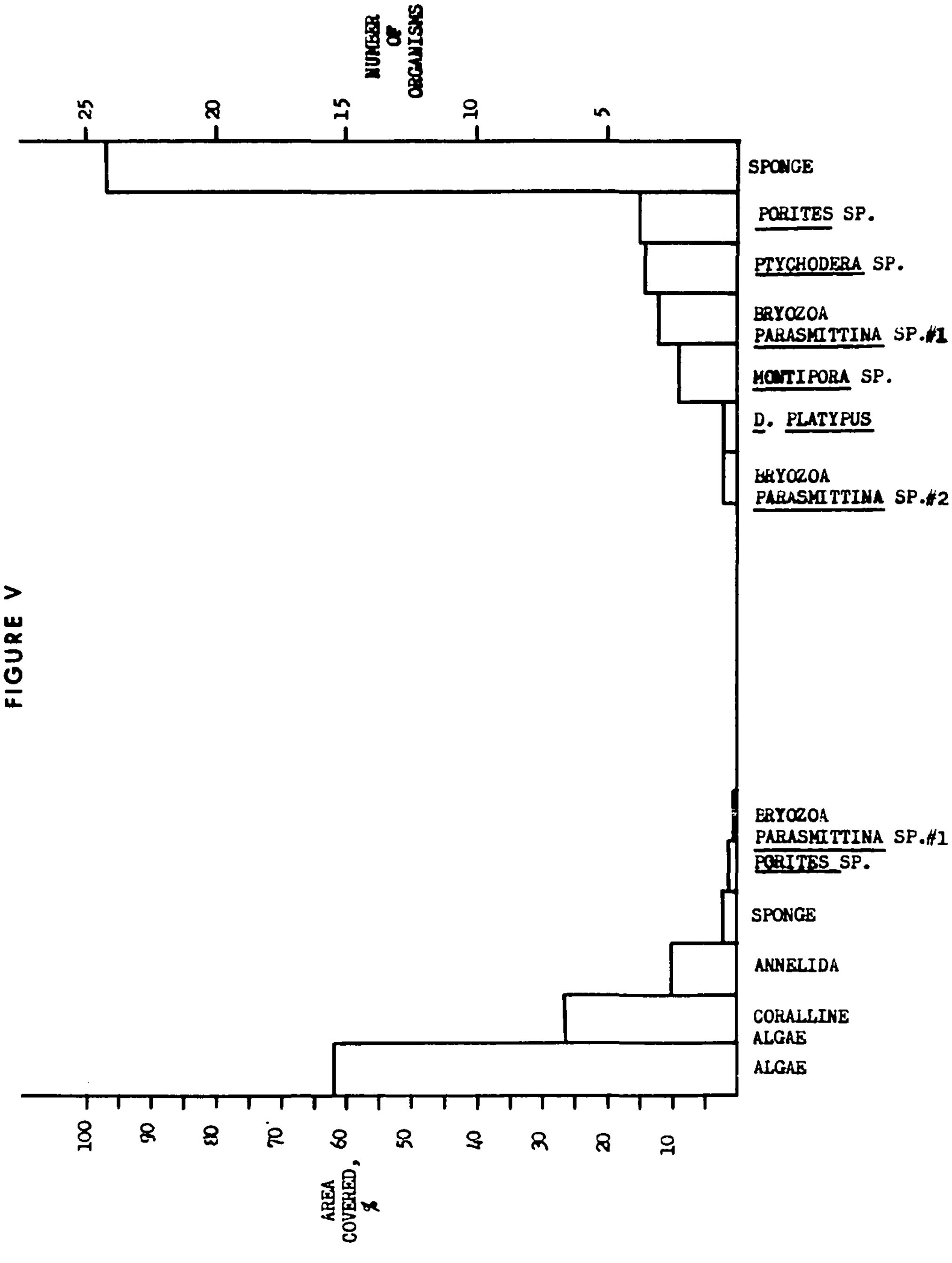
Colonization by Fishes.

In previous studies of artificial reefs, no attempts were made to determine the direction from which fish immigrated to the new substrates. The M-1968 pipe increment was purposely separated by 200 m from the rest of the artificial reef areas to determine their pattern of movement

FIGURE V

Most common epilithic organisms on natural substrate at M-1968 site before pipe deposit expressed in numbers per $\frac{1}{4}m^2$ and relative area covered.

FIGURE V


NUMBER OF ORGANISMS
25
20
15
10
5
SPONGE
PORITES SP.
PTYCHODERA SP.
BRYOZOA PARASMITTINA SP.#1
MONTIPORA SP.
D. PLATYPUS
BRYOZOA PARASMITTINA SP.#2
BRYOZOA PARASMITTINA SP.#1
PORITES SP.
SPONGE
ANNELIDA
CORALLINE ALGAE
ALGAE
100
90
80
70
60
50
40
30
20
10
AREA COVERED, %

onto the new reef. Forty-nine species were tagged, 747 fishes before the pipe drop and 155 fishes after the pipe drop. Colored tags were used to designate each of the four surrounding quadrants. See Table IIIa in the Appendix for the number of fishes tagged for each species.

Observations were then made to determine if the fishes moved onto the area from offshore, inshore or longshore positions. Two types of tags were used to mark the fishes. The majority of tags were of the dart design (Plate 11) implanted into the fishes with a special tagging gun (Floy Tag and Manufacturing, Inc. FD-67 tagging gun). The remainder were Petersen disk tags (Plate 12) applied according to the method of Randall (1956).

Specimens were obtained for tagging by as many methods as possible to assure that a wide spectrum of species were sampled. Most were taken in fish traps, many were caught with hook and line and some were gill-netted. *Myripristis berndti*,[1] schooling fish that shelter within pipes during the day, was captured by having divers scare them through a pipe and into a gill net secured at its far end. In this case the fish were tagged underwater with the tagging gun and released immediately.

Tag retention was very poor with the dart tags. Many fishes were observed with lesions in their flesh where the

---

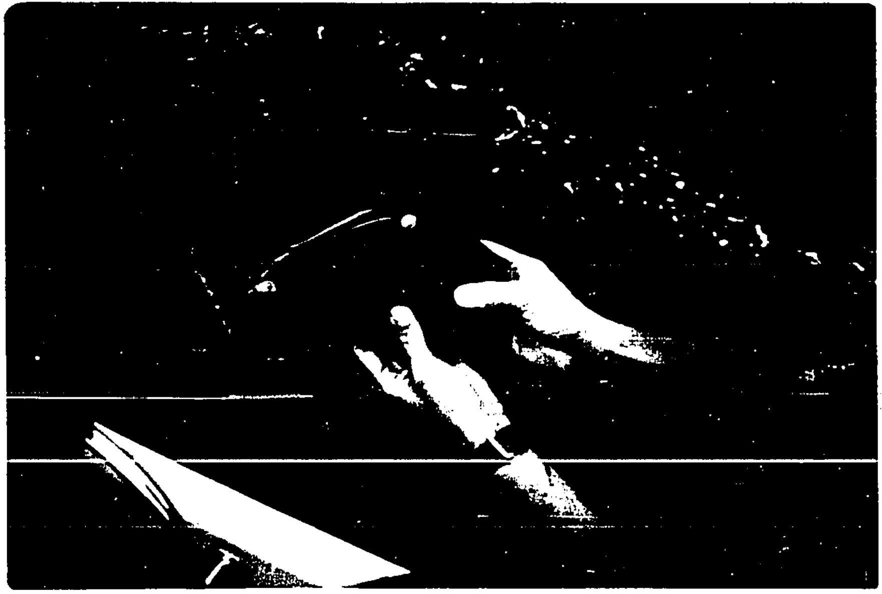
[1] Species name *Myripristis berndti* is in the process of being changed to *M. murdjan* (D.W. Greenfield, in press).

Plate 11

Chromis verater with attached dart tags.

Plate 12

Naso lituratus with color coded Petersen disk tag.



tags had fallen out, and detached tags were found on the bottom. Other fishes were observed picking at the tags and at the small wound where the plastic streamer pierced the skin. Another problem developed when diatoms coated the tags obscuring their color and thereby negating the code system. Fishes had to be speared and the tags cleaned to make positive identification.

Table I summarizes the fish tagging and sighting data. All tagging operations were within 600 feet (182 m) of the pipe increment, and the fishes observed must have come from within this radius. The results indicated very little movement of tagged fishes. Only two species (7 specimens) appeared on the M-1968 site from the surrounding area. *Parupeneus multifasciatus* was most frequently observed and came onto the area from all but the offshore quadrant. The more frequent appearance of this species could be expected as more specimens (153) were tagged. The fact that only 15 specimens of *Bodianus bilunulatus* were tagged and that two specimens from different quadrants appeared on the M-1968 area may indicate that this species is inclined to move onto new reef areas.

TABLE I. Fishes tagged near and sighted on the M-1968 study area.

Tagging	Number Tagged		Tag returns--fishes observed M-1968 site
	Individuals	Species	
Maile Point quadrant	164	22	*Parupeneus multifasciatus* *Bodianus bilunulatus*
Kaena Point quadrant	285	41	*P. multifasciatus* (2)
Offshore quadrant	272	21	*B. bilunulatus*
Inshore quadrant	127	18	*P. multifasciatus* (2)
M-1968 site	53	12	*Chaetodon fremblii* (2) *P. multifasciatus*

Schooling surgeonfishes, such as *Naso lituratus*, *Naso unicornis*, *Naso brevirostris*, *Acanthurus olivaceus* and *Acanthurus nigroris*, were responsible for the initial upswing in new reef biomass. These species were not observed in large numbers in any of the tagging quadrants, and they probably came onto the reef site from without the tagging radius. This agrees with Bardach's (1959) observation that schools of surgeonfish covered large distances due to their browsing habits, and with Odum and Odum (1955) who noted that the larger herbivores traveled in schools and ranged widely.

Those species depending on the substrate for shelter were frequently observed on the home areas where they were tagged. Chaetodon fremblii, Chaetodon miliaris, Chromis verater, Dascyllus albisella, Ctenochaetus strigosus and Zebrasoma flavescens were sighted in the immediate area in which they were tagged. One marked specimen of Cheilio inermis was sighted on the deepest section of the reef over 600 feet from the tagging station.

Summary and Conclusions.

Colonization by fishes of the new habitat offered by the artificial reef was in most instances a matter of immigration. The primary factors inducing this immigration appeared to be shelter, increase in food, and orientation to a higher topographical relief.

The majority of invertebrate life observed on the pipe substrates was recruited from the plankton and the surrounding substrates. The composition of the pioneer communities apparently depends upon the time of year that substrates are immersed, or in other words, the composition of the plankton at any specific time.

Data resulting from the fish tagging seem to indicate that species in natural areas adjacent to an artificial reef do not necessarily migrate to the new area. Browsing species that do not depend upon the substrate for shelter tend to arrive on the reef before resident species. These itinerant schooling species may come onto the new area from fairly great distances (over 600 feet).

CHAPTER IV

SUCCESSION OF ALGAE AND INVERTEBRATES ONTO A NEW REEF

Of the three life zones censused on the pipes, only the exterior top surface and the interior roof of the pipe will be discussed in this chapter. The communities found in these two zones were compared because they showed the greatest differences in speciation. This dissimilarity appeared to be due to differing amounts of available light and to orientation of the substrate which affects larval settlement. The community on the side of the pipe where it met the substrate consisted of a mixture of forms from the exterior top and interior roof of the pipe, both in numbers and species composition. In the crevice formed at this juncture there were many small crabs, shrimps, and mollusks important to the food web of the reef. These mobile invertebrates are discussed in Chapter VI, Section D.

Permanent and random grid counts of macroscopic organisms as well as microscopic examination of glass slides were the methods used to determine the succession of algae and invertebrates onto the Pokai Artificial Reef. The results obtained from grids on newer substrates and from glass slides were combined with the grid data from the oldest station to give a fairly complete picture of sessile invertebrate communities and their sequence of succession. Glass slides were used for investigation of colonizing diatoms, but algal succession on the top surfaces of pipes was determined by collecting algae from dated surfaces rather than by grid counts.

Algal Succession.

Algae predominated on the top surfaces of pipes. In order to establish the successional sequence, algae were collected periodically from dated substrates. A complete list of all species found on the pipes is included in the Appendix.

The algal community structure varied depending upon time of year (i.e., amount of solar radiation, etc.) as well as the point in successional sequence. Because of variations in algae available for settling, the month at which a substrate was immersed probably was important in determining the initial algal community. For instance, pipes dropped in March 1968 showed a heavy growth of the red alga *Asterocytis ramosa* which attracted large numbers of herbivores (Plates 13 and 14), while pipes dropped in November 1969 showed only a bloom of blue-green algae and diatoms which attracted relatively few grazers.

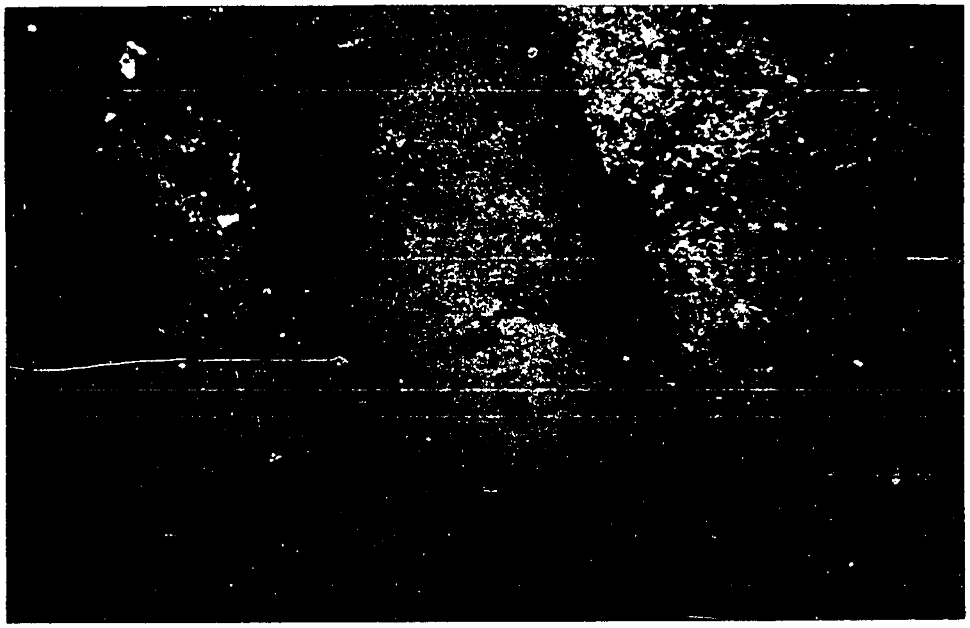
The first algae found on the pipes were diatoms. The most common were *Nitzschia closterium*, *Biddulphia mobiliensis*, *Synedra undulata*, *Climacosphenia moniligera*, *Thallasiothrix* sp., *Fragilaria* sp., *Coscinodiscus* sp., and Naviculoid diatoms.

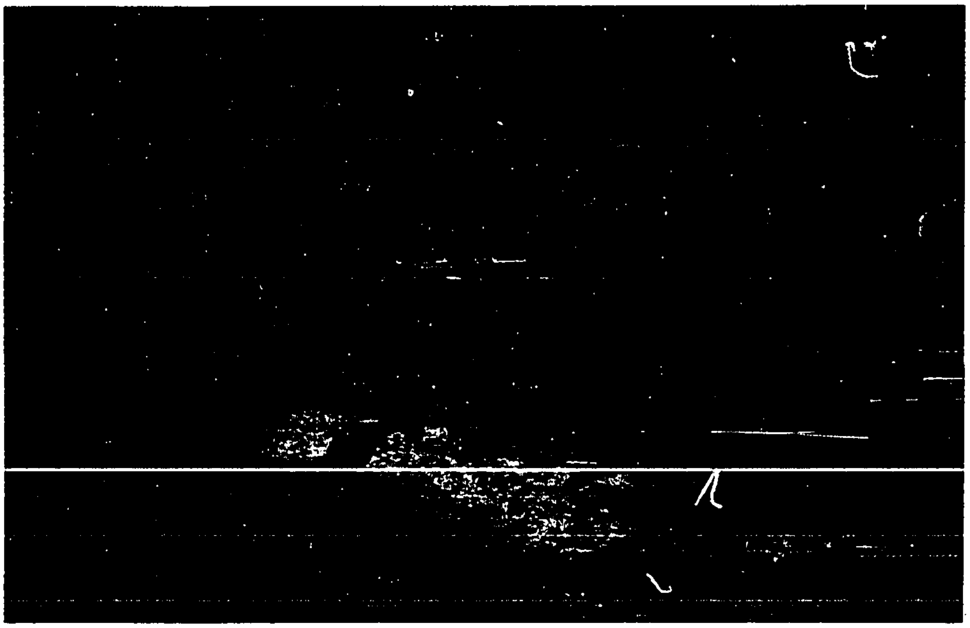
Plate 13

The urchin *Tripneustes gratilla* grazing on the algae *Asterocytis ramosa* on the M-1968 site.

Plate 14

An aggregation of *Acanthurus olivaceus* grazing on a heavy growth of *Asterocytis ramosa* on the M-1968 site.





Thereafter, the most common forms were the brown alga *Dictyota* sp., the red alga *Herposiphonia* sp. and the blue-greens *Schizothrix calcicola* and *Lyngbya majuscula*. If, as on the M-1968 site, an alga such as *Asterocytis ramosa* became dominant immediately after immersion, it usually was grazed and eventually replaced by a community composed principally of blue-greens such as *L. majuscula* and *S. calcicola*. Jones (1969) and Randall (1961a) made the observation that fishes prefer to feed on the reds and algae other than the blue-greens. This preferential feeding is probably the reason that the standing crop of algae on the Pokai Artificial Reef was composed primarily of blue-greens--the fishes selectively grazed on the other groups leaving the Cyanophyta behind.

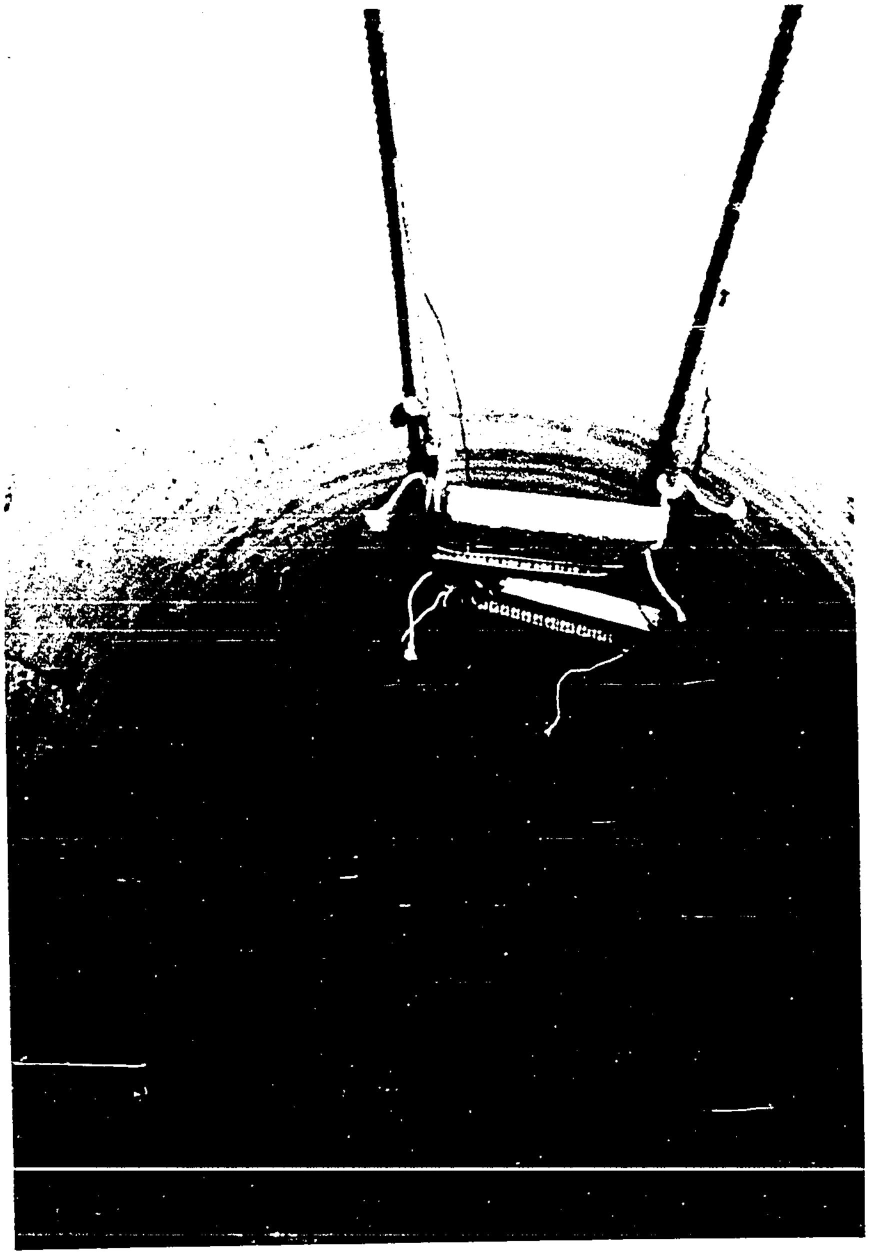
In older communities, coralline algae (Lithophylleae) became evident on the upper surfaces of the pipes. These formed round crustose colonies one to two centimeters in thickness.

Succession Observed on Glass Slides.

Tared glass slides were placed in five slide boxes and secured to the inside roof of a pipe (Plate 15). These were taken up after 1, 2, 4, 8 and 16 weeks respectively. Each slide box was duplicated by a box covered with plastic screening to reduce predation and grazing. Half the slides from each slide box was censused for organisms, while the

Plate 15

Boxes of glass slides secured to the inside roof of a pipe on the M-1968 study site.



other half was dried in an oven at 80°C, weighed, then ashed and reweighed to quantify total dry residue and its components: ash weight and ignition loss. The weight of material lost in ignition was primarily organic carbon while the ash weight was composed of mineral matter. Besides giving an indication of what was settling out of the plankton onto pipe surfaces during this time, this method allowed an estimate of the successional sequence and amounts of inorganic carbon and organic carbon fixed by invertebrates with time.

Macroscopic and microscopic examinations of the glass slides were used in conjunction with the data obtained from pipe surfaces to form a more complete picture of early succession. Slides taken up after 5 days showed an abundance of marine ciliates, foraminifera and diatoms as well as an occasional oyster spat. After 12 days hydroid colonies (*Campanularia* sp.) containing up to 34 polyps, bryozoan colonies containing up to 11 polyps and oysters ranging up to 1.25 mm in diameter were present on the slides. After 26 days, maximum hydroid polyp numbers per slide increased to 400, Bryozoa polyps to 65 and oysters attained a diameter of 2 mm. Serpulid worms and the tunicate *Didemnum candidum* appeared on the surfaces. At this time, hydroid colonies were producing medusae which would be available later for settling and colonization. An unidentified aeolid nudibranch was found associated with and feeding upon the hydroid colonies. This pattern of hydroid growth and predation by a specific nudibranch on artificial substrates was also followed by Turner (1962a) in California. After 56 days calcareous sponges, sabellid worms and occasional solitary tunicates (Ciona sp.) were observed on the glass slides. At this time, Bryozoa and tunicates spread to cover fairly large areas of the surface. These data agree with the trend of events described for fouling in marine waters (Woods Hole Oceanographic Institute, 1952; Edmondson, 1944; Long, 1969).

Table II shows the amount of organic and inorganic matter fixed or captured by periphyton on glass slides secured to the inside roof of a pipe. Biomass estimates are in grams per m^2 for the indicated time of immersion. Both the slides open to grazing (open) and those protected by plastic screening (closed) are represented. These data indicate that protective screening kept more biota from settling on the slides than it protected from predation. This estimate of material fixed by the invertebrates found on the interior of pipes does not take into consideration the greater growth of organisms along the edge of slides, and there were slight losses of material due to handling. This estimate is only an indication of biotic contribution from the organisms on the roof of the pipes to the mass of the reef. Judging from the older pipe community, the oyster would probably be the most important contributor to this biomass.

TABLE II. Biomass development on glass slides with time as indicated by gravimetric analyses.

Days Immersed	Ignition Loss*		Ash Weight*		Total Dry Residue*	
	Opened	Closed	Opened	Closed	Opened	Closed
12	.022	.024	.044	.085	.065	.108
26	.075	.035	.365	.190	.439	.224
56	.107	.175	1.332	1.204	1.439	1.378

*All values in grams per square meter.

Sessile Invertebrate Succession on Principal Life Zones.

The random and permanent grid counts used to study invertebrate successional sequence were made on pipes of varying age (Plate 16). The oldest grid counts were made on pipes deposited in April 1964. Invertebrate communities on these substrates were assumed to be in climax condition. However, the movement of some pipes during storms destroyed their attached biota. When these pipes later rested in a secure position, a new community developed. Random grid counts were, therefore, restricted to those pipes that obviously had not moved since the inception of this study. An unmoved pipe was recognizable by the advanced degree of development of the sessile invertebrate community.

Random grid counts were accomplished by using two grids. Both were one-fourth meter wide by one meter long; one was of wood, the other of metal. The wooden grid was used on

Plate 16

Enumerating epilithic macrofauna in a randomly placed quarter-meter grid.

the interior roof of the pipes where flotation helped to hold it in place. The metal grid was used on the exterior of the pipes.

Monthly counts were made of the two biotic zones described earlier. Whenever possible, the number of individuals of a particular species was recorded on an underwater writing slate. Enumeration of individuals was not possible for certain colonial organisms (e.g., bryozoans and compound tunicates) and their abundances were estimated only in percentage. A complete enumeration of all species was found impractical for underwater observations although most of the macroscopic invertebrates were tallied.

Many micro-mollusks, vermetids, mesogastropod limpets, and various corals were associated with the algal community on the surfaces of pipes. Occasionally there were colonies of a grey compound tunicate, a white bryozoan (probably Steginoporella sp.) and solitary oysters Ostrea hanleyana.

Figure VI compares the relative abundance of the four most abundant organisms with time on the top of the pipes: the corals Pocillopora meandrina and Porites lobata, the mesogastropod limpet Hipponix pilosus and the vermetid mollusk Dendropoma platypus on the M-1968 study area. The histogram on the right of Fig. VI gives a direct comparison for the same organisms found on the substrates at the A-1964 study site at the end of the study. Figure VII follows the same organisms on the D-1966 site during the study. Height

FIGURE VI

The abundance of the corals Porites lobata and Pocillopora meandrina, the mesogastropod limpet Hipponix pilosus and the vermetid Dendropoma platypus on the upper exterior surface of the M-1968 pipes as a function of time. The inset shows comparable values for these organisms on the A-1964 site for the last census in November 1969. The vertical scale is the same for both sets of data, and the arrow at the base of the graph indicates when the pipes were deposited on the M-1968 site.

FIGURE VI

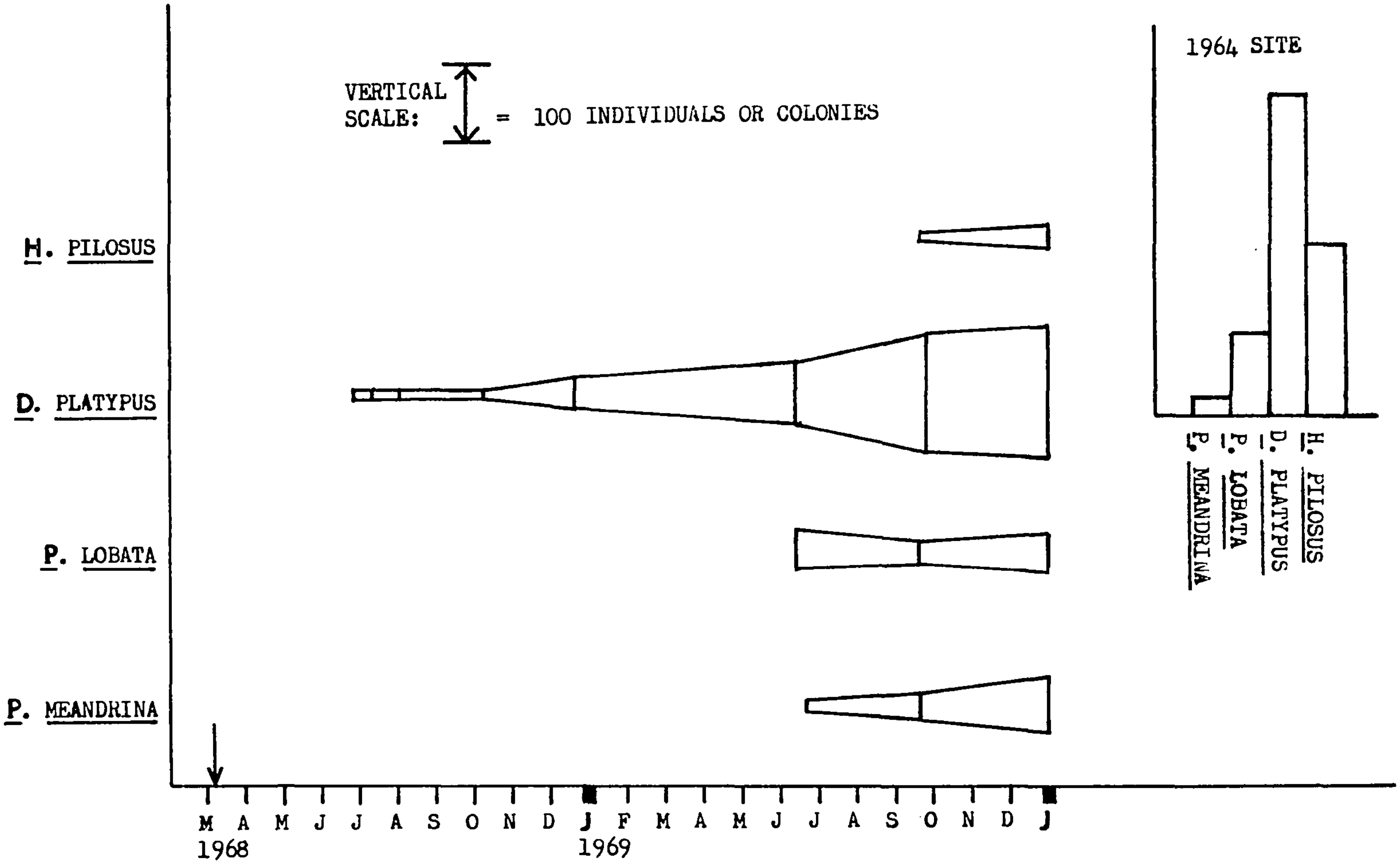
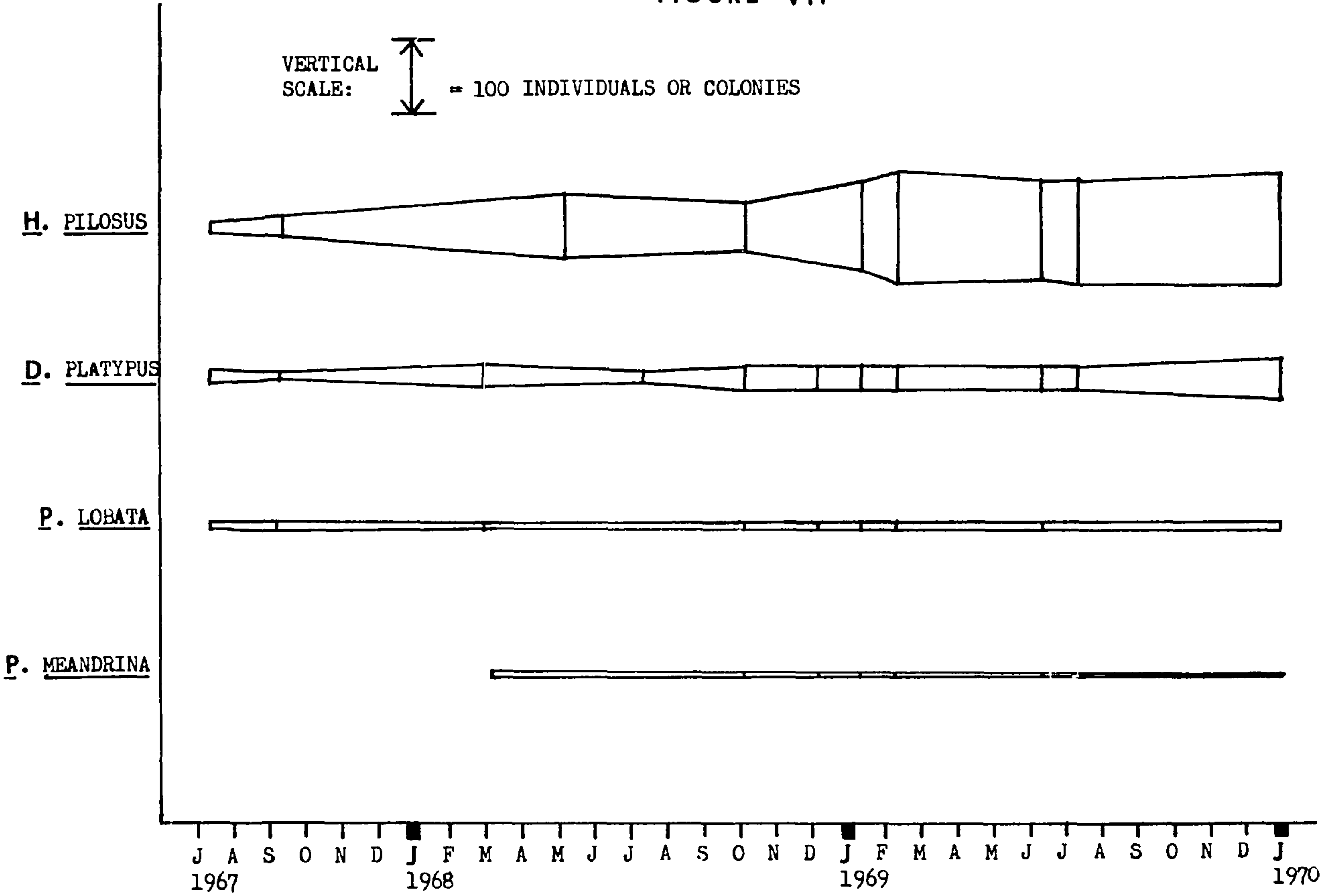

VERTICAL SCALE: = 100 INDIVIDUALS OR COLONIES
H. PILOSUS
D. PLATYPUS
P. LOBATA
P. MEANDRINA
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
1968
1969
1964 SITE
P. MEANDRINA
P. LOBATA
D. PLATYPUS
H. PILOSUS

FIGURE VII

The abundance of the corals Porites lobata and Pocillopora meandrina, the mesogastropod limpet Hipponix pilosus and the vermetid Dendropoma platypus on the upper exterior surface of the D-1966 pipes as a function of time.

FIGURE VII


VERTICAL SCALE: = 100 INDIVIDUALS OR COLONIES
H. PILOSUS
D. PLATYPUS
P. LOBATA
P. MEANDRINA
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
1967
1968
1969
1970

of the vertical component represents the number of organisms observed. For both graphs, each datum point represents the average of two to five grid counts.

The initial sequence of sessile biota settling on pipe surfaces is shown in the data for the M-1968 site, where community development was followed from the beginning. The vermetid, Dendropoma platypus, appeared on the pipes in June and increased in numbers steadily thereafter. A grey compound tunicate (not represented graphically) also appeared in large numbers but by the end of the summer had disappeared due, in part to grazing by fishes and general atrophy. Not until June 1969, were the two corals, Pocillopora meandrina and Porites lobata, noted on the pipe surfaces, while the mesogastropod limpet Hipponix pilosus was not found until October 1969, 20 months after the substrate was immersed. In looking at the data for the two older stations, one finds that once corals became established the number of colonies on any pipe increased very slowly with time while the numbers of Hipponix pilosus and Dendropoma platypus increased at a greater rate.

The bryozoan Steginoporella sp., among others, is characteristic of the early sessile community found on exterior lateral surfaces of pipes.

The greatest diversity of sessile biota was found on the inside roofs of pipes. A difficulty arises in analysis of the data in that some organisms were better represented by estimating their per cent coverage while others were tallied by counting individuals. Because of this, there are two graphs for both the D-1966 and M-1968 study sites (Fig. VIII-XI, inclusive); one illustrates relative surface and the other, enumeration. Each datum point is the average of two to five grid counts at that zone on the pipe. Again, the data obtained on the oldest substrates would have been too repetitious to relate to a time sequence, and the end point in data has been included on the graphs with the M-1968 study area as a direct comparison of a young community to an older one.

The first organisms that became noticeable on the inside of pipes were hydroids. On the M-1968 site they appeared within 5 days as solitary individuals which eventually sent runners in all directions. These stolens and the stalks of upright polyps acted as a matrix which caught both organic and inorganic sediments (Plate 17 A). Diatoms adhered to the bases of hydroids and attached to pipe surfaces adding mass to the periphyton community.

Figure IX indicates that the oyster, Ostrea hanleyana; the bryozoan, Phidelopora sp.; and the compound tunicate Didemnum candidum appeared within 3 weeks on the M-1968 substrates. The above organisms were scattered evenly throughout the hydroid colonies (Plate 17 B). Other bryozoan species were present after 5 weeks, and calcareous sponges were observable after 2 months of pipe immersion.

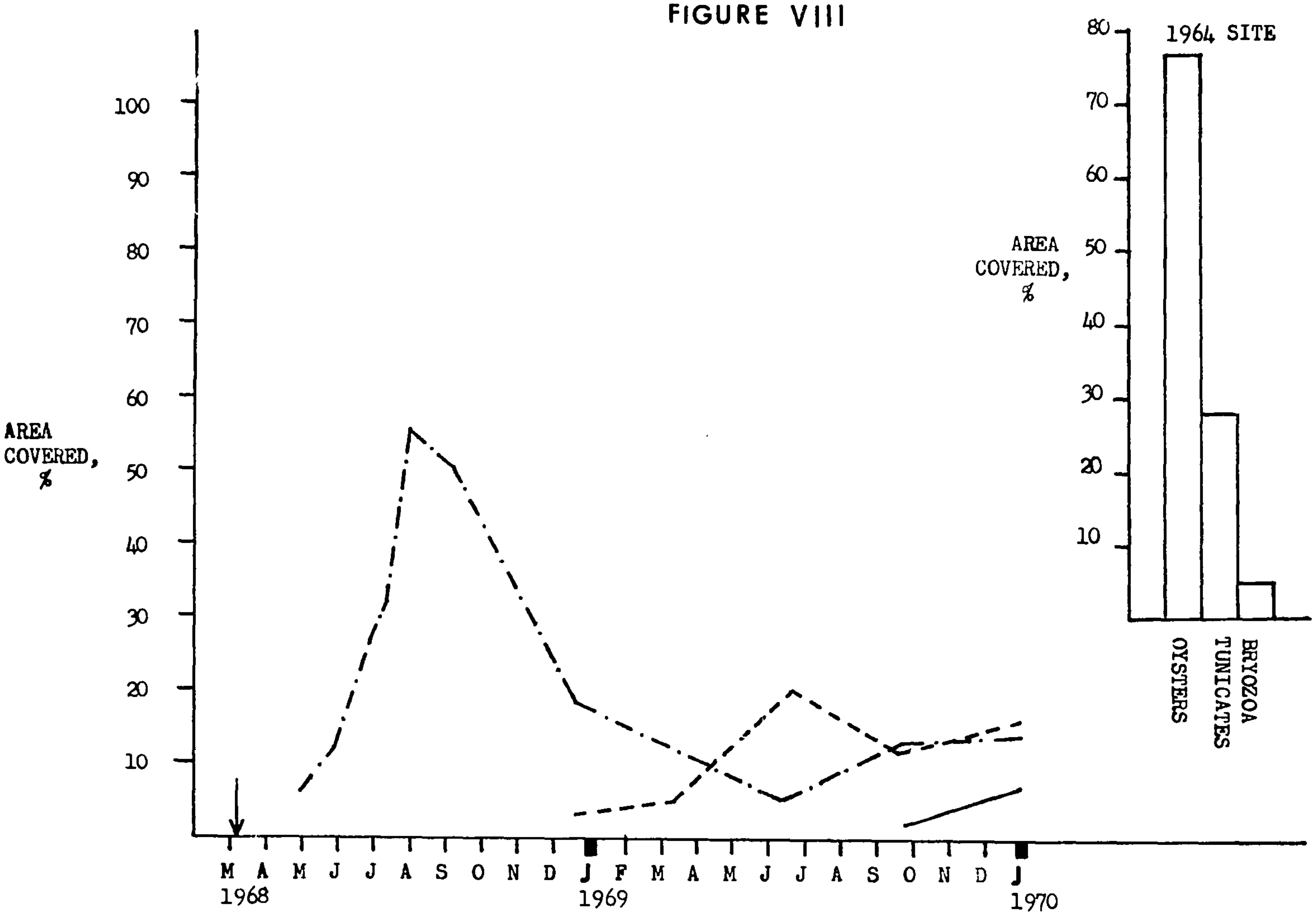
FIGURE VIII

Per cent coverage of encrusting Bryozoa (all species), colonial tunicates and oysters on the interior roofs of pipes on the M-1968 study site. The inset shows the per cent coverage for the same organisms on the A-1964 site for the last census in November 1969. The arrow at the base of the graph indicates when the pipes were deposited on the M-1968 site.

Legend

·—·—·—·—	Bryozoa
— — — — —	Tunicates
————	Oysters

FIGURE VIII



AREA COVERED, %
100
90
80
70
60
50
40
30
20
10
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
1968
1969
1970
1964 SITE
AREA COVERED, %
80
70
60
50
40
30
20
10
OYSTERS
TUNICATES
BRYOZOA

FIGURE IX

The abundance of calcareous sponges, the erect bryozoan *Phidelopora* sp., five principal species of encrusting Bryozoa, the colonial tunicate *Didemnum candidum* and oysters on the interior roofs of pipes as a function of time on the M-1968 study site. The inset shows the values for these same organisms on the A-1964 site for the last census in November 1969. The vertical scale is the same for both sets of data, and the arrow at the base of the graph indicates when the pipes were deposited on the M-1968 site.

FIGURE IX

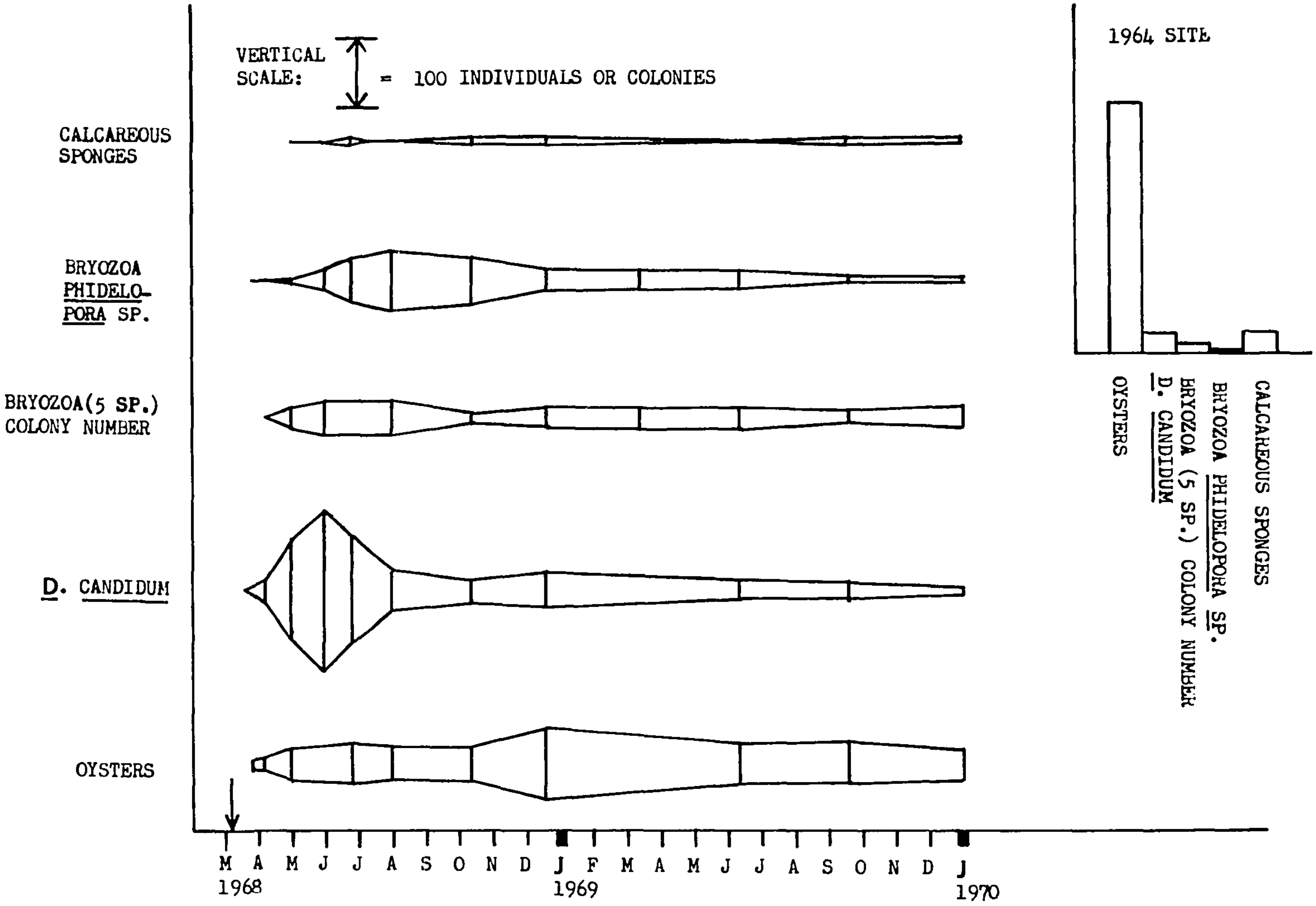

VERTICAL SCALE: = 100 INDIVIDUALS OR COLONIES
CALCAREOUS SPONGES
BRYOZOA PHIDELOPORA SP.
BRYOZOA(5 SP.) COLONY NUMBER
D. CANDIDUM
OYSTERS
M A M J J A S O N D J F M A M J J A S O N D J
1968
1969
1970
1964 SITE
OYSTERS
D. CANDIDUM
BRYOZOA (5 SP.) COLONY NUMBER
BRYOZOA PHIDELOPORA SP.
CALCAREOUS SPONGES

FIGURE X

Per cent coverage of oysters, compound tunicates and encrusting Bryozoa on the interior roofs of the D-1966 pipes as a function of time.

<u>Legend</u>

—·—·—·—	Bryozoa
– – – – – –	Tunicates
————	Oysters

FIGURE X

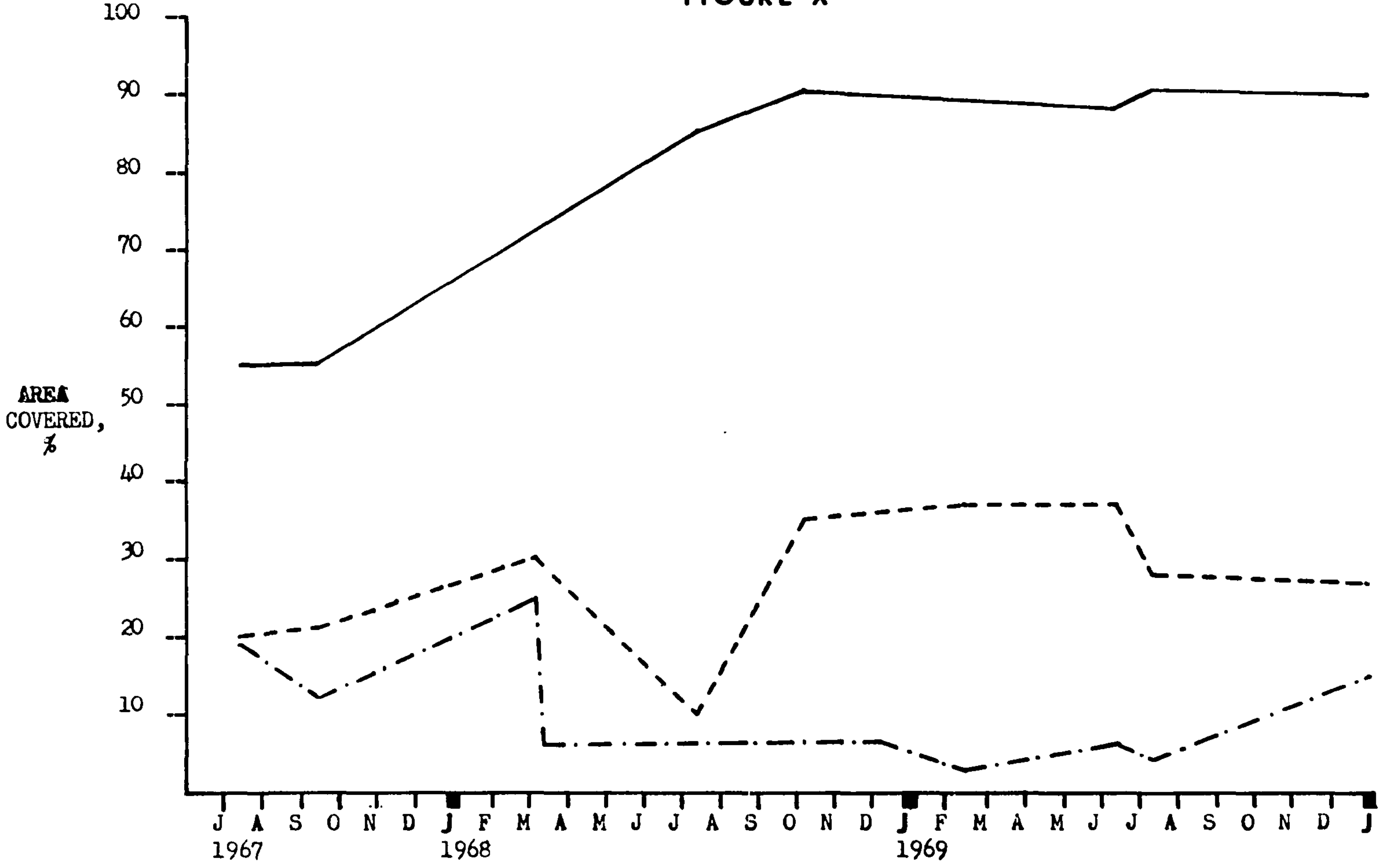
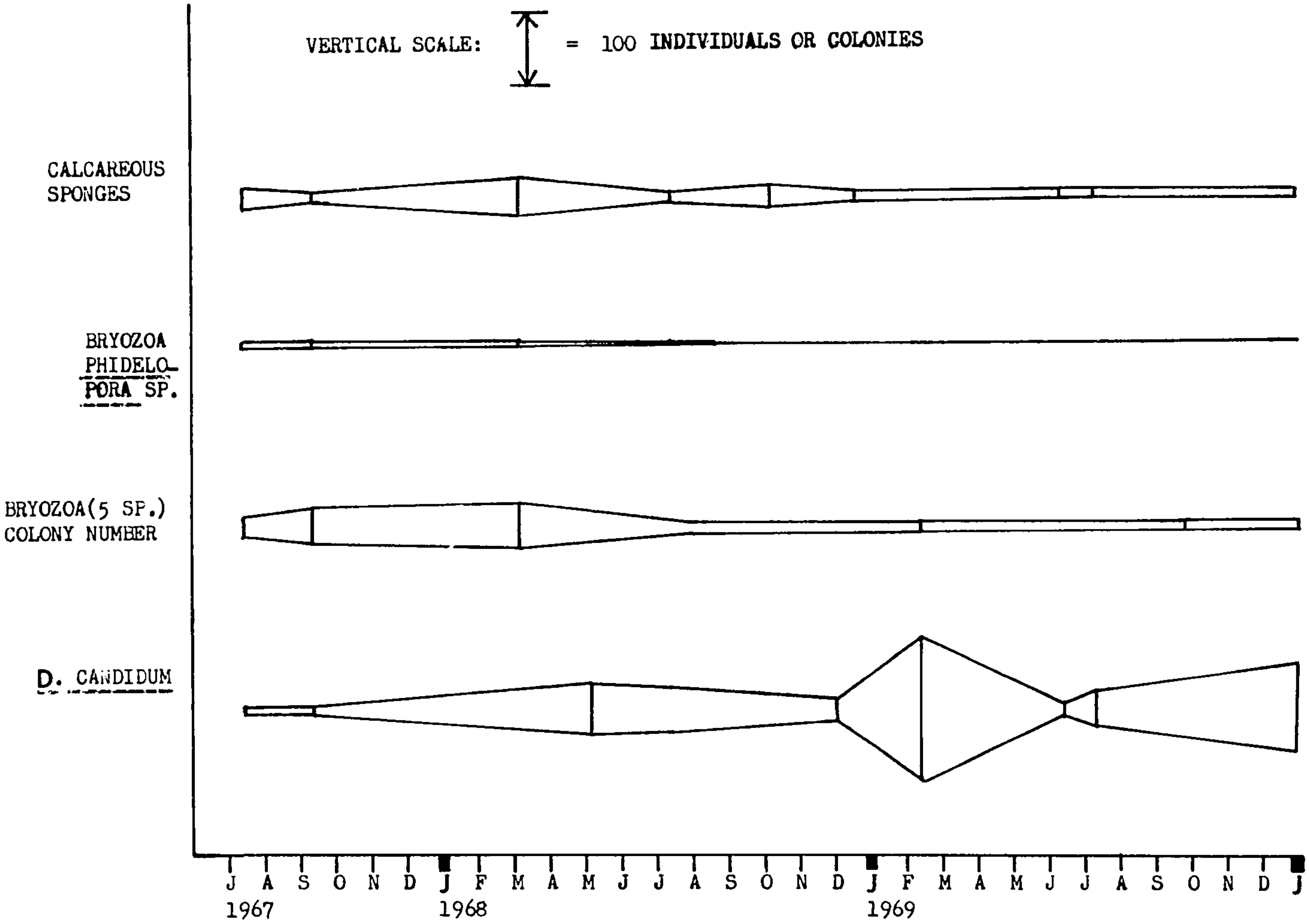

AREA COVERED, %
100
90
80
70
60
50
40
30
20
10
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
1967
1968
1969

FIGURE XI

The abundance of calcareous sponges, the erect bryozoan *Phidelopora* sp., five principal species of encrusting Bryozoa and the colonial tunicate *Didemnum candidum* on the interior roofs of pipes as a function of time on the D-1966 site.

FIGURE XI



VERTICAL SCALE: = 100 INDIVIDUALS OR COLONIES
CALCAREOUS SPONGES
BRYOZOA PHIDELOPORA SP.
BRYOZOA(5 SP.) COLONY NUMBER
D. CANDIDUM
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
1967
1968
1969

Plate 17

Successional stages in the development of an epilithic community on the upper interior surface of a pipe on the artificial reef.

A

At one month, hydroids are dominant. Oysters, tunicates, and Bryozoa, not yet visible, have begun to settle.

B

At 6 weeks, hydroids have spread to cover a large percentage of the pipe surface.

C

At 4 months, Bryozoa are spreading over the substrate. Oysters and the white tunicate *Didemnum candidum* have become visible.

D

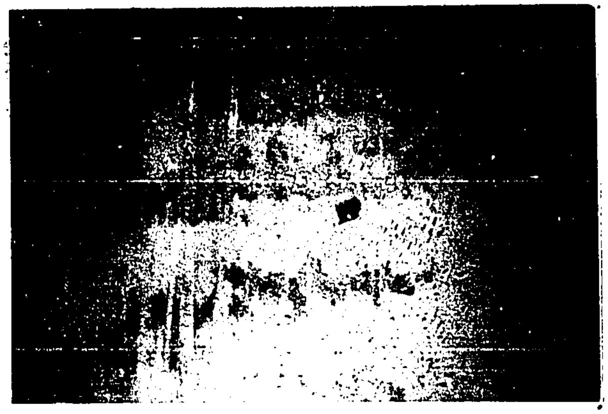
Six-month-old community showing enlargement of oysters, bryozoan colonies and other biota.

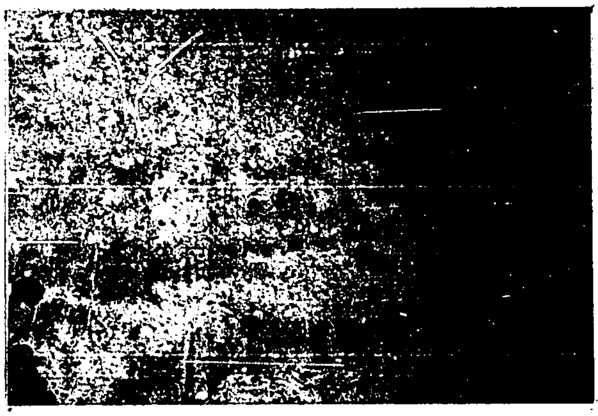
E

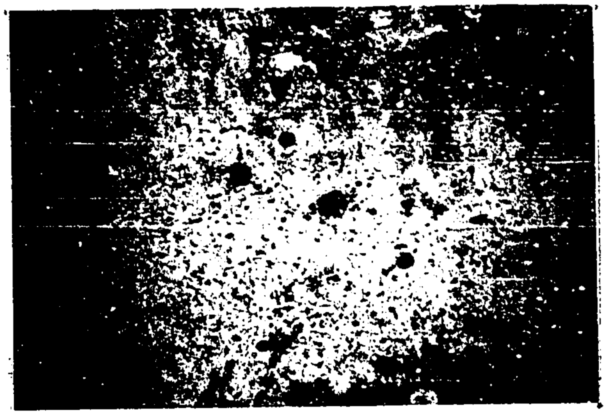
Year-old community showing large *Phidelopora* sp. and *Didemnum candidum* colonies.

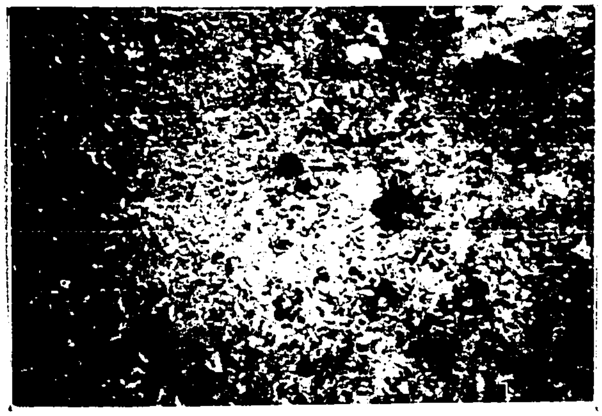
F

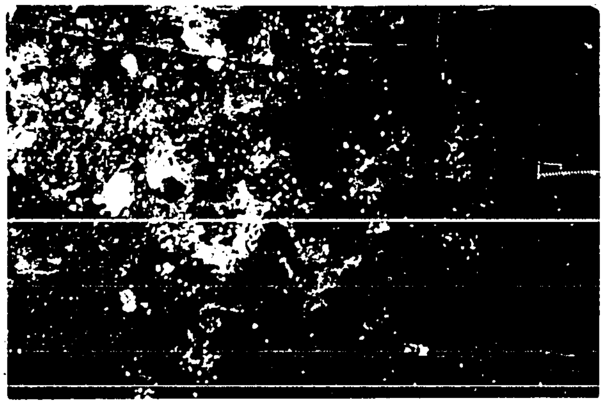
Three-year-old climax community showing abundance of oysters, encrusting Bryozoa and tunicates.

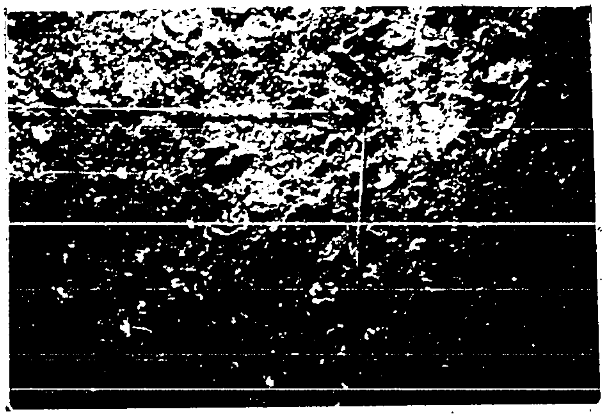












The percentages of organisms (Fig. VIII) could not be determined until the encrusting Bryozoa and tunicates began, after 2 months, to spread rapidly over the pipe surfaces (Plates 17 C, D, E). After 8 months, Bryozoa declined in abundance while a compound tunicate increased its coverage of the pipe surfaces. Oysters were estimated in percentage of coverage after 20 months of substrate immersion (Plate 17 F).

A comparison of the younger communities with more mature ones (Fig. X and XI) and the histograms on the right of Fig. VIII and IX show that oysters tended to increase in numbers and in coverage until they were the predominant life form on the inside roofs of pipes. The many crevices formed by the oysters' irregular growth provided microhabitats in which small shrimps, crabs, and various sessile organisms that contributed to the food web of the reef were found. An unidentified purple compound tunicate also increased to cover a significant percentage of the pipes, and covered the exterior of oyster shells without apparent harm to the animals. After an initial peak, encrusting Bryozoa decreased in numbers until they averaged 5% of the available interior substrate. Sponges, mostly calcareous (Leucetta sp.) but some siliceous, became more abundant in the older communities and were found in the holes between oyster shells. The compound tunicate Didemnum candidum was also found in the niches between oysters.

There are probably many reasons for fluctuations in the abundance of particular species with time. Most variations in numbers may be due to competition or predation. An exception was the bryozoan *Phidelopora* sp. which seemed to be limited by the amount of surge in relationship to the colony size. *Phidelopora* became very numerous soon after substrates were immersed (Plate 6). The colonies grew rapidly, and being erect, delicate forms, they offered a broad surface on which wave force could act. Strong surge action occurring during winter storms wrenched the larger *Phidelopora* off the pipes and settling conditions in older communities were not suitable for re-establishment, presumably because of competition. *Didemnum candidum* and various encrusting Bryozoa also reached a peak within about 3 months of immersion. Fishes (scarids) definitely were seen grazing on Bryozoa, and the urchin *Echinothrix calamaria* rasped over the whole sessile community. This depredation and later crowding by other organisms kept *D. candidum* and encrusting Bryozoa at lower levels than were originally obtained. Occasionally, as can be seen in Fig. XI, conditions were right for an increase in *D. candidum* which seemed better adapted for spreading over previously colonized surfaces than other biota studied.

Summary

A definite succession of biotic communities was found for the two pipe life zones examined in this study. A fairly stable (climax) community was obtained for both life zones after approximately 18 months. The exterior top surface of pipes was characterized by algae interspersed with corals, vermetids, limpets and oysters, while the interior roof of pipes was characterized by oysters interspersed with Bryozoa, tunicates, sponges and hydroids.

In general, the sequence of animals settling onto the glass slide surfaces was the same as on the pipe substrate. The microscopic examination enabled earlier detection of larval forms and recognition of smaller biota such as diatoms, foraminifera and protozoa.

CHAPTER V

SUCCESSION OF FISHES ONTO A NEW REEF

General.

The succession of fishes onto the Pokai Artificial Reef was traced on each of three, one-tenth acre quadrats. The visual transect method described by Brock (1954) was used to determine fish biomass. Each month during the course of this study, numbers and sizes of individuals in each species were tallied with the aid of an underwater tape recorder. Size estimates were converted to biomasses using length-weight regression coefficients prepared by the Hawaii Division of Fish and Game. Biomass estimates for this study were always computed in the English system to enable direct comparisons with previous estimates by Brock (1954) and by the Hawaii Division of Fish and Game. Data were obtained by swimming along the 145-foot transect and observing all the fishes in the water column immediately above the quadrat. Pipe interiors, holes and crevices were examined for seclusive species. All counts were made between 9:30 AM and 3:00 PM to avoid diurnal rhythmic fluctuations.

The census method described by Brock (1954) has weaknesses which have been discussed by Randall (1963). Wass (1967) cited a major weakness as the loss of observational continuity resulting from recording data on an underwater writing tablet. This error was eliminated by the use of an underwater tape recorder. Another source of error noted was the tendency to miss fishes that hide in crevices and cracks during the day. The relatively simple topography and absence of intricate interstices on the Pokai Artificial Reef minimized this error. Wass (1967) obtained a correlation of only 42% between visual census and rotenone recovery at his study site, a labyrinthine coral reef. Although a rotenone poisoning was not performed for this study, a correlation of 75% is assumed between observed and actual biomass values for the artificial reef due to the simpler physical features of the area and the improvement in the technique offered by the tape recorder. However, the absolute accuracy of visual biomass estimation is unimportant to the within-study comparisons (temporal changes on quadrats, between-area differences) that follow.

The succession of fishes onto the M-1968 site was followed more closely than at the other two sites. A dive was made the first night to ascertain what species moved into the area immediately after placement of the new substrate. To follow community development closely, five censuses were made during the first month of immersion of these new substrates.

A further clarification of succession onto the M-1968 site was obtained when analyses were conducted on 17 representative fish species. These species were selected in view of their importance as sport or commercial fish, their migratory or residential habits, and their representation of some large group important to the ecology of the region. Six of the 17 are shown in Plate 18.

Observations on the first night of immersion at the M-1968 site revealed several species (i.e., Parupeneus multifasciatus, Acanthurus sandvicensis, Acanthurus olivaceus, Diodon hystrix and Monotaxis grandoculis) using the pipes as night shelter (Plate 19). The fact that these species range widely in search of food may have influenced their early appearance.

After 3 days of pipe immersion, the fish biomass in the area had doubled. This time period was far too short for the sessile biota to become a fish-food source, and the upswing in biomass probably was due entirely to the shelter offered by the addition of pipes to the area.

After 10 days, an algal bloom of Asterocytis ramosa appeared to attract large numbers of herbivorous fishes. Within a month, the biomass was roughly 100 times larger than before the pipes were placed. The number of fish species increased from 22 to 46 after 26 days of immersion. The biomass increase was due mainly to surgeonfishes (Acanthurus olivaceus, Naso lituratus, and Naso unicornis) which fed on the long algal filaments covering the outside surfaces of the pipes. Within two months, this algae was grazed to a closely cropped mat by the numerous herbivores.

Plate 18

Six important food fishes in their characteristic habitat on the Pokai Artificial Reef during daylight hours.

A

Parupeneus porphyreus (Kumu) was found abundantly on the reef.

B

Parupeneus multifasciatus (Moano) was often seen investigating the crevices under pipes where prey could be found.

C

Myripristis berndti (Menpachi) was relatively inactive during the day.

D

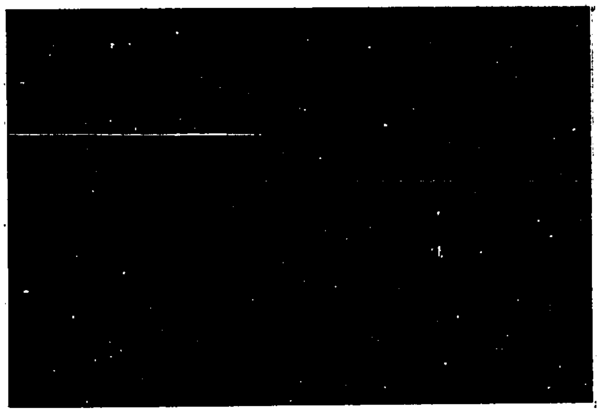
Holocentrus xantherythrus (Squirrelfish) remained sheltered during daylight hours.

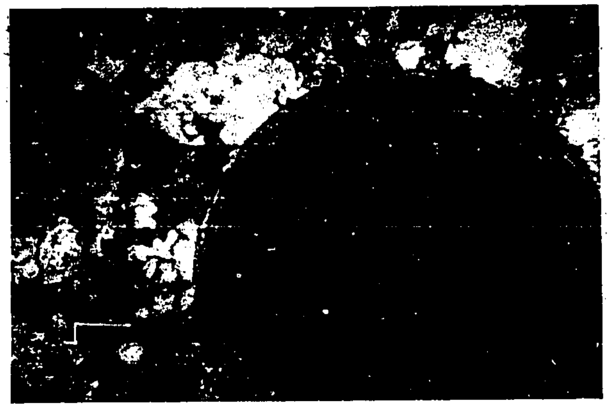
E

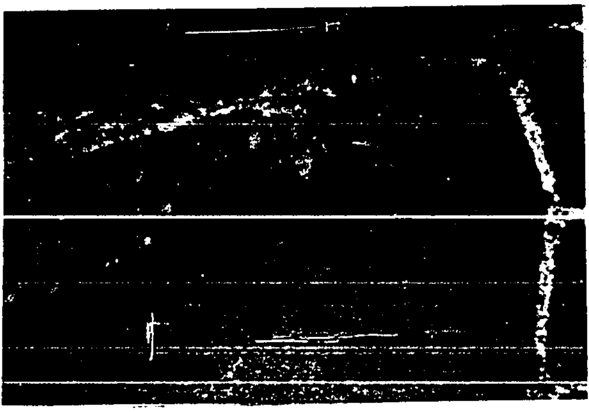
Priacanthus cruentatus (Aweoweo) was found close to the protections of a pipe during the day.

F

Schools of *Monotaxis grandocilis* (Mu) were frequently observed hovering above the artificial reef. Note two color phases.







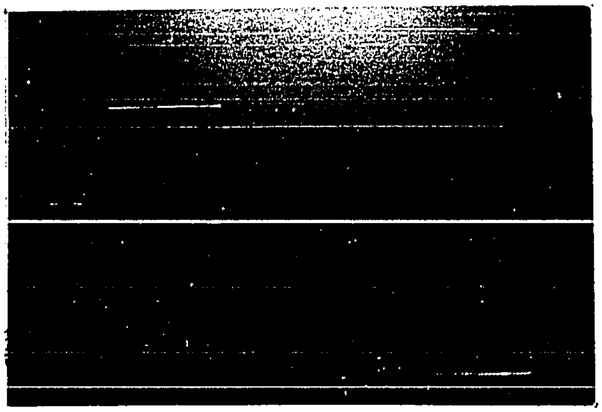


Plate 19

Parupeneus multifasciatus found under pipe rubble on the M-1968 site the first night of pipe deposition.

Thereafter, the number of herbivores permanently found on the reef decreased and appeared to be limited by the amount of algae available for grazing. Many predatory fishes, such as *Aprion virescens* and large carangids, were noted in the vicinity of the pipes during the time of peak herbivore concentration. However, these were carnivores that are known to range over large areas, and resident carnivores such as the priacanthids, holocentrids and mullids did not become established on the reef for five or six months.

Figure XII compares the development of the M-1968 reef increment in terms of total fish numbers with the two other study areas. Although numbers fluctuated irregularly, a trait observed in other fish studies (Carlisle et al., 1964), they appeared to level off between 500 and 600 fishes per one-tenth acre after 6 months. These fluctuations seemed to be caused by tide and turbid water. The numbers found on the D-1966 and M-1968 sites were similar, while the A-1964 site definitely had fewer fishes. This discrepancy apparently resulted from low pipe concentration and reduced productivity of benthic algae at the deeper A-1964 station.

Total biomass and average weight are similarly graphed in Fig. XIII and XIV, respectively. The data lines correspond to those of Fig. XII indicating that increases of biomass at specific points of time were due to both an increase in average weight of fish and the numbers of fishes tallied in the censuses. The high biomass and average fish

FIGURE XII

Number of fishes (all species) per one-tenth acre as a function of time on each of three transect areas. Time intervals are in 100 days.

Legend

— · — · — · —	A-1964 transect area
— — — — — —	D-1966 transect area
————————	M-1968 transect area

FIGURE XII

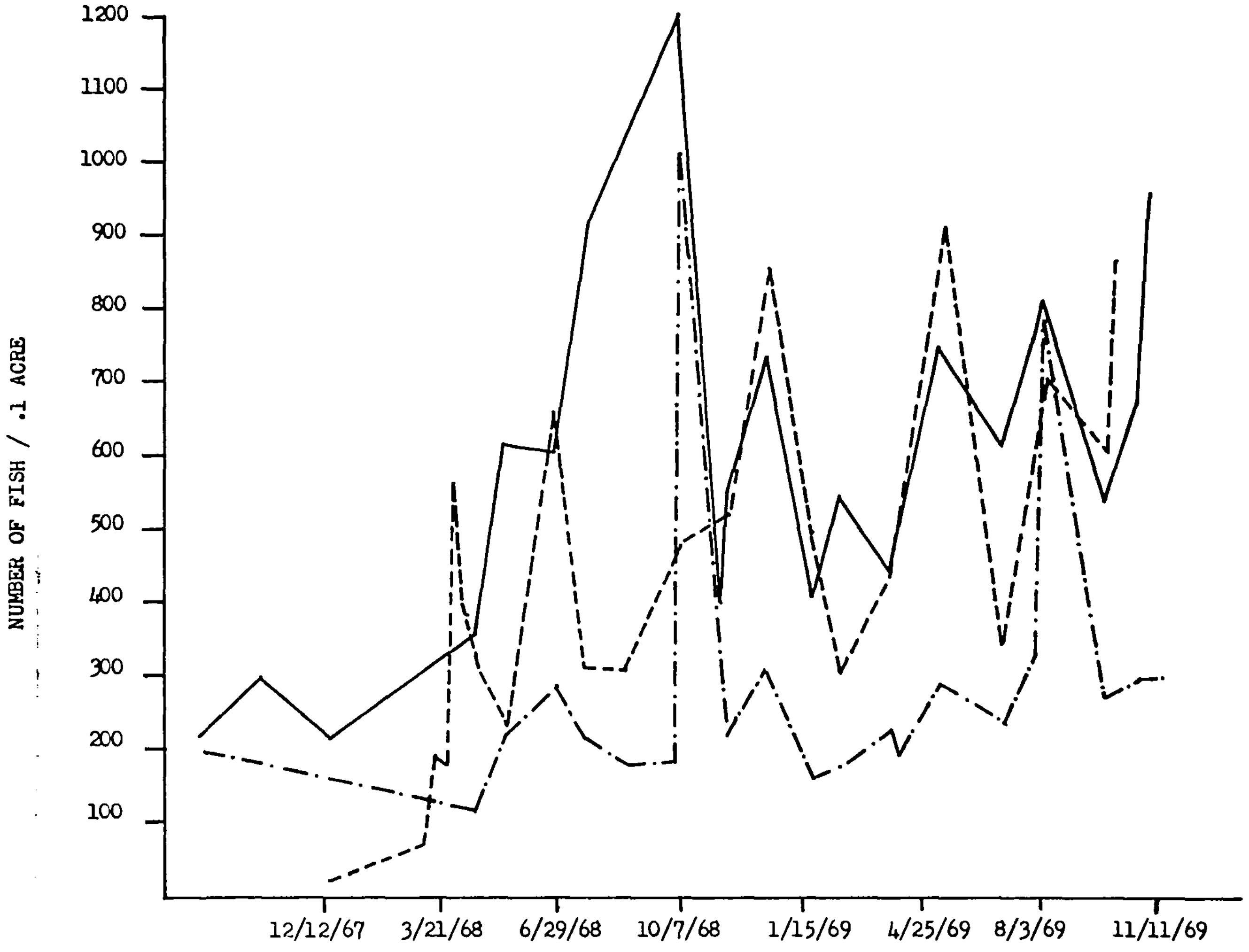

NUMBER OF FISH / .1 ACRE
1200
1100
1000
900
800
700
600
500
400
300
200
100
12/12/67
3/21/68
6/29/68
10/7/68
1/15/69
4/25/69
8/3/69
11/11/69

FIGURE XIII

Total biomass of fishes (all species) on each of the three transect areas as a function of time. Time intervals are 100 days.

Legend

—·—·—·—	A-1964 transect area
— — — — —	D-1966 transect area
————	M-1968 transect area

FIGURE XIII

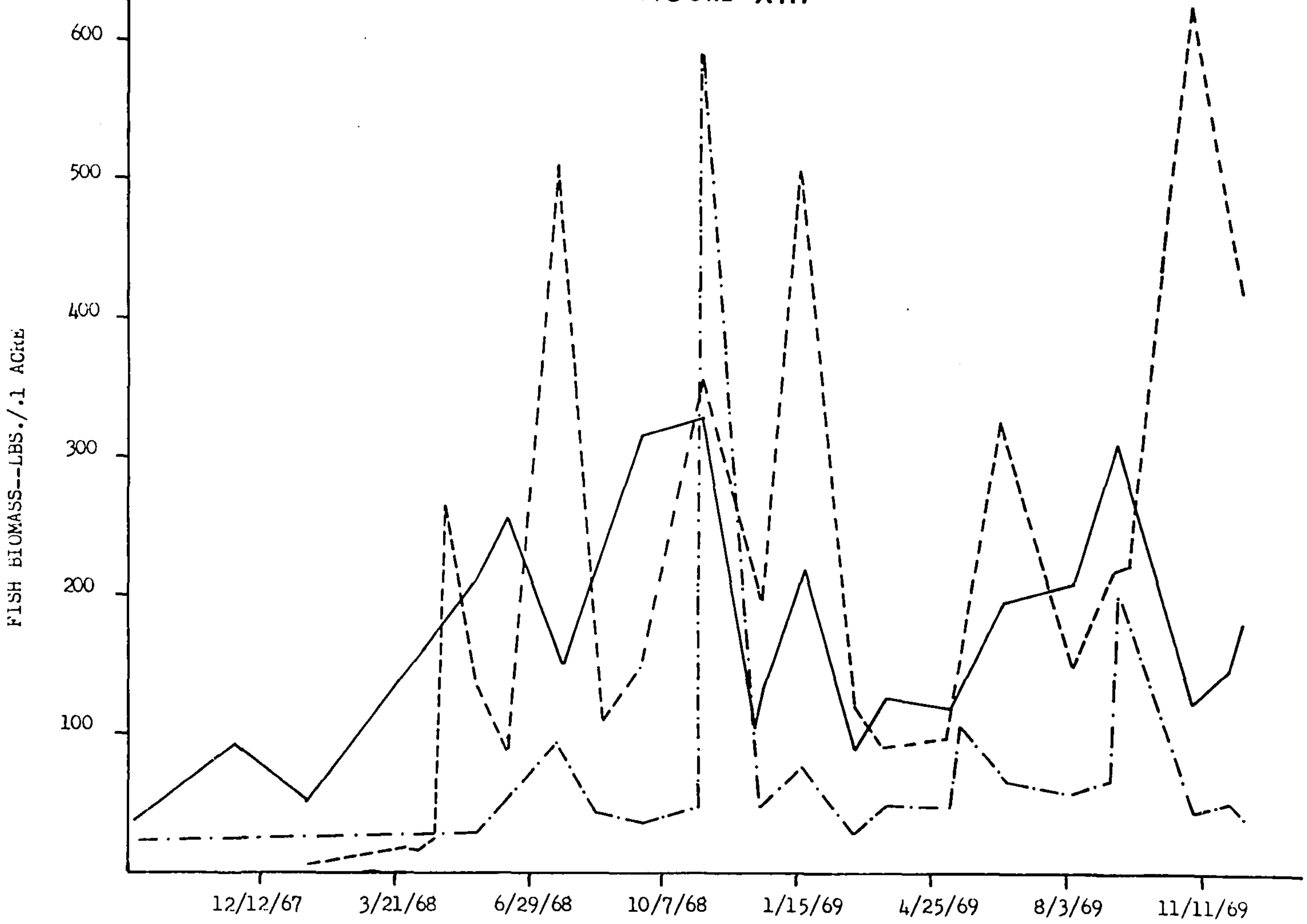

FISH BIOMASS--LBS./.1 ACRE
600
500
400
300
200
100
12/12/67
3/21/68
6/29/68
10/7/68
1/15/69
4/25/69
8/3/69
11/11/69

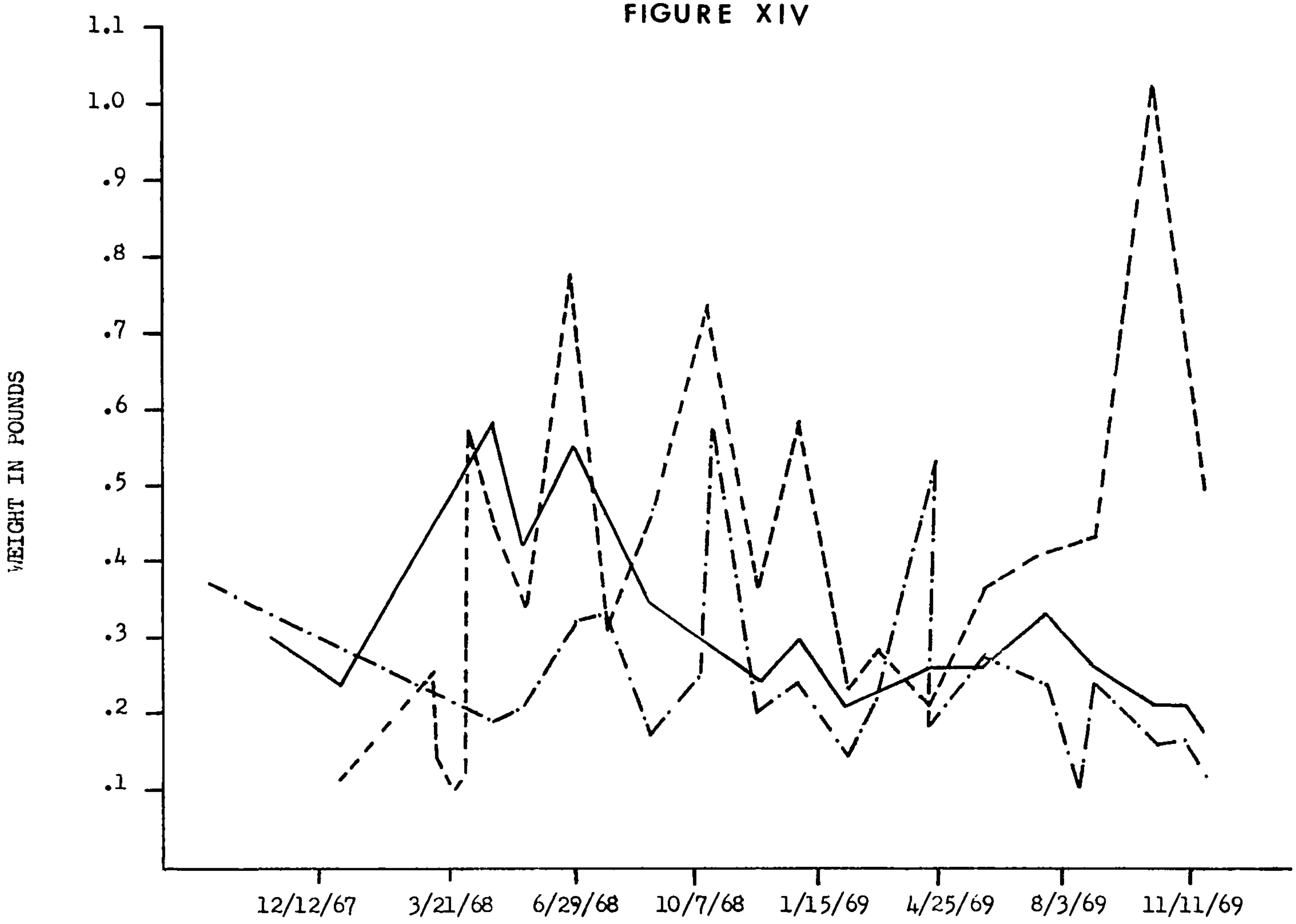
FIGURE XIV

The average weight of a fish (all species) on each of the three transect areas as a function of time. Time intervals are 100 days.

Legend

—·—·—·—	A-1964 transect area
– – – – – –	D-1966 transect area
————	M-1968 transect area

FIGURE XIV


WEIGHT IN POUNDS
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
12/12/67
3/21/68
6/29/68
10/7/68
1/15/69
4/25/69
8/3/69
11/11/69

weight values for the M-1968 site in Fig. XIII and XIV indicate that the average weight of a fish was larger on this shallower station. The species responsible for this were the large acanthurids (Acanthurus dussumieri, Acanthurus olivaceus, Naso brevirostris and Naso hexacanthus), the scarids (Scarus dubius and Scarus perspicillatus) and the mullid Parupeneus chryserydros. All these species appeared to be more abundant on the M-1968 site than on the two older stations.

There is difficulty in distinguishing between the colonization by fishes and the succession of fishes onto a new reef area. The study of fish colonization was more concerned with the area from which the fishes came, whereas the succession study is concerned with the reasons for their arrival. Fishes may be attracted to an artificial reef for a variety of reasons, such as: shelter, increased food, reproduction, orientation to topographical relief, thigmotropism, or perhaps, some chemical attraction.

Increased food was one of the main factors for initial attraction to the Pokai Artificial Reef. Large numbers of invertebrates were smashed when the pipes were dropped, and this readily available food supply may have attracted the first fishes. However, after the food was consumed, shelter and/or orientation of fishes to a higher point of topographical relief became important. This can best be illustrated by the appearance of large numbers of fishes on the new reef site before any sessile biota could be discerned on the pipe surfaces. The species which came onto the new reef area first were those that tended to be more migratory in nature. Later, the increasing importance of the developing biotic communities on the new substrates became evident. As mentioned, large numbers of herbivores were attracted to algal growth, and resident carnivores became more abundant as invertebrate communities became more complex.

Therefore, successional sequence seems to depend primarily upon readily available food; shelter and/or orientation to higher topographical relief; and complexity of biotic communities. Juveniles recruited from plankton also were important but will be discussed in the following section on representative fish species.

Representative Species.

The sequence of fish species onto the M-1968 increment of the artificial reef is best understood by examining the fish census data for the 17 species previously mentioned. Total biomass, total number and average weight of a fish were monitored for each of the species at the M-1968 study area. These data were placed on computer cards, and straight line regressions were run for each of the three factors versus time. The same analyses for the A-1964 and D-1966 areas will not be discussed as most of the species considered had already reached a population equilibrium on these two areas. A straight line regression analysis was retained for all species, whether applicable or not, in order to maintain consistency in comparisons.

In the following sections, there are three graphs for each species: one for total biomass increase with time; one for the change in numbers of fish with time; and one for change in the average weight of a fish with time. The arrows on the average fish weight graphs indicate the date when the pipes were deposited. The time axis is in 100-day intervals. By analyzing these graphs, assumptions could be made as to whether or not an increase of biomass with time was due to an increase in numbers and/or an increase in the average weight of a fish.

The species examined fell into two distinct groups: those that were already established on the area or that came onto the area immediately after pipe deposit (early colonizers), and those that took from one to 6 months before they became established on the reef (delayed colonizers).

Early-colonizing Species.

Parupeneus multifasciatus, *Parupeneus pleurostigma*, *Acanthurus olivaceus*, *Naso hexacanthus*, *Zebrasoma flavescens*, *Monotaxis grandoculis*, *Chaetodon miliaris*, *Holocentrus xantherythrus*, *Aprion virescens*, *Dascyllus albisella* and *Chromis ovalis* were already present or came onto the M-1968 area immediately after the pipes were deposited. The majority of these species are migratory and because of their wandering habits could be expected to come onto the new reef increment before the more resident species. *H. xantherythrus*, *Z. flavescens* and *D. albisella* are resident species, as indicated by the tagging study, but they were already present on the M-1968 site prior to pipe deposit and did not change greatly in numbers thereafter. Therefore, they were considered as early-colonizing species.

All of these species are discussed individually in the following section.

Parupeneus multifasciatus

Parupeneus multifasciatus (Plate 18 B) was the goatfish most frequently caught by anglers drifting over the Pokai Artificial Reef. It generally roams widely in feeding and was one of the first tagged fishes to appear on the M-1968 site. However, tagged fish were frequently seen in the same locations indicating that there was a home range.

The data in Fig. XV do not show a significant correlation to regression other than in the average fish weight graph. A definite trend for an increase in the weight of a fish was noted on the new reef increment. This, of course, would lead to an increase in the biomass present if numbers remained constant. Because P. multifasciatus moved about freely, biomass in the transect varied considerably resulting in the poor fit of the regression lines to total biomass and numbers.

Populations of P. multifasciatus on the D-1966 and A-1964 study sites appeared to have reached maximal size by the time this study was begun. The small average size of fish on the M-1968 site, 0.16 lbs. compared to 0.21 and 0.23 lbs. on the other two sites, may reflect the influence of the smaller fish found at the initiation of the new pipe increment. Observations on natural areas around the reef showed that juveniles were associated with flat bottom areas with a good algal mat and small coral heads. Larger fish were noted around areas of higher relief. When pipes were introduced to the new area, perhaps the habitat was changed enough that larger fish were favored ecologically. Larger individuals have been observed feeding on juveniles on three occasions.

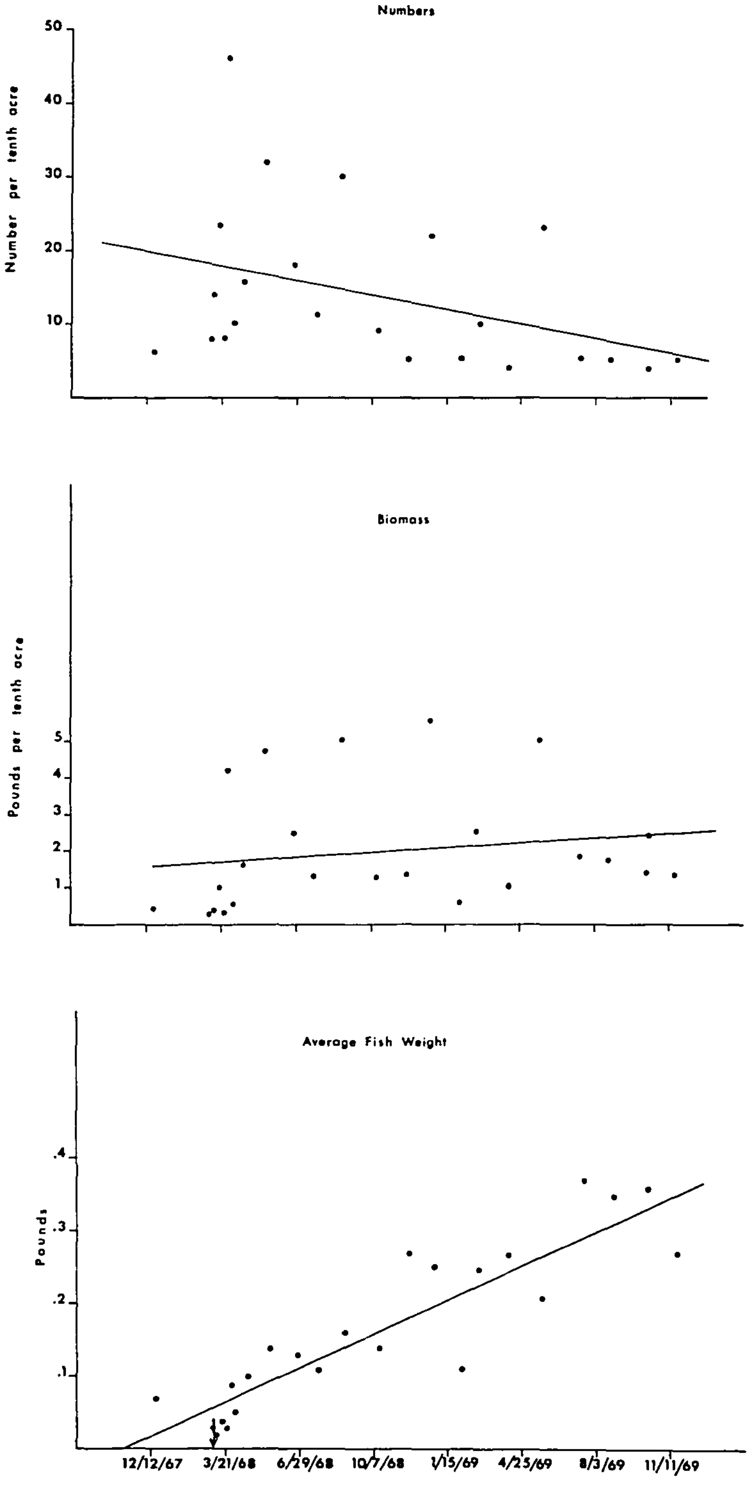
Stomach contents of 27 specimens, ranging in size from 92 to 185 mm, were examined. Their food consisted primarily of shrimps, crabs, stomatopods, small octopuses and an occasional fish. They were diurnal, fed over rocky bottoms and sheltered under the pipes during the night.

FIGURE XV

Parupeneus *multifasciatus*--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XV

Parupeneus multifasciatus



Parupeneus pleurostigma

Parupeneus pleurostigma was ubiquitous on the Pokai Artificial Reef, but quantitatively, the least important of the goatfishes described here.

Figure XVI shows the graphs of the regression on total biomass, number of fish and average weight of a fish with time for *P. pleurostigma*. Only the data on total biomass increase show a significant correlation to the regression line at the P=.05 level. There was an initial upswing in biomass after the pipes were deposited. Biomass fluctuated depending upon the movements of the fish over the transect area, but there was a slight trend for higher estimates in the late summer.

The populations of fish over the other two study areas remained about the same during the course of the study. At the conclusion there was a higher biomass of fish (4.10 lbs. compared to 2.28 and 1.10 lbs.) on the M-1968 site when compared to the A-1964 and D-1966 sites respectively.

Adult *P. pleurostigma* associated more with sandy than with rocky bottoms. Individuals on the D-1966 site were twice the average weight of those on the other two sites (0.30 lbs. versus 0.15 lbs.), possibly because of the large sand channel adjacent to that area.

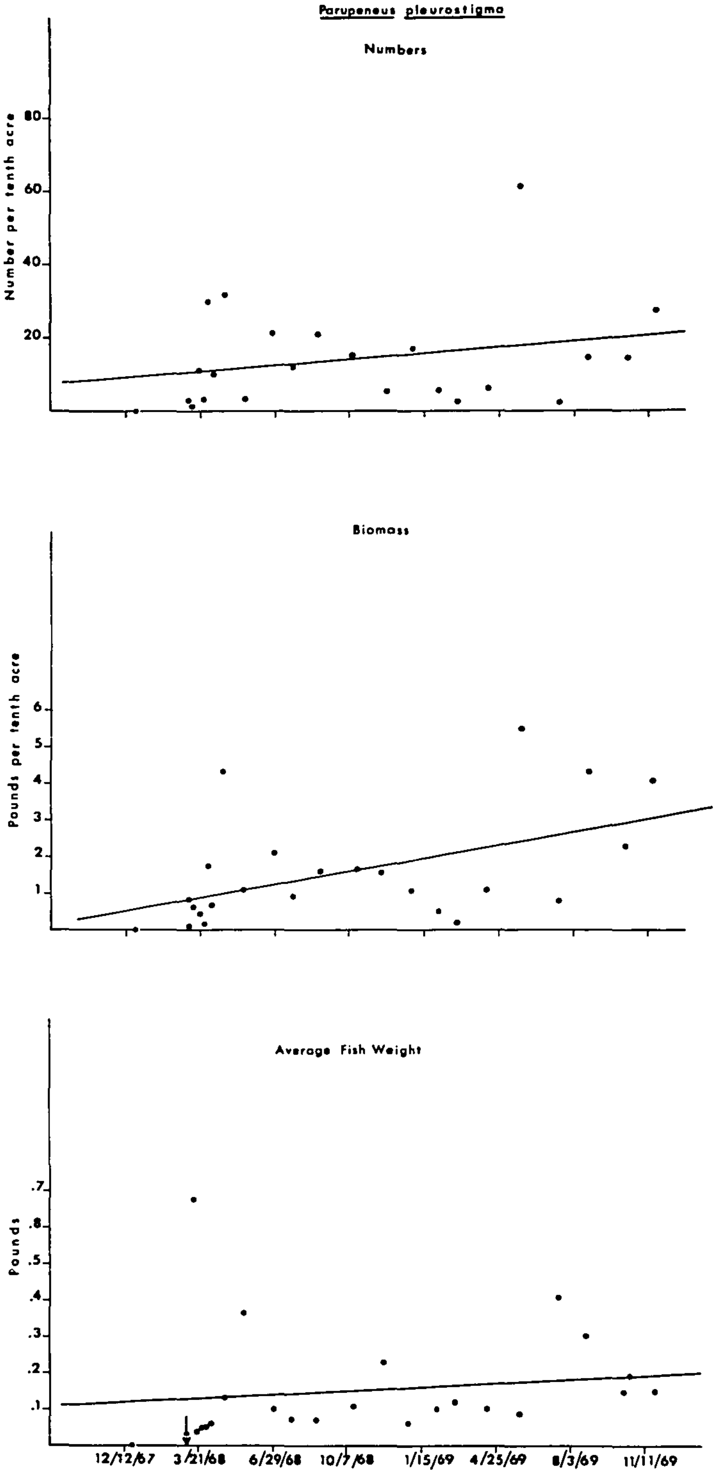
They were diurnal and sheltered in the pipes at night. Stomach contents of 18 specimens, ranging from 105 to 189 mm in size, were examined. Their principal diet consisted of crustaceans, annelids, small fishes and an occasional gastropod mollusk. They fed by hunting mobile prey and also by retaining food items from gulped masses of sand.

FIGURE XVI

Parupeneus pleurostigma--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XVI

Parupeneus pleurostigma



Numbers

Biomass

Average Fish Weight

Acanthurus olivaceus

Acanthurus olivaceus was one of the most abundant acanthurids on the Pokai Artificial Reef. Figure XVII shows the relationships between total biomass, number of fish and average weight of a fish against time for this species. None of the data shows significant correlation to regression lines as a result of the highly fluctuating nature of populations over the transect areas.

A. olivaceus wandered in large schools over extensive areas of bottom, a behavior characteristic of large herbivores (Odum and Odum, 1955). The initial upswing in biomass on the M-1968 reef was due to large schools of adult fish that came onto this area to feed immediately after the bloom of the alga *Asterocytis ramosa* (Plate 16). They departed after grazing on the long filaments of algae growing on the pipes. Schools of fish reappeared periodically to graze in the daytime, and sheltered at night among the pipes.

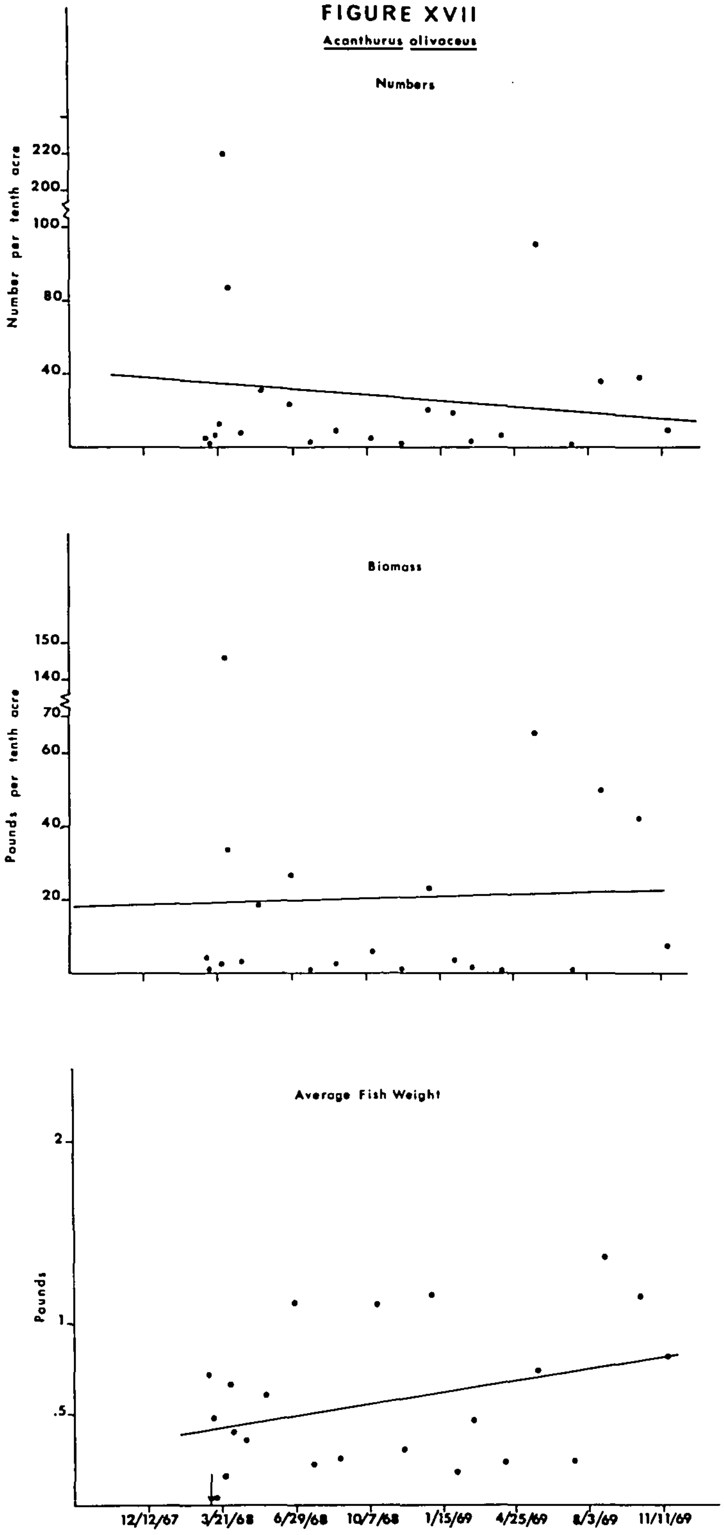
Jones (1968) classified *A. olivaceus* as a grazer which he defines as any fish that pick up bits of substrate while feeding. Hiatt and Strasburg (1960) stated that they feed on short algal cover on sandy bottom or by scraping algae from coral rubble. The latter was the form of feeding most often observed when they fed on the algal mat and filaments attached to the pipes.

FIGURE XVII

Acanthurus olivaceus--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XVII

Acanthurus olivaceus



Numbers

Biomass

Average Fish Weight

Naso hexacanthus

Naso hexacanthus was very abundant on the Pokai Artificial Reef at times. Figure XVIII shows the graphs for this species with respect to biomass, total numbers and average weight of a fish with time. The percentage of variation of Y due to X is minimally significant. Even though there is a positive correlation of the data to each regression line for all three parameters ($P=.05$), curvilinear regressions would fit these particular data better.

Scattered individuals appeared within 3 weeks after the pipes were deposited, but larger schools did not appear on the area for over a year. The increase in biomass was due to an increase in the number of fish present and a general increase in the weight of the fish on the reef. The other two stations showed a slight decrease in the biomass of Naso hexacanthus present during the study.

They seemed to be migratory, and their intermittent presence on the D-1966 and A-1964 study areas indicated roving tendencies. They also showed a tendency to congregate on the shallower M-1968 site, although groups observed at different times probably were not the same because the size of individuals varied.

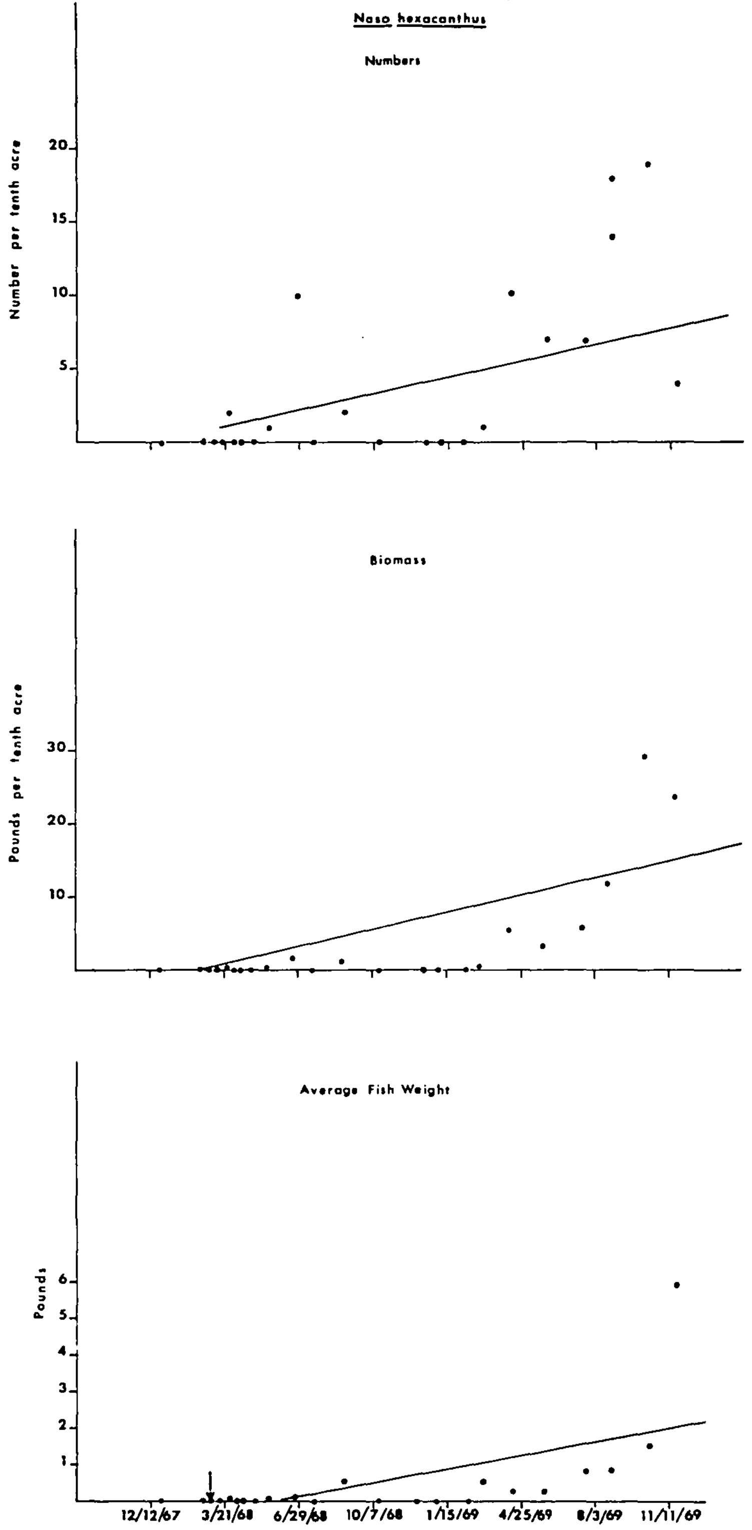
Jones (1968) classified N. hexacanthus as a zooplankton feeder that feeds in midwater, with a diet consisting primarily of copepods, crab zoea and megalops, mysids, and pelagic eggs. Their longshore movement, following the turbid water masses rich in plankton, is consistent with their feeding habits.

FIGURE XVIII

Naso hexacanthus--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XVIII

Naso hexacanthus



Zebrasoma flavescens

Many Zebrasoma flavescens occurred on the M-1968 study pipe before the pipes were deposited, and their numbers fluctuated widely until the end of the study. Tagging has shown that they maintain close proximity to home areas.

The data show significant correlation to the regression lines (Fig. XIX) for the total increase in biomass and average weight of a fish at the P=.05 level. The data on the increase in fish numbers do not fit a straight line regression. There was an increase in biomass with time, and this appeared to be due primarily to an increase in average fish weight, but slight increase in the numbers of fish is also suggested.

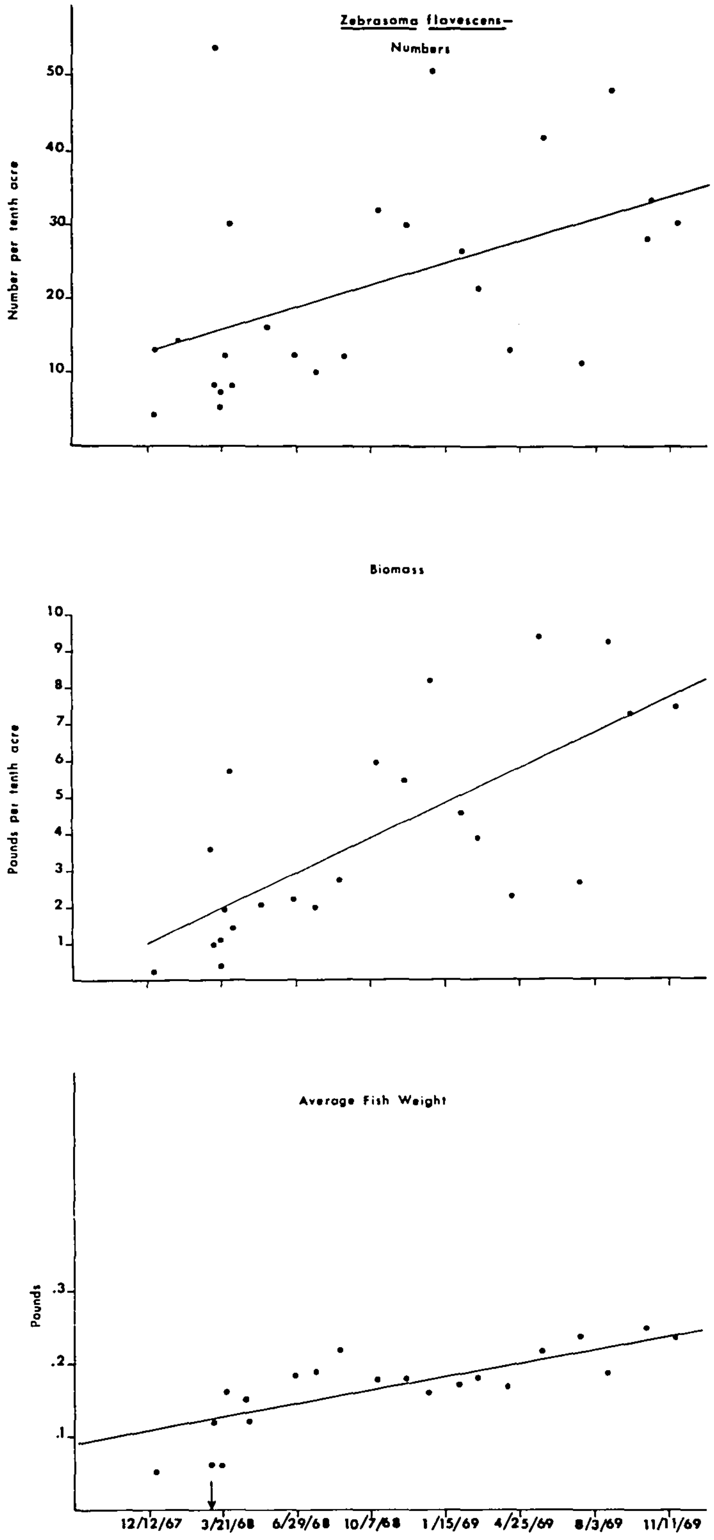
Z. flavescens fed in the same area with Ctenochaetus strigosus, and they frequently were seen together grazing on the top surfaces of the pipes. Jones (1968) stated that Z. flavescens is a browser that feeds primarily on the algae Acrochaetium, Centroceras, Ceramium, Champia, Chondria, Griffithsia and Polysiphonia. Among these, only Polysiphonia was found on the artificial reef. Judging from the observations, this species obtained nutriment from diatoms and other algae which composed the algal mats on the top of the pipes. Jones (1968) stated that the extended snout is well adapted to browsing algae recessed crevices, and Z. flavescens was frequently seen on the Pokai Artificial Reef probing in holes and cracks.

FIGURE XIX

Zebrasoma flavescens--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XIX

Zebrasoma flavescens—



Monotaxis grandoculis

Monotaxis grandoculis is a popular food fish in Hawaii. Their relative numbers in the transect areas varied considerably due to their tendency to move freely over the bottom. This tendency made interpretation of the data shown in Fig. XX difficult. In general, they tended to orient to the higher topography and shelter afforded by the artificial reef. Before pipes were dropped on the M-1968 site, none was noted in the area. Scattered individuals appeared soon after the pipes were dropped, and in about 3 months, a school of this species was consistently observed on the site (Plate 18 F). None of the data shows a significant correlation to the respective regression lines for biomass, number or average weight of a fish.

Information from fishermen indicated that they were primarily crepuscular feeders. Their diet was varied but consisted of large gastropod mollusks and crabs which they ground with their powerful molars. Small octopuses and shrimps were also found in the stomachs of the four specimens (length ranging from 250 to 350 mm) that were examined.

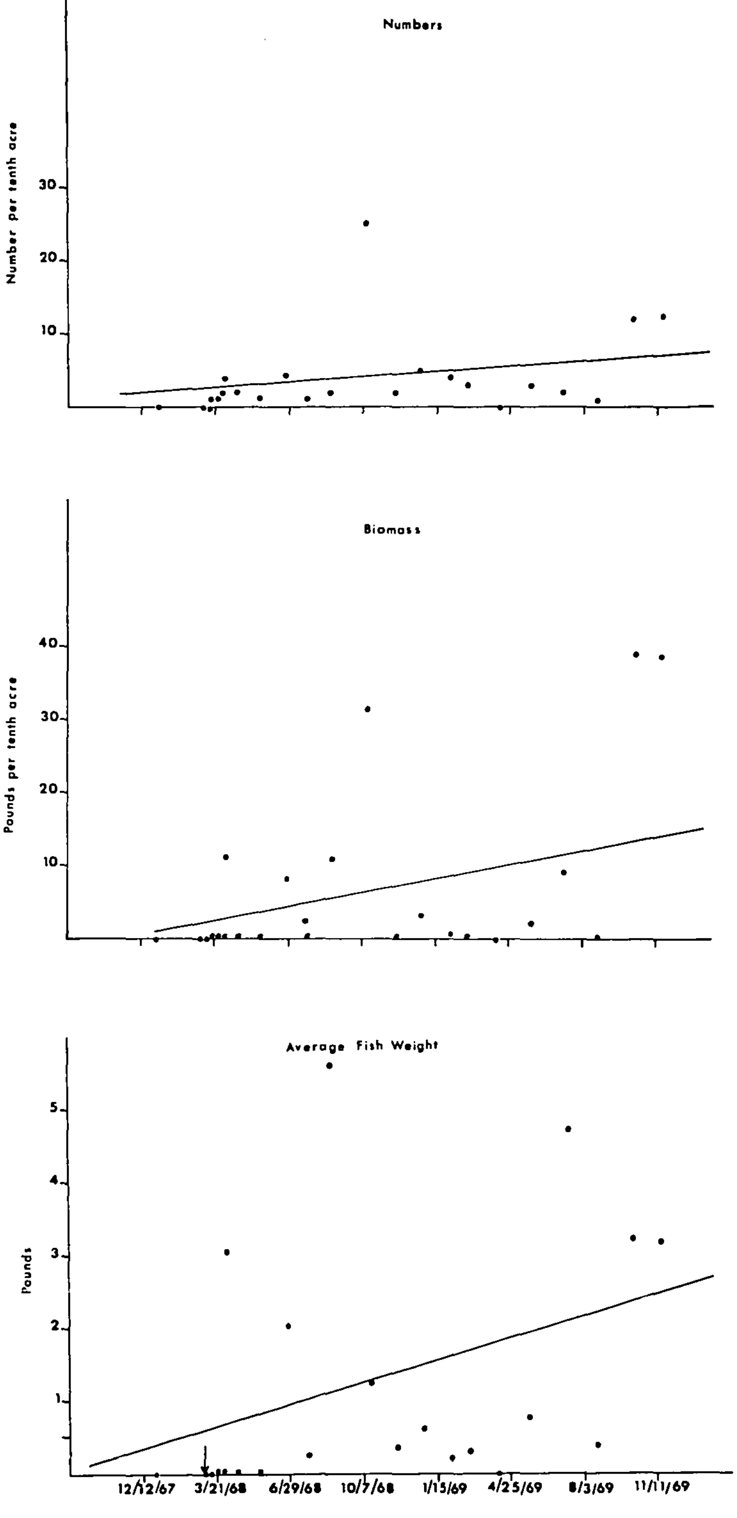
During the day, they formed loose schools 5 to 10 feet above the bottom. They were extremely wary when approached, and spearing specimens was difficult. Night observations indicated that they were still active but tended to remain solitary rather than in schools.

FIGURE XX

Monotaxis grandoculis--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XX

Monotaxis grandoculis



Chaetodon miliaris

The most abundant butterflyfish on the artificial reef was Chaetodon miliaris, although Chaetodon fremblii, Chaetodon corallicola and Chaetodon multicinctus were common. Several C. miliaris were present on the M-1968 site before the pipes were dropped, and with the exception of two fish censuses, this number remained about the same. Twice during periods of turbid water, wandering schools came onto the M-1968 site. These schools were probably feeding aggregations following the richer water mass.

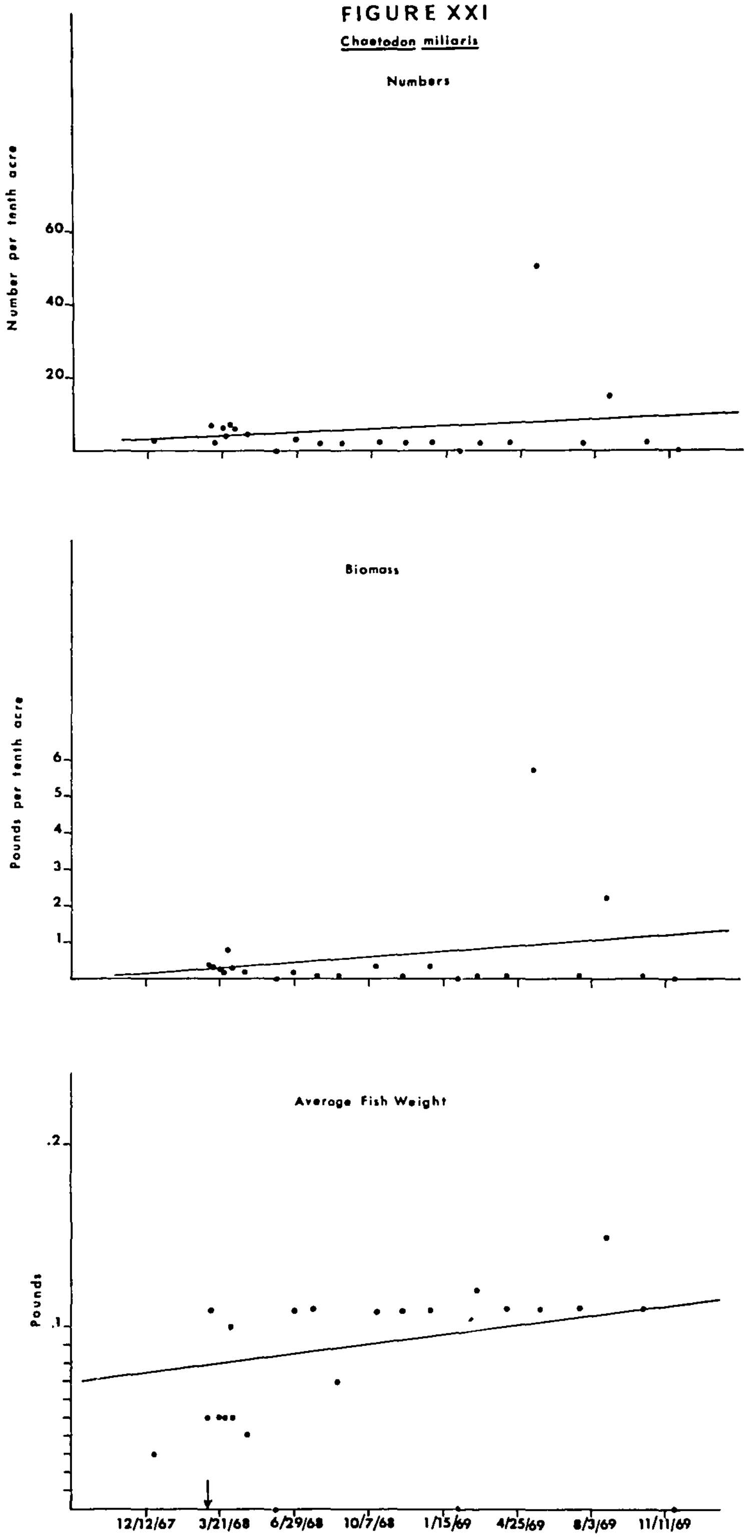
There is no significant correlation to regression lines (Fig. XXI) for any of the data. In the graph on the average weight of a fish, the fish at the beginning of the study appeared smaller than those at the end. The smaller fish were associated with a fairly large coral head in the transect area. This coral was broken when strong surge rolled pipes over it, and these fish probably moved off the transect area onto a more suitable habitat. The larger C. miliaris appeared to be better adapted to the habitat provided by the pipes, and they remained on the site.

C. miliaris was primarily carnivorous and was observed feeding on a wide variety of animal material, including plankton, fishes eggs adhering to rocks and smashed urchins. C. miliaris acted as a cleaner for various fishes, and Burgess (personal communication, Department of Zoology, University of Hawaii) observed this species picking at coral polyps. It was diurnal and rested near the bottom at night. This data corroborates the observations of Hobson (1965).

FIGURE XXI

Chaetodon miliaris--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXI



Chaetodon miliaris

Numbers

Biomass

Average Fish Weight

Holocentrus xantherythrus

Holocentrus xantherythrus was one of the most abundant holocentrids on the M-1968 area before the pipe deposit. Their number and average weight remained about the same during the course of the study (Fig. XXII). The dip in population after January 1969 was probably due to the destruction of habitat by a storm that occurred at that time. There is no significant correlation of the data to a regression line.

Both the D-1966 and A-1964 sites had larger populations of this species. The population on the D-1966 area showed a significant correlation to regression (P=.05) for both an increase in numbers and in biomass. This may indicate the presence of better habitat on these areas and perhaps preference for deeper water.

The abundance of H. xantherythrus at the various sites seems to be due to the differences in suitable shelter available. They required small holes and crevices where they could retire in the daylight hours (Plate 18 D). Large pipes did not offer such habitat and only on the D-1966 site where smaller pipes were concentrated was there a sizeable population of this species. They were found primarily under the pipes resting against the coral mound on this study area.

Stomach contents of five specimens, ranging in size from 45 to 85 mm, were examined. These observations on diet agree with the observations made by other authors (Hobson, 1968; Starck and Davis, 1966; Hiatt and Strasburg, 1960), who noted that holocentrids feed on crustaceans.

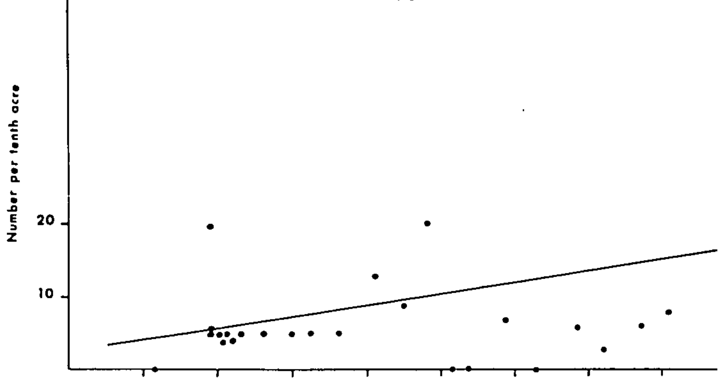
FIGURE XXII

Holocentrus xantherythrus--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

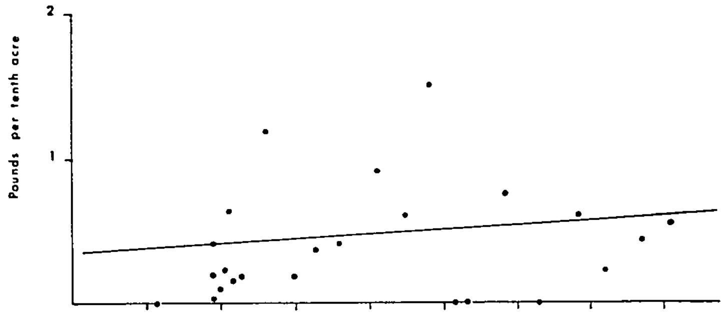
FIGURE XXII

Holocentrus xantherythrus

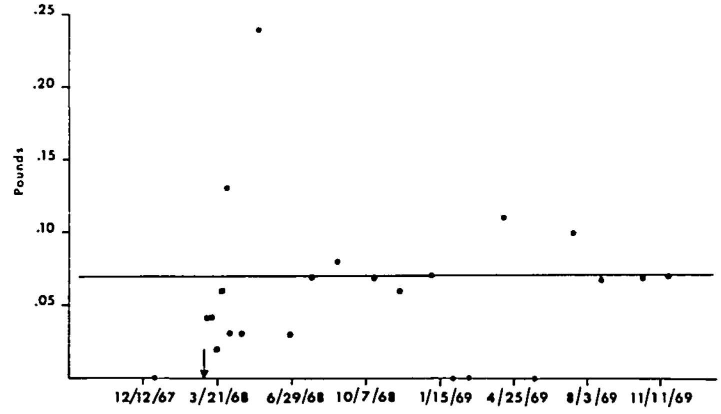
Numbers



Biomass



Average Fish Weight



Aprion virescens

Aprion virescens, largest and one of the most desirable food fishes discussed here, appeared occasionally over the fish transect areas. It is included here because of its recreational and commercial importance in Hawaii. The data (Fig. XXIII) show no significant correlation to regressions for any of the three parameters examined on any of the three transect areas. The data do show that the weight of individuals in a school varied considerably and that larger individuals tended to be solitary.

A. virescens is a broad ranging predator that feeds primarily on fish and crustaceans (Hiatt and Strasburg, 1960). They frequently were seen trailing schools of *Decapterus pinnulatus* or swimming on the outskirts of schools of *Mulloidichthys samoensis*. Although actual predation has never been observed, Hiatt and Strasburg (1960) considered them a potential predator of small reef fishes. The young of fishes common to the Pokai Artificial Reef (e.g., acanthurids, chaetodonts, labrids, scarids) would be possible prey for this species.

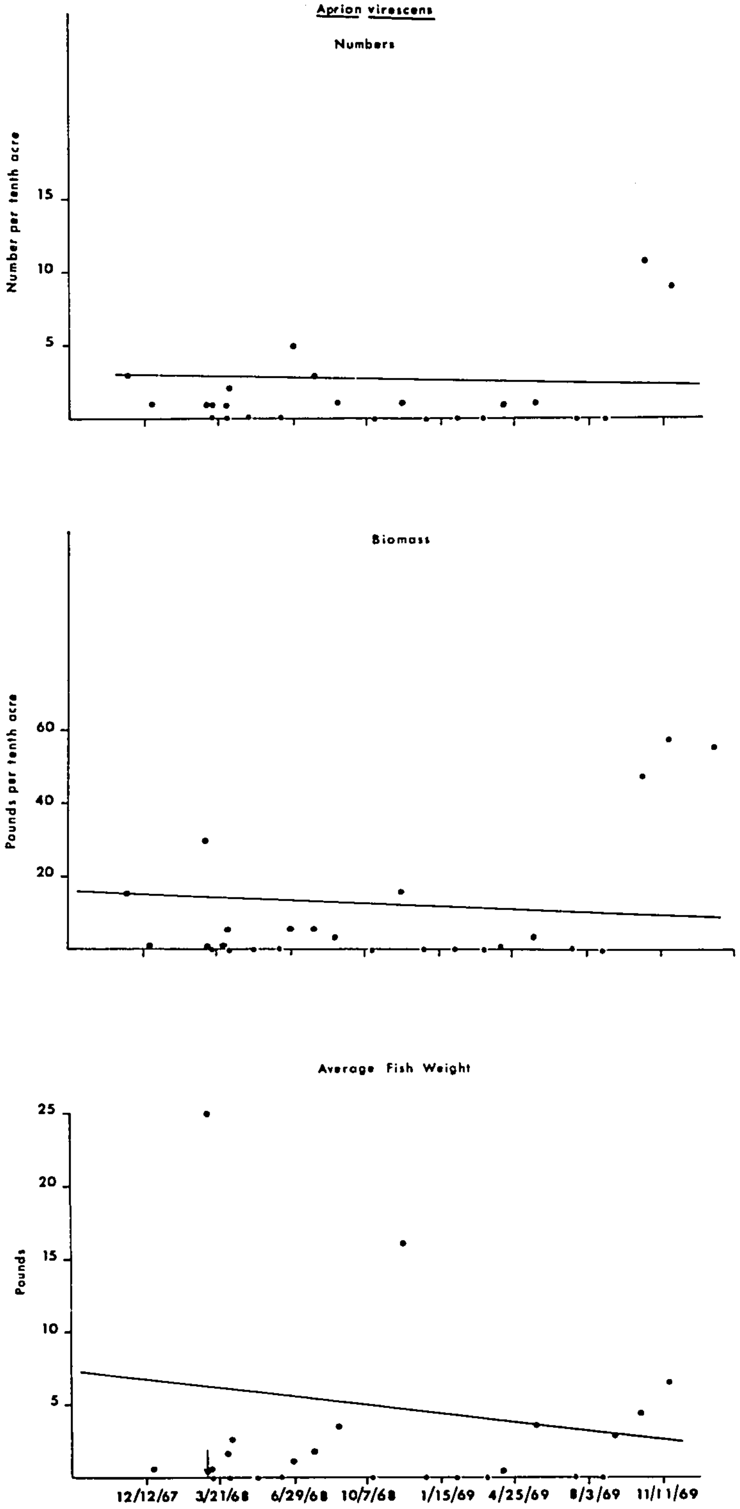
A. virescens was caught during daylight hours and at night, indicating that it may feed at any time. They generally swam about 20 feet above the bottom as if patrolling an area.

FIGURE XXIII

Aprion virescens--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXIII

Aprion virescens



Dascyllus albisella

Dascyllus albisella, a small damselfish, was abundant on the Pokai Artificial Reef. Figure XXIV shows the graphs of the total biomass, number and average individual weight of fish data against time for the species on the M-1968 site. There is significant correlation (P=.05) of the data to the respective regression lines for total biomass and total number. The slopes of these lines are slightly positive, but actually there is little difference in these two parameters from the initial estimates. Any increase in biomass appears to be due mainly to an increase in numbers.

Both the A-1964 and D-1966 study sites had large populations of *D. albisella* when the study was begun, and there was no appreciable change with time. Observations of tagged specimens indicated they maintained a home range, and in most cases, individual fish were found at a specific pipe area.

They were active diurnally, hovering above the pipes and feeding on zooplankton. Stevenson (1963) found their diet consisted primarily of copepods although crab megalops, polychaete worms and small shrimps were also found in their stomachs. At night, they sheltered amid pipe rubble and in other holes and crevices.

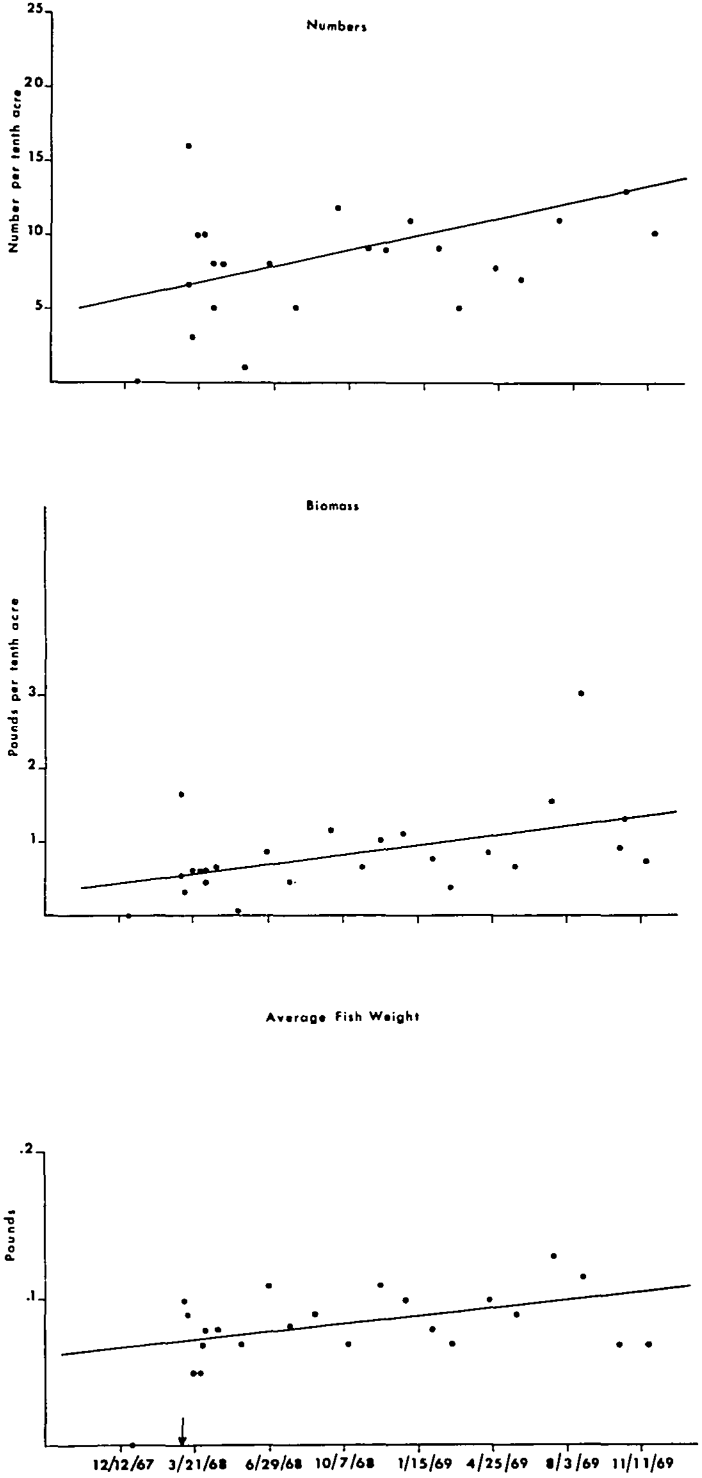
During spawning, they deposited eggs in nests on surfaces of the pipes. They became exceedingly territorial at this time and defended nests vigorously. Spawning occurred in the early spring on the Pokai Artificial Reef, although Stevenson (1963) found a peak of spawning to occur in June and July off Kaneohe Bay, Oahu.

FIGURE XXIV

Dascyllus albisella--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXIV

Dascyllus albisella



Chromis ovalis

Chromis ovalis, a damselfish studied intensively by Swerdloff (1970), was not common on the M-1968 study area. However, it was abundant on the D-1966 site and always present on the deeper A-1964 area. The regressions on the data for the M-1968 area (Fig. XXV) show negative slopes and insignificant correlations of data to the regression line. This indicates reduction in numbers with time.

Within a month after the pipes were deposited, many juvenile *C. ovalis* were seen on the M-1968 site. As they matured, they moved off the substrate and joined the wandering schools of adults. Thereafter, the presence of the fish depended upon whether or not a school was passing over the transects.

The populations of *C. ovalis* on the other two areas remained much the same for the term of study. *C. ovalis* and *C. verater* both had approximately the same diet (see discussion on *C. verater*). *C. ovalis* fed diurnally in the water column in a manner similar to *C. verater*. Food did not appear to be a limiting factor. A slight behavioral difference was noted in that *C. ovalis* tended to cover more area during feeding than *C. verater*.

Swerdloff (1970) discussed the interactions of these species in what appears to be the same niche and concluded that differences in reproductive habits and depth range, among other factors, could reduce competitive interactions.

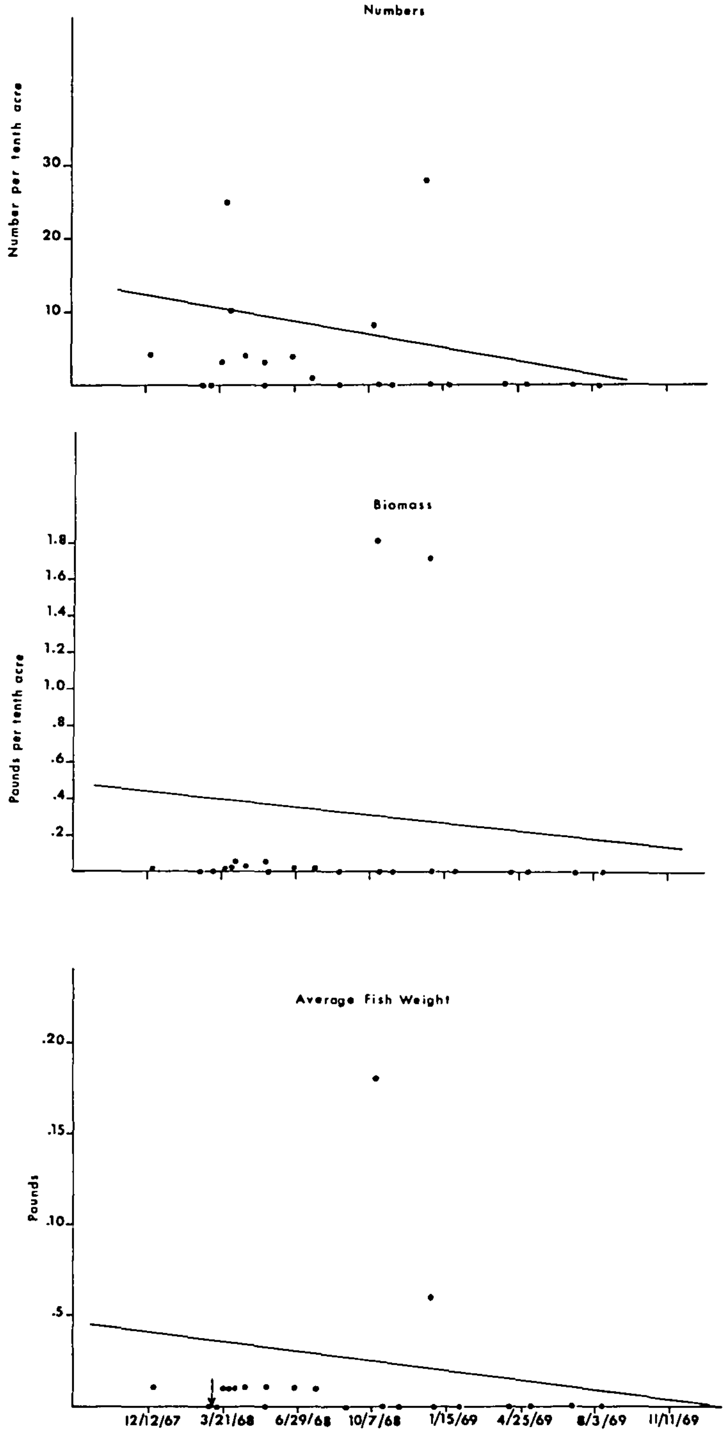
This species frequently was found sheltering amid pipe rubble at night. During the spawning season, many individuals used the top surfaces of pipes for depositing their eggs (Plate 6 A).

FIGURE XXV

<u>Chromis</u> <u>ovalis</u>--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXV

Chromis ovalis



Delayed-colonizing Species.

Priacanthus cruentatus, *Myripristis berndti*, *Parupeneus porphyreus*, *Mulloidichthys samoensis*, *Ctenochaetus strigosus* and *Chromis verater* took several months to become established on the M-1968 area. All of these tended to be resident or territorial species that required reef shelter. Observations of tagged specimens indicated that they stayed close to the tagging area. This tendency to remain in one place may explain why they did not come onto the M-1968 site immediately.

Each of these species is discussed separately in the following section.

Priacanthus cruentatus

Priacanthus cruentatus is a popular food fish in Hawaii. Figure XXVI compares weight, total numbers and average weight of a fish with time. They did not appear on the study area until 4 months after the pipes were immersed.

The data show good correlations to all regression lines (P=.05). The increase in biomass appeared to result from increases in both number and average individual weight on the reef. Although this species was not tagged, certain individuals, recognizable by the pattern of scars or wounds on their bodies, were seen repeatedly at the same pipe. Apparently, immature migrants found favorable habitat and food conditions on the reef, and remained to maturity. The decrease in biomass after August 1969 occurred when commercial fishermen removed an estimated 80 pounds of *P. cruentatus* with surround nets. The average weight of a fish on the M-1968 site was 0.41 pounds compared to 0.68 pounds and 0.64 pounds for the other two areas where larger individuals were already established. At the termination of the study, there were more fish on the shallower M-1968 site than at the other two stations.

P. cruentatus fed nocturnally although some specimens had food in their stomachs in late afternoon. Stomach contents of 34 specimens, ranging in size from 130 to 250 mm, were examined. The main constituents of their diet were small shrimps, crabs, stomatopods and octopuses. These food items were found abundantly in and around the pipes and especially in the crevices formed by the pipes meeting the substrate.

During the day, these fish hovered near the mouths of pipes or actually within the cylinders (Plate 18 E). They were usually found singly or in pairs, but large aggregations formed in the late summer. When this occurred, the school swam farther above the bottom.

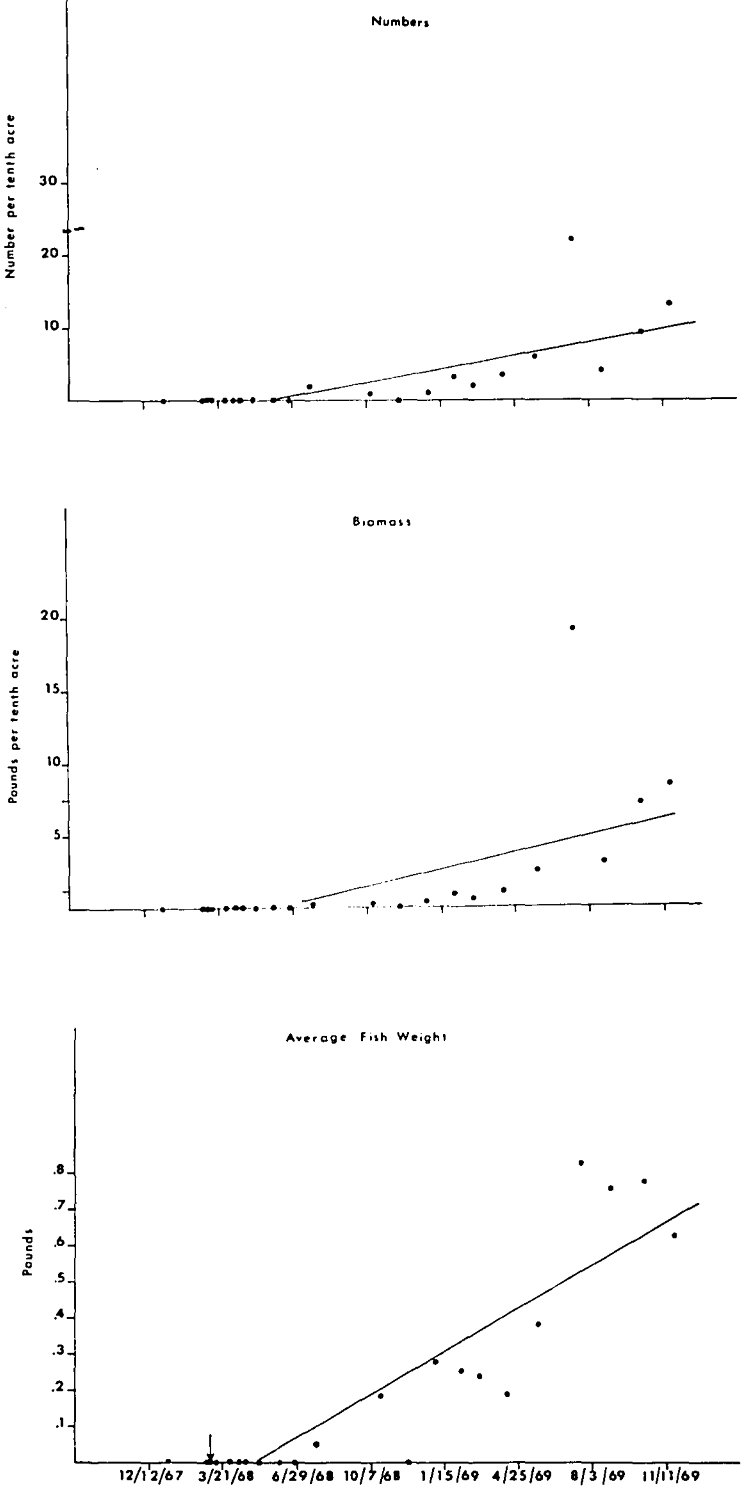
At night, none was seen around the pipes. According to observations by local fishermen, they can be attracted and caught near a light suspended above the water. This indicates that they moved up in the water column at night to feed, but their diet showed that they also fed on benthic organisms.

FIGURE XXVI

Priacanthus cruentatus--temporal changes on the M-1968 site in average weight, and total numbers and biomass per tenth acre. This reef segment was established 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXVI

Priacanthus cruentatus



Myripristis *berndti*

Myripristis *berndti* was selected for analysis as it is a popular food fish and perhaps the best example of resident fish among the delayed colonizers. The graphs for this species are shown in Fig. XXVII. There was good correlation of the data to straight line regression in all three parameters (P=.05).

Only one specimen was noted on the M-1968 site before July. Both numbers and average weight of a fish increased with time, indicating constant recruitment to the artificial reef and growth of individuals after their establishment. The population had not reached an equilibrium at the time this study was concluded.

Larger fluctuations in biomass were probably due to fishing mortality. Fishing boats were frequently seen over the artificial reef at night, and discussion with the fishermen indicated that a large portion of their catch consisted of *M*. *berndti*. The highest population of fish occurred on the D-1966 site where there were more favorable habitats associated with the small ledge against which many pipes were resting.

During the day *M*. *berndti* was found in well-protected darker areas, such as in the arch formed by two parallel pipes, or within the pipes themselves (Plate 18 C). An apparently preferred pipe arrangement was a nested pipe set where they positioned themselves between the top of the smaller pipe and the roof of the larger one.

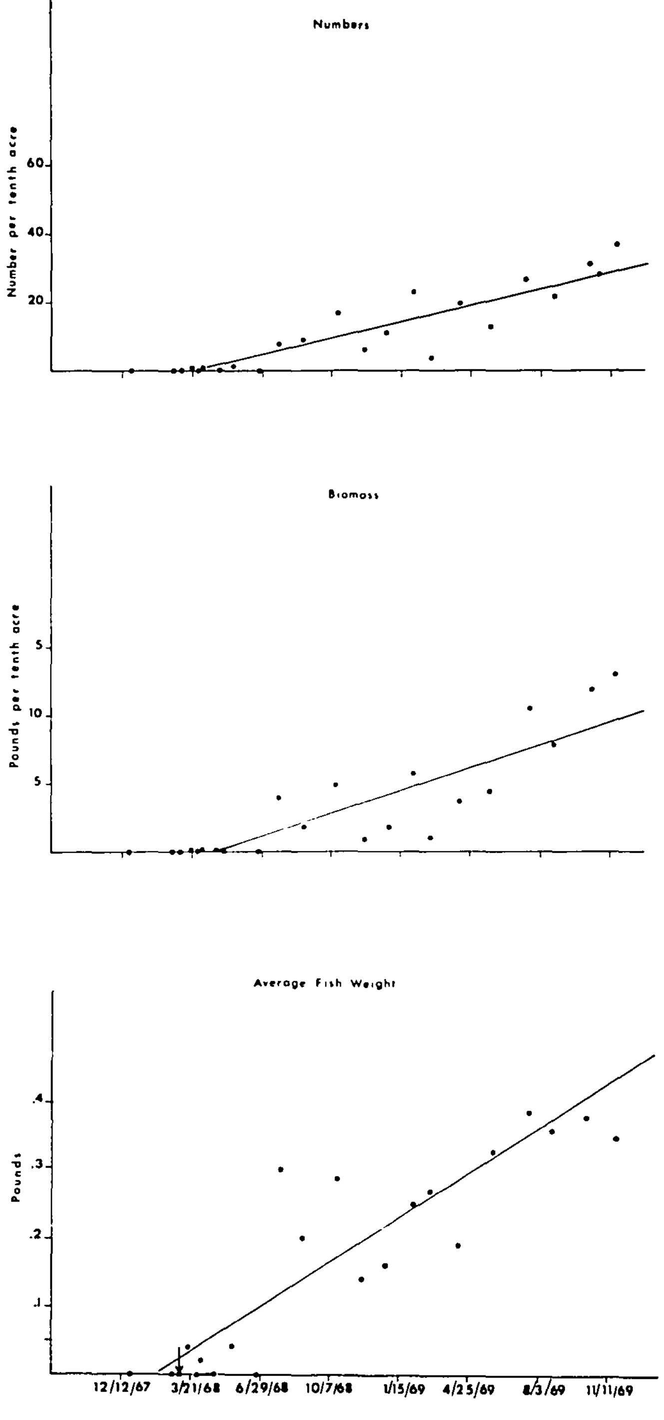
At night, they emerged from the pipes and were found in midwater, as well as near the bottom, feeding on small crustaceans which composed the principal part of their diet (Hiatt and Strasburg, 1960; E.L. Brecknock, personal communication, Department of Zoology, University of Hawaii). Stomach contents of only five specimens were examined because information was available from a concurrent study (Brecknock, *op. cit.*) of this species that included populations on the artificial reef. Crab megalops, stomatopods, shrimps, small gastropods and fishes have been found in their stomachs. Stomachs were empty by late afternoon, indicating that they fed at night. This agrees with the observations of Starck and Davis (1966), Longley and Hildebrand (1941), and Hobson (1965, 1968) who noted that holocentrids feed primarily at night.

FIGURE XXVII

Myripristis berndti--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXVII

Myripristis berndti



Parupeneus porphyreus

Parupeneus porphyreus, an important sport and commercial fish, was one of the most abundant goatfishes on the reef. Figure XXVIII shows the increase in biomass, number of fish and average weight of a fish with time. All data show a significant correlation to the straight line regression ($P=.05$).

They did not appear on the new pipe deposit until late into the second month of immersion. Both an increase in average individual weight of fish and in the number of fish contributed to the increase in total biomass after their first appearance on the M-1968 site. Apparently, young individuals arrived on the site and found favorable growing conditions.

At the end of this study more were found on the shallower M-1968 pipe increment than at the other stations. However, the average weight of a fish at the deeper A-1964 station was greater (0.5 lbs.) compared to that at the M-1968 station (0.37 lbs.). This trend for larger fish offshore also has been noticed by professional divers in the area.

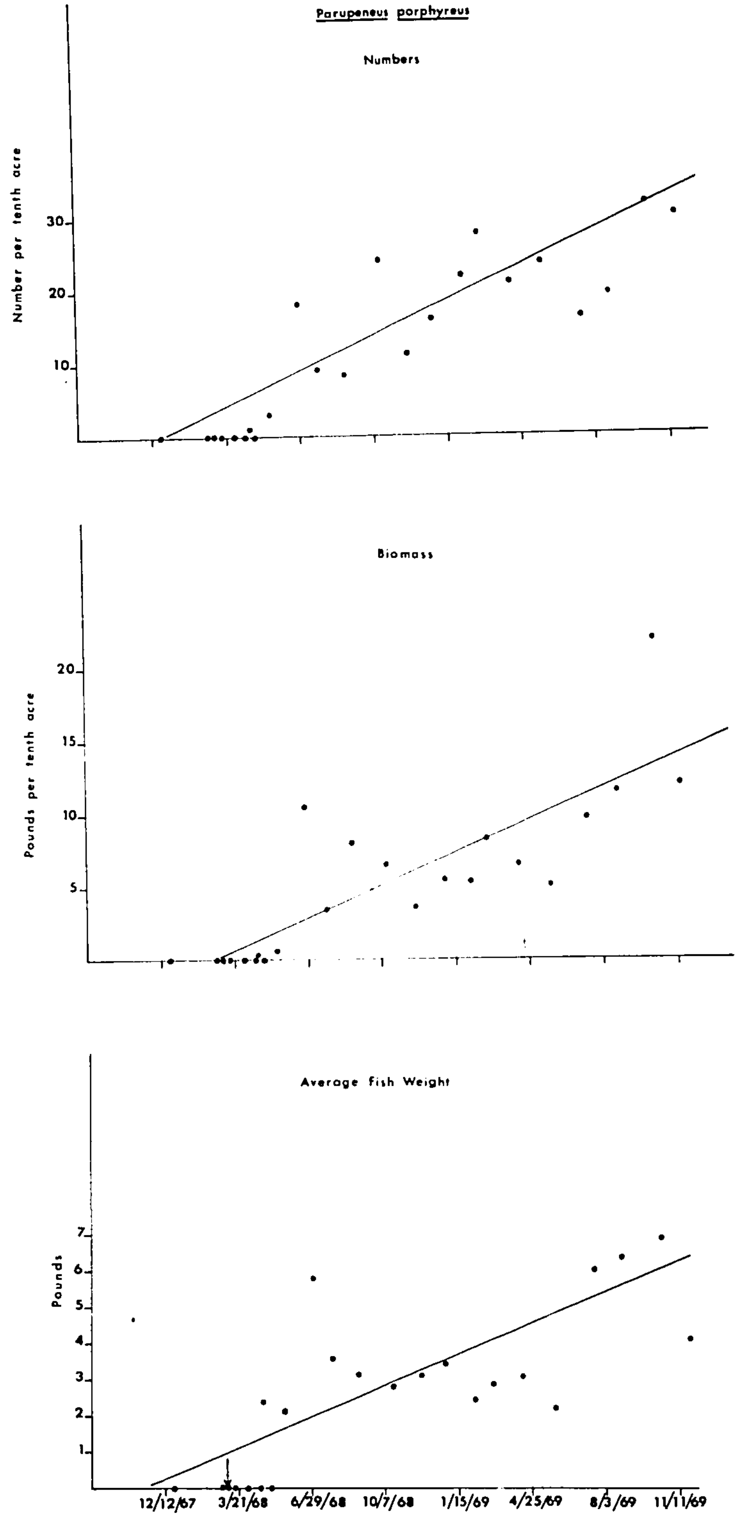
During the day, P. porphyreus was found resting on the surfaces of pipes and on the substrate amid pipe rubble (Plate 18 A). Mahi (1969) believed them to be crepuscular feeders. She also stated that they probably moved off a reef at night to sleep on flat sand near or under rocks. This may explain why none was observed on the artificial reef after dark. Mahi (*op. cit.*) determined feeding time by examining the stomachs of specimens. At the Pokai Artificial Reef, they were observed on one of the dusk dives in feeding behavior which agrees with Mahi's observations. Feeding individuals probed small cracks and crevices in the rock and pipe rubble with their barbels. Stomach contents of twenty specimens, ranging in size from 100 to 150 mm, were examined. Their diet consisted of crabs, shrimps, stomatopods, isopods and amphipods plus an occasional fish.

FIGURE XXVIII

Parupeneus porphyreus--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXVIII

Parupeneus porphyreus



Mulloidichthys samoensis

Mulloidichthys samoensis is an important commercial fish and professional divers were frequently seen over the pipes catching them with large surround nets. They did not appear on the M-1968 site until late July when a school of approximately 120 fish were seen hovering over the transect area (Plate 1). They tended to be a shallow water fish, and very few were observed over the deep station. Individuals on the deep A-1964 station were smaller (0.17 lbs.) on the average than those at the shallower stations (0.30 and 0.37 lbs.).

The data (Fig. XXIX) show a fair correlation to the line of best fit for the number and biomass of fish per tenth acre (P=.05). There was a large fluctuation in their numbers and biomass with time, and this was probably due to the removal of fish by commercial divers. The individual weight of fish on the reef site fluctuated considerably during the study period.

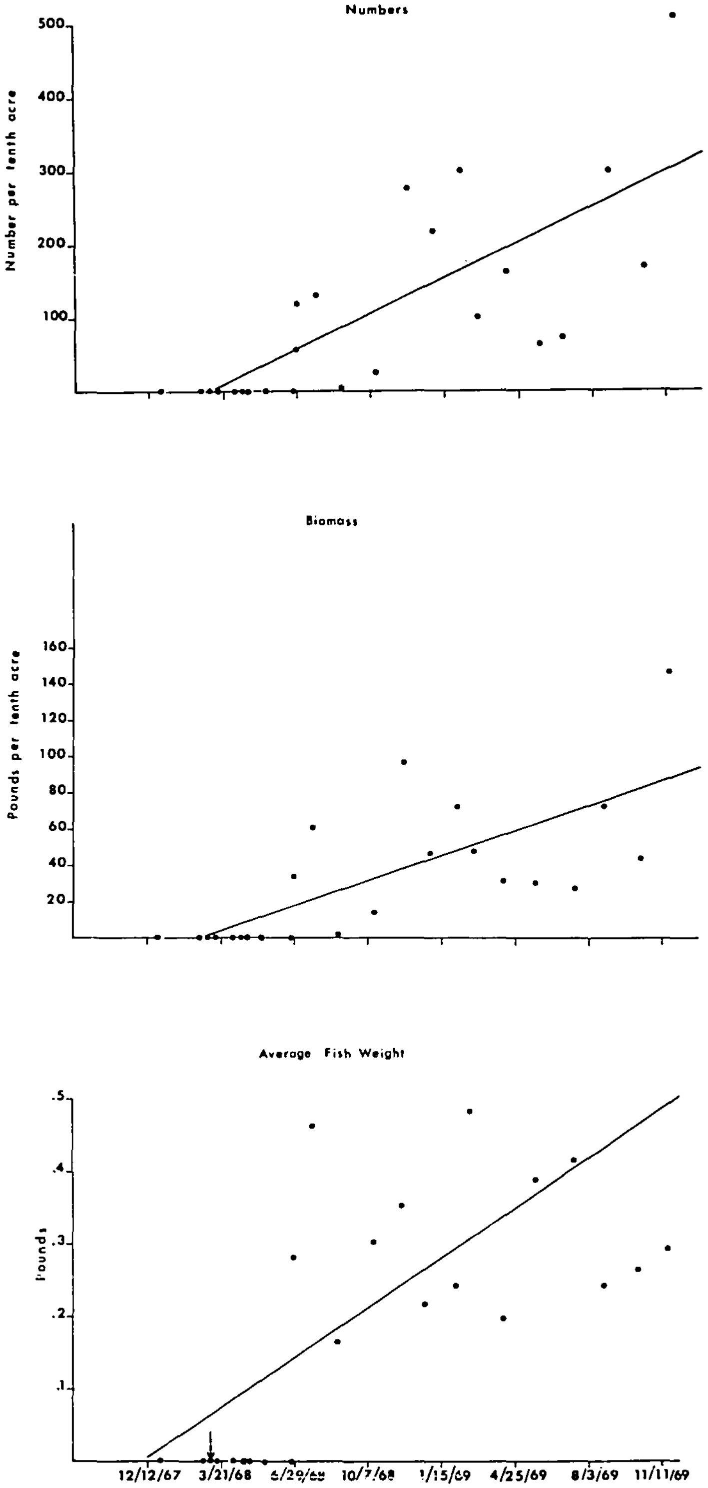
Visual observations showed M. samoensis to be a crepuscular feeder. Schools moved slowly over sandy areas, and groups dipped to the substrate and gulped mouthfuls of sand, retaining utilizable food materials. Several authors (Starck and Davis, 1966; Hobson, 1968) have stated that goatfishes are diurnally schooling species that disperse at night to feed.

FIGURE XXXIX

<u>Mulloidichthys</u> <u>samoensis</u>--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

FIGURE XXIX

Mulloidichthys samoensis



Ctenochaetus strigosus

Ctenochaetus strigosus was one of the most common acanthurids on the reef. Figure XXX shows that total biomass, total numbers and average weight of a fish increased with time for this species. All data show significant correlations to respective regression lines (P=.05). Both increase in numbers and average weight of a fish were responsible for the increase in total biomass on the M-1968 site.

They remained in a home territory, as demonstrated by observations on tagged individuals. Perhaps due to this territoriality, they did not arrive on the M-1968 site until late August, 5 months after the pipes were deposited. There were slight increases in numbers of fish at the A-1964 and D-1966 sites during the study period, but in general, these areas had achieved a fairly stable population by the time this study was begun.

C. strigosus was a diurnal herbivore that fed primarily on the top surfaces of pipes. At night they sheltered in the pipes. Jones (1968) stated that they feed on diatoms and detritus from a calcareous matrix on the rock and dead corals of reefs. Randall (1955) noted that they have trouble feeding on filamentous algae, and that feeding by scraping or possibly by a sucking mechanism is the predominant method. The tops of pipes showed very good diatom growth, and *C. strigosus* grazed widely over the surface scraping off the thin mat of diatoms, associated detritus and other organisms.

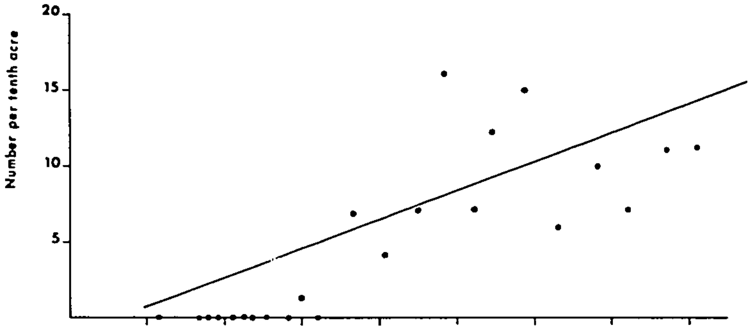
FIGURE XXX

Ctenochaetus strigosus--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef segment was established on 3/7/68 (arrow). Time scale is in 100-day intervals and regression lines were calculated.

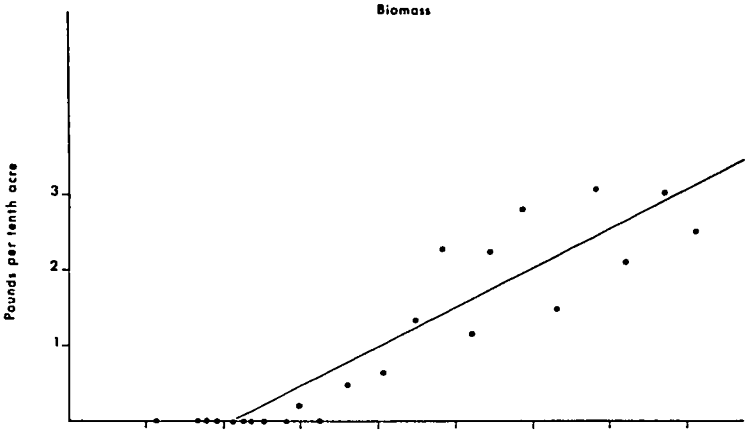
FIGURE XXX

Ctenochaetus strigosus

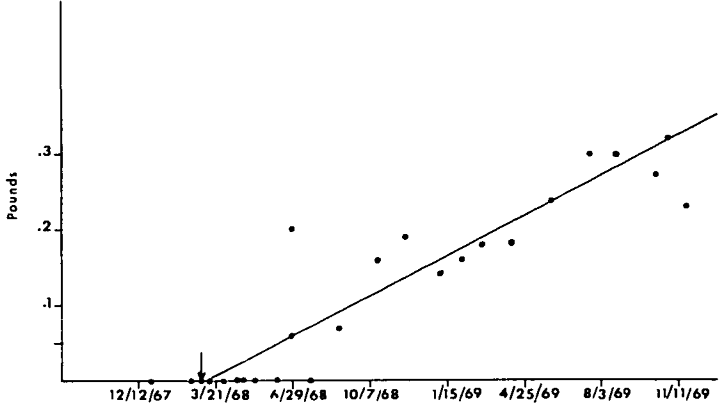
Numbers



Biomass



Average Fish Weight



Chromis verater

Chromis verater, a pomacentrid studied by Swerdloff (1970), was numerous on the artificial reef. Due to their wandering while feeding, they frequently were absent over the fish transect areas. As a result, the data do not show significant correlations to the regression lines on total biomass or total numbers of fish with time in any of the three census areas (Fig. XXXI).

The consistency of values (0.2 lbs.) for the average weight of a fish indicates that the size of fish in feeding schools remained about the same. This is reasonable as the young of this species remained close to the substrate in deeper water and did not appear in the censused population until they reached a larger size.

They fed diurnally on plankton in midwater. Swerdloff (1970) found that the diet of C. verater on the Pokai Artificial Reef consisted primarily of calanoid copepods intermixed with fishes eggs, malacostracans (mysids and euphausids), siphonophores, tunicates (Oikopleura sp.), polychaetes and an occasional molluscan larva, ostracod or chaetognath. The most common copepod genera were: Undinula, Euchaeta, Eucalanus, Scolocethrix and Candacia.

C. verater sheltered in the pipes at night, presumably to avoid predation, and used the pipes as spawning substrates. The largest and most consistent population was associated with the coral mound on the D-1966 study area (Plate 11).

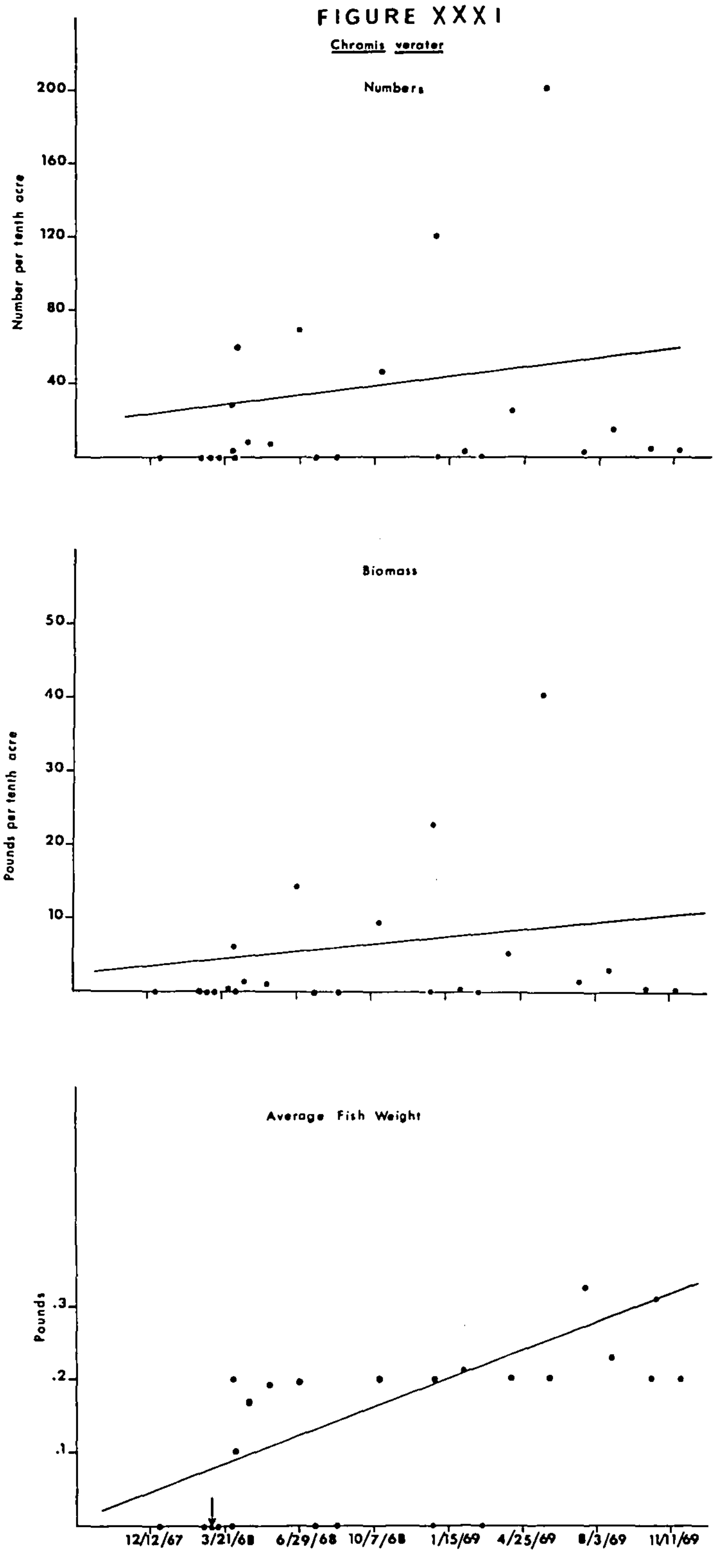
The dense pipe concentration along with the effect of piling pipes against a topographical rise created a good protective habitat.

FIGURE XXXI

Chromis verater--temporal changes on the M-1968 site in average individual weight, and total numbers and biomass per tenth acre. This reef increment was established on 3/7/68 (arrow). Time scales are in 100-day intervals and regression lines were calculated.

FIGURE XXXI

Chromis verater



Discussion and Conclusions.

For many of the preceding species, the data did not fit a straight line regression. The data points for these species were usually distributed widely around the regression line. However, the straight line regression analyses were retained because a relationship could be seen between the correlation of the data to straight line regression and whether or not a fish was an early or delayed colonizer. Those species that showed poor correlations tended to be those that were the first species on the reef, while those that were delayed in their appearance on the reef, generally showed significant correlations. As already mentioned, the delayed colonizers were generally the resident or territorial species, and the early colonizers were, with three exceptions, the migratory species. To further clarify this relationship, the data for each group of species were combined and a regression run on the total biomass and numbers of fishes composing these two groups (Fig. XXXII and XXXIII).

The analyses showed that delayed colonizers had per cent variations of Y due to X of 72 and 64, respectively, for biomass and number of fishes, compared to 23 and 2 for the same parameters in the early-colonizer group. Delayed-colonizing species, predominantly residents, thus showed a much higher correlation to the straight line regression than the early-colonizing migratory species.

FIGURE XXXII EARLY-COLONIZING SPECIES

Summary graph for early-colonizing species recorded in numbers of fishes per one-tenth acre and pounds per one-tenth acre as a function of time with straight line regression analyses. Each datum point represents the total biomass or numbers for the following migratory species: *Acanthurus olivaceus*, *Naso hexacanthus*, *Zebrasoma flavescens*, *Monotaxis grandoculis*, *Chaetodon miliaris*, *Holocentrus xantherythrus*, *Aprion virescens*, *Dascyllus albisella*, *Chromis ovalis*, *Parupeneus pleurostigma* and *Parupeneus multifasciatus*. The arrow at the base of the graph indicates the time at which the pipes were dropped. The time intervals are 100 days.

FIGURE XXXII EARLY-COLONIZING SPECIES

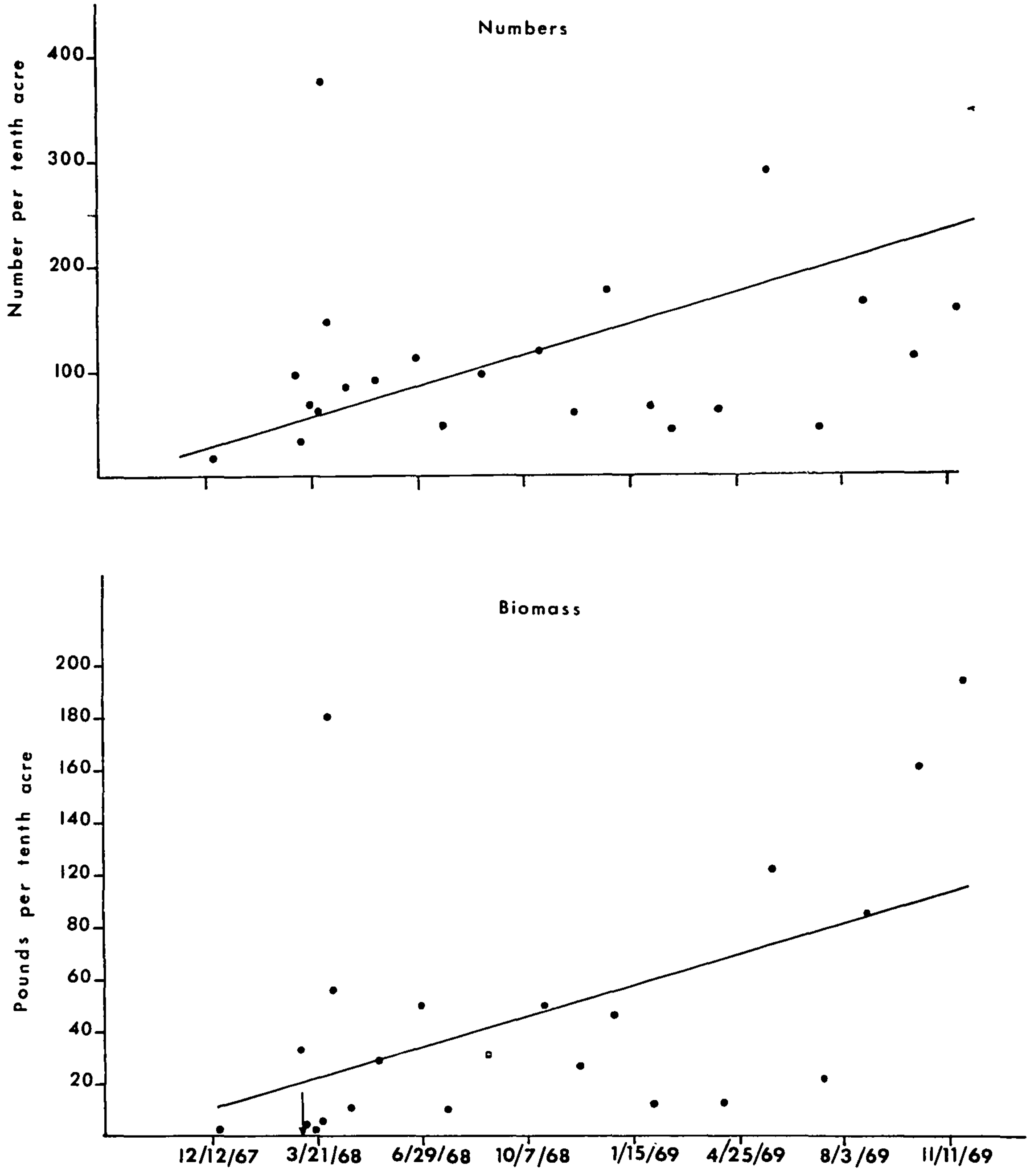
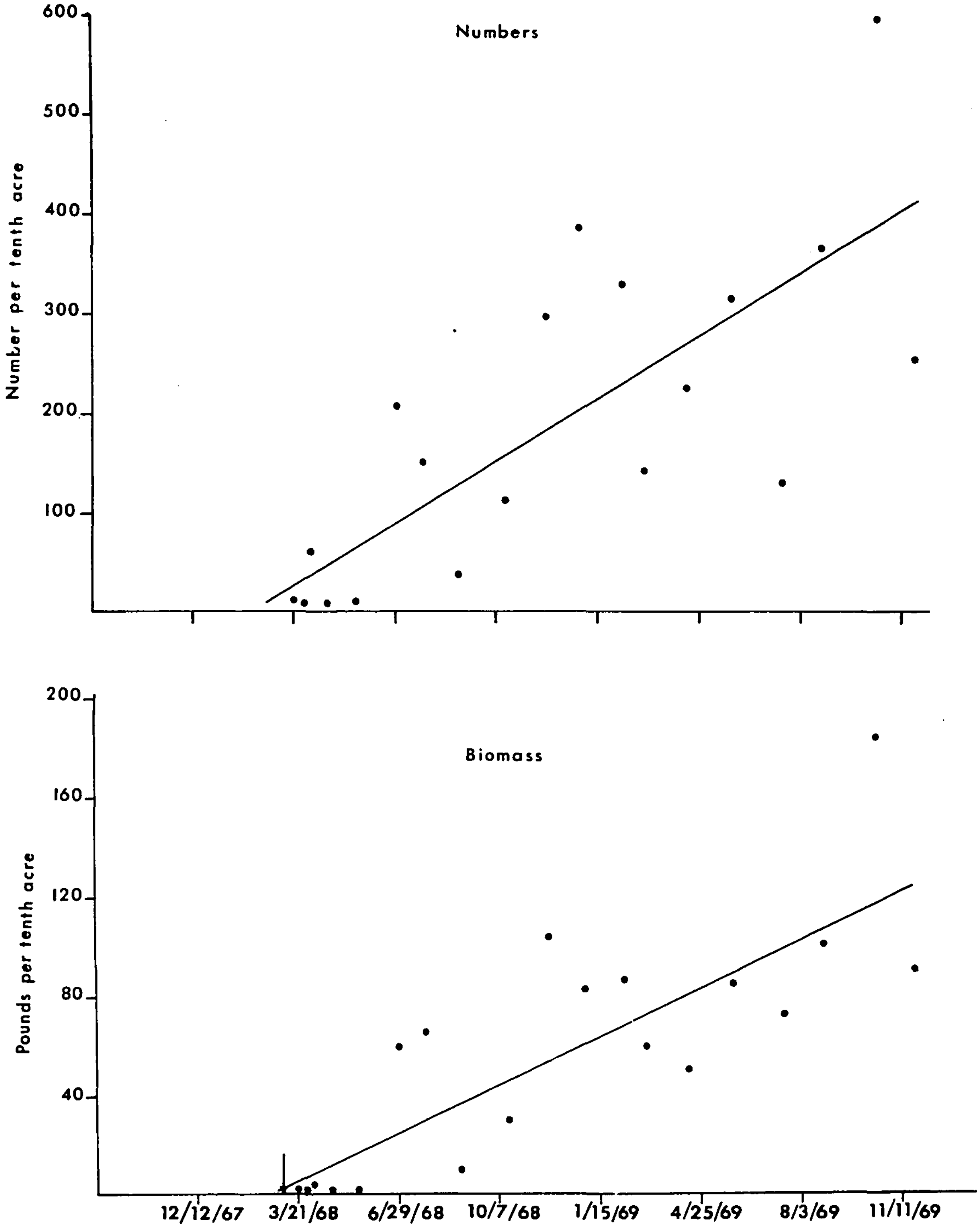


FIGURE XXXIII DELAYED COLONIZING SPECIES

Summary graph for delayed-colonizing species recorded in numbers of fishes per tenth acre and pounds per tenth acre as a function of time with straight line regression analyses. Each datum point represents the total biomass or numbers for the following resident species: *Priacanthus cruentatus*, *Chromis verater*, *Ctenochaetus strigosus*, *Mulloidichthys samoensis*, *Myripristis berndti*, and *Parupeneus porphyreus*. The arrow at the base of the graph indicates the time at which the pipes were dropped. The time intervals are 100 days.

FIGURE XXXIII DELAYED-COLONIZING SPECIES



Observations on feeding behavior showed that 82% of the species studied were carnivores, and there did not appear to be any relationship between feeding habits and early or delayed colonization. However, those carnivores that fed nocturnally on crustaceans (i.e., *Myripristis berndti*, *Priacanthus cruentatus*, *Parupeneus porphyreus* and *Holocentrus xantherythrus*) were resident species that depended upon the shelter of the pipes during the day.

Usually, feeding took place in such a way as to reduce competition between species. This is well exemplified in the goatfishes found on the Pokai Artificial Reef. *Mulloidichthys samoensis*, a crepuscular and nocturnal feeder and *Parupeneus pleurostigma*, a diurnal feeder, fed over sandy bottoms but at different times. *Parupeneus multifasciatus* and *Parupeneus porphyreus* fed over rocky bottoms at different times of the day. *Parupeneus chryserydros* and *Mulloidichthys auriflamma* fed heavily on fishes, but *P. chryserydros* was active in the day while *M. auriflamma* was not.

CHAPTER VI

FISH ABUNDANCE ON THE POKAI ARTIFICIAL REEF

As previously mentioned, abundance of fishes in an area varies depending upon ocean floor topography. In this chapter, comparisons in fish abundance are made between the Pokai Artificial Reef and natural and artificial reef areas studied by other authors. Comparisons are also made between the fish abundance found on the Pokai Artificial Reef and that found on surrounding natural reef areas. Additional factors influencing abundance, such as water transparency, time of day (diurnal rhythms) and pipe configuration, are also discussed.

Relationship to Selected Reef Areas.

Many authors have made estimates of standing crops of fishes in a wide variety of habitats. Estimates representative of tropical environments included in Table III range from 230 to 6,230 lbs/a. The average biomass for natural reef areas (740 lbs/a) was only one-third the average biomass for five artificial reef areas (2,256 lbs/a). Biomass on the Pokai Artificial Reef (2,340 lbs/a) was higher than all natural and artificial reef areas except for the concrete block reef in the Virgin Islands (6,230 lbs/a). The study by Morris (1965) on the three artificial reefs around the Hawaiian Islands showed a large variation in the

TABLE III. A comparison of fish biomass in tropical and subtropical areas.

Reference	Location	Lbs/Acre	Kg/Ha
	Natural Reef Areas		
Randall (1963)	Virgin Islands	1,420	1,590
Wass (1967)	Kaneohe Bay, Oahu	1,120	1,250
Bardach (1959)	Bermuda	440	490
Odum & Odum (1955)	Eniwetok Atoll	400	450
Brock (1954)	Average of 9 Hawaiian areas	320	360
	Average for all natural areas	740	828
	Artificial Reef Areas		
Randall (1963)	Virgin Islands (concrete blocks)	6,230	6,980
Present Study	Pokai Artificial Reef (concrete pipes) Average of 16 censuses	2,340	2,620
Morris (1965)	Pokai Artificial Reef (car bodies)	1,480	1,660
	Maunalua Bay, Oahu (car bodies)	900	1,010
	Keawakapu, Maui (car bodies)	230	260
	Average for all artificial reef areas	2,256	2,506

standing crops of fishes. The Maunalua Bay reef and the Keawakapu reef were composed entirely of car bodies, and both had standing crops less than that of the Pokai car body reef. All three car body reefs showed standing crops less than that found in the present study on concrete pipes. Therefore, concrete pipe reefs appear to be the most attractive to fishes when comparing car body reefs, concrete pipe reefs and natural reefs in Hawaii.

According to Brock (1954), Bardach (1959) and Randall (1963), variations observed in fish biomass (Table III) were probably due to a combination of the nature of the substrates where the censuses were taken and the physical characteristics of the surrounding area. Randall (1963) and Wass (1967) point out that whenever a reef is surrounded by shelterless areas, the biomass estimates will be large. As mentioned, natural areas surrounding the Pokai Artificial Reef offered little shelter to fishes, thus accounting for the high biomass of fishes observed on the reef.

Two methods were used to determine the standing crop of fishes in the above studies. Brock (1954), Odum and Odum (1955), Bardach (1959) and Morris (1965) used a visual census method similar to that employed here (Chapter V). Randall (1963) and Wass (1967) used surround nets and rotenone to collect all the fishes in the area. All biomasses in this chapter are expressed as originally reported (i.e., without regard to the efficiency or accuracy of the technique employed in their measurement).

A comparison of the Pokai Artificial Reef to six natural areas along the Waianae Coast was made during the summer of 1969. The natural areas were chosen randomly by traveling for predetermined times away from the artificial reef. The perimeter of a one-tenth acre area was marked on the natural site by stretching a line between four, concrete, corner blocks. Two divers placed the transect on the bottom and returned to the boat. After waiting 10 minutes to let the fishes resume their positions, a census was taken using an underwater tape recorder.

Table IV summarizes the data for these locations. The transects were conducted immediately offshore of the designated positions (Plate 20). Natural areas showed less biomass and fewer fishes than equivalent areas on the artificial reef. In addition, the average size of fishes on the natural areas was smaller.

The Pokai Artificial Reef provided higher relief and both small and large niches. This greater complexity in habitat may be responsible for the five-to sevenfold difference in fish numbers and the greater species diversity on the artificial reef. The biomass of fishes on all sites of the artificial reef was more than 20 times the average for the six natural areas.

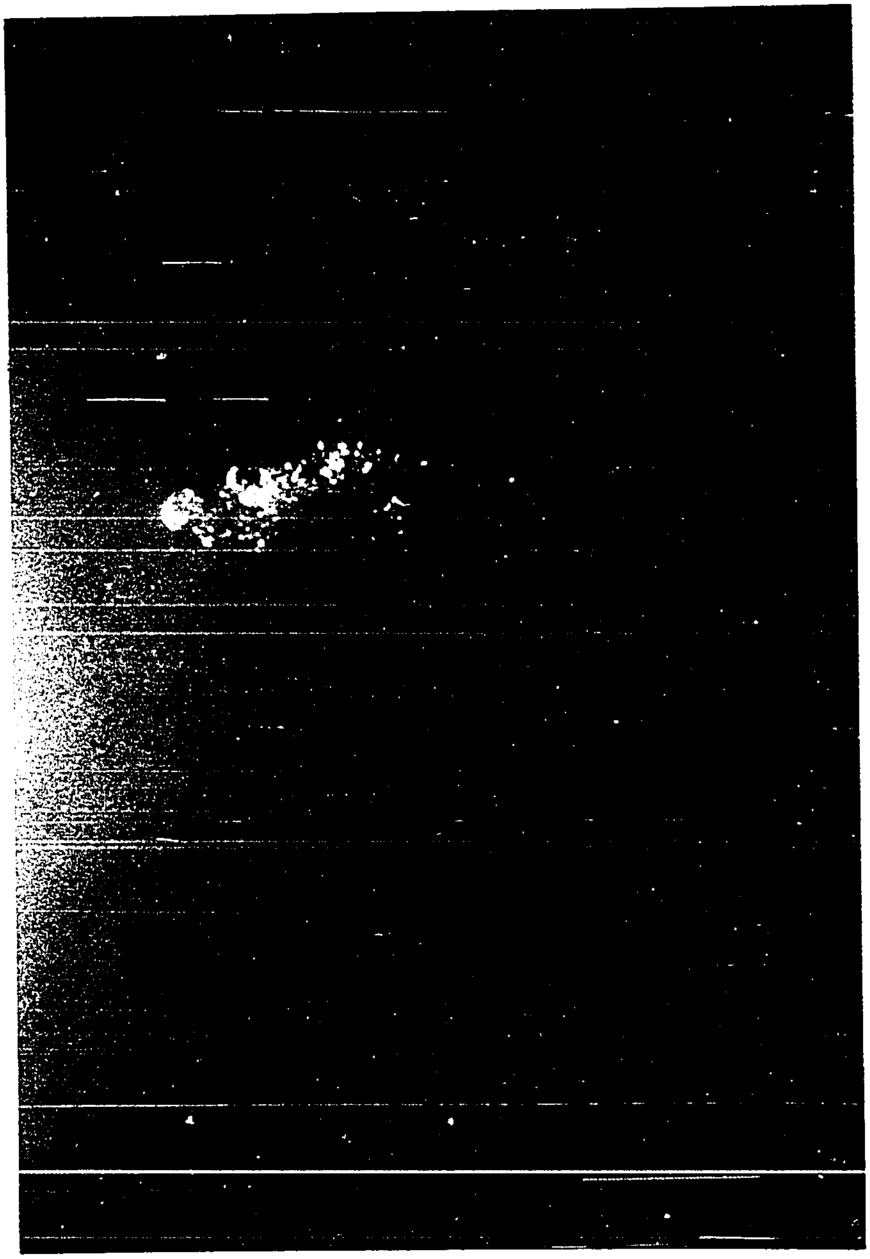
Reasonably, larger fishes would be attracted to the habitats offered by the artificial reef. Possibly, the

TABLE IV. A summary of data concerning fish abundance on six natural areas along the Waianae Coast and on three reef locations during the time period August 2, 1969-September 6, 1969

Location (shore reference)	Water Data (feet)		Fish Census Data			
	Depth	Transparency	No. of Species	No. of fishes	Average weight (pounds)	Biomass per 0.1 acre (pounds)
Puu Mailiilii	80	102	7	15	0.26	3.97
Pokai Bay Marina apt.	50	95	11	38	0.24	3.12
Army Rec. Center	60	69	31	313	0.06	17.73
Waianae High School	80	128	30	119	0.09	11.81
Maipalaoa Park	40	98	28	96	0.12	11.33
Maile Beach	50	131	13	34	0.03	1.10
Average of the 6 transects			20	102	0.13	8.13
Artificial reef values						
A-1964	65	115	51	755	0.28	213.83
D-1966	85	105	47	784	0.25	193.66
M-1968	50	46	60	703	0.44	309.28

Plate 20

Fishes were censused by recording visual sightings along a transect line on a tape recorder mounted in a watertight housing. Substrate shown reflects typical topography of natural areas adjacent to the Pokai Artificial Reef.



presence of larger fishes associated with high relief features precluded the abundance of juvenile fishes on the artificial reef. For instance, two large specimens of *Parupeneus multifasciatus*, a goatfish, were found with juveniles in their stomachs. Other predators were common, and only larger fishes were immune to their attacks. This may account for the segregation of juveniles into areas of low relief until such a time as they reached adult size. Juveniles were frequently seen where there was adequate cover, but juveniles of only nine species were consistently seen on the artificial reef. These were: *Chromis ovalis*, *Chromis verater*, *Bodianus bilunulatus*, *Zebrasoma flavescens*, *Ctenochaetus strigosus*, *Thallassoma duperreyi*, *Coris flavovittata*, *Parupeneus multifasciatus*, and *Parupeneus pleurostigma*. *Z. flavescens*, *C. strigosus*, *T. duperreyi*, *P. multifasciatus* and *P. pleurostigma* were observed in the late summer and fall while the others were observed primarily in the spring. Randall (1963) found that the majority of fishes that colonized his reef were juveniles, while Wass (1967) and the present study indicate that adult fishes were responsible for the greatest upswing in fish abundance.

Relationship to Water Transparency.

Observations early in the course of study suggested that an inverse relationship might exist between fish numbers and water transparency (Plate 21). Thereafter, horizontal water clarity was measured at each fish census to verify this relationship. In each case, a 20-inch Secchi disk attached to one end of a calibrated line was extended between two divers on the bottom until the disk was no longer visible (Plate 22). This method is similar to one described by Bushby (1967).

Water transparency ranged between 13 and 56 m for the three study areas. The deepest stations had an average water transparency of 42 m for the time period May 1968 to November 1969. Mean values for the more shallow D-1966 and M-1968 study areas were 29 and 26 m respectively. These differences were caused by tides bringing clearer water from the northwest or more turbid water from the Maile Point area (Chapter II, Section D).

Figure XXXIV compares the transparency of water and the standing crop of fishes at two of the principal study sites (D-1966, M-1968) on the Pokai Artificial Reef. The relationship appears to be curvilinear. A likely explanation for this is that the fishes involved were migrating with the tide from the Maile Point area to the artificial reef. The fact that more fishes were present as the water became more turbid may reflect the action of heavy surf on the inshore fish populations. As the swells became larger and the water more turbid, fishes moved toward deeper water. The artificial reef served as a focal point for migrating

Plate 21

Typical congregation of fishes on the M-1968 site during turbid water conditions. *Naso brevirostris* is the predominant species.

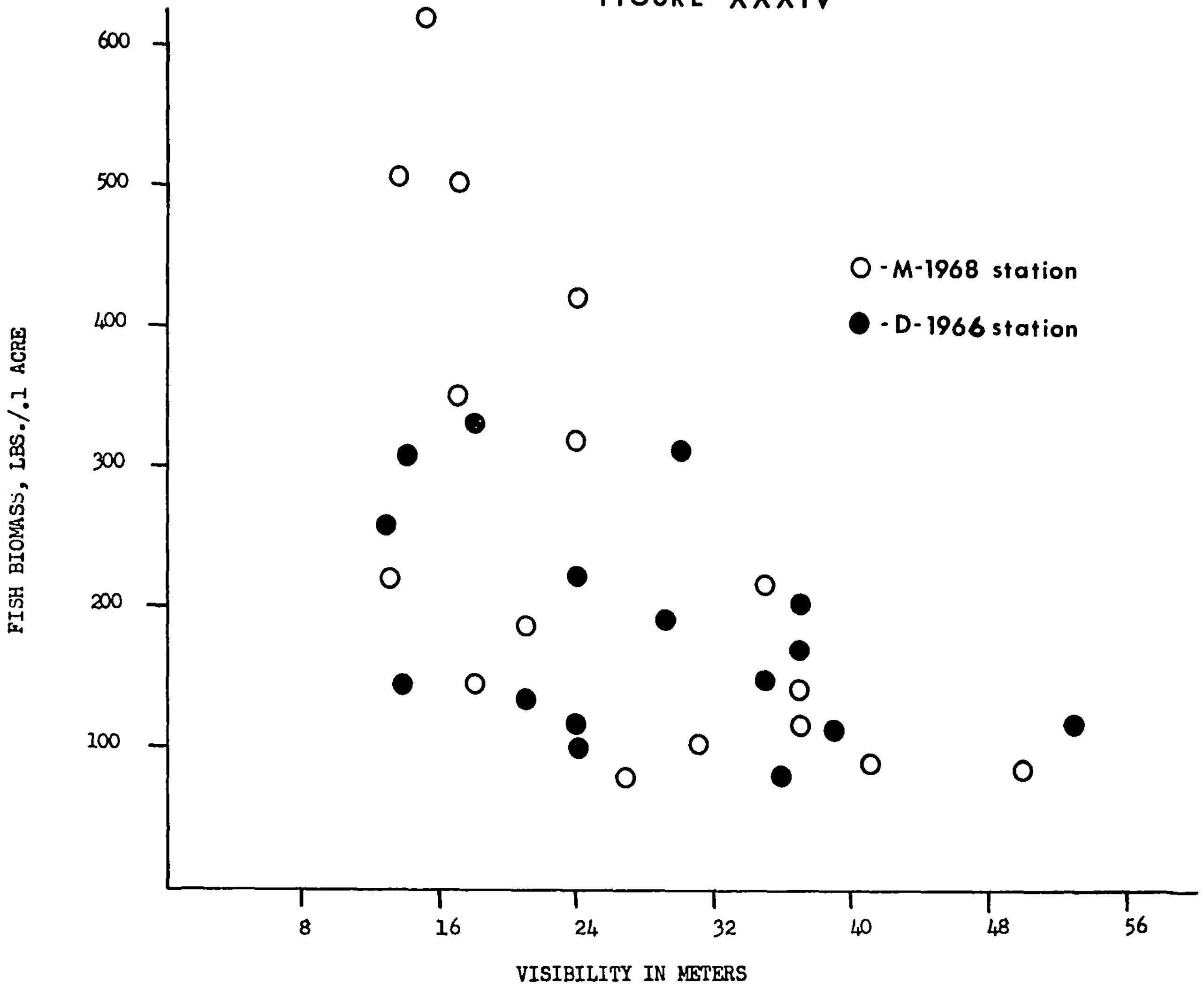
Plate 22

Horizontal water transparency near the bottom was measured with the aid of a Secchi disk and calibrated line.

FIGURE XXXIV

The relationship between horizontal water transparency (Secchi disk visibility in meters) and the standing crop of fishes (pounds per one-tenth acre) on the D-1966 and M-1968 study sites.

FIGURE XXXIV



fishes as it provided better shelter and more orientational relief than the surrounding natural substrate. Observations in all directions away from the pipes showed that the many fishes present during more turbid water conditions were concentrated only over areas containing pipes.

Since turbidity was due to filterable particles suspended in the water mass, analyses of particulate carbon were conducted. Both surface and bottom waters were sampled in various areas on the reef (Plate 23). Two liters of water were filtered through 2.4 cm/Whatman GP/C glass fiber filters that had been precombusted at 400°C to remove residual carbon. The filters were then analyzed for particulate organic and inorganic carbon after the method described by Klim (1969) and based on the method by Menzel and Vaccaro (1964). Summarily, the filters were first acidified to evolve the inorganic carbon as CO_2, then oxidized to similarly decompose organic carbon. The carbon dioxide produced by each reaction was measured with a recording infra-red spectrophotometer. See Fig. XXXV for a diagram of the apparatus. The amount of POC (particulate organic carbon) and PIC (particulate inorganic carbon) in the sample was determined by comparing the area under the recorded curve with the areas under curves obtained for known amounts of carbon. Areas under the curve for blank determinations were subtracted from the sample curve areas.

POC values ranged from 0.04 to 0.13 mg/liter for clear

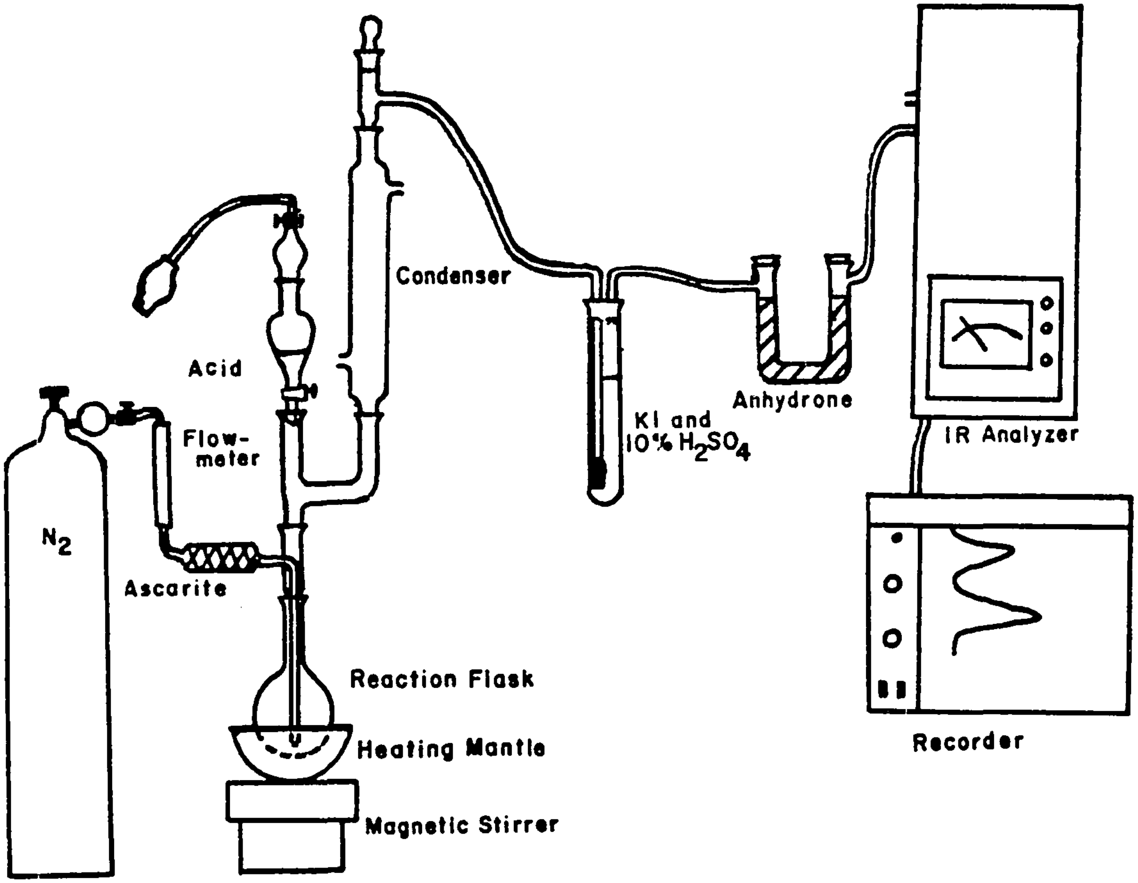
Plate 23

Bottom water samples were taken by clearing surface-filled bottles with air at the selected location.

FIGURE XXXV

Diagram of the apparatus used in the analysis of particulate carbon. Figure is excerpted from Klim (1969).

FIGURE XXXV


Condenser
Acid
Flow-
meter
N_2
Ascarite
Reaction Flask
Heating Mantle
Magnetic Stirrer
KI and
10% H_2SO_4
Anhydrone
IR Analyzer
Recorder

water and turbid water, respectively. PIC ranged from non-detectable to 0.75 mg/liter of water. Highest values of particulate carbon coincided with times of highest surf. The same correlation also held true for PIC. However, the ratio of surface PIC on days of intermediate surf compared to high surf days was less than the POC. This indicates that the surf in and around Maile Point must obtain a certain height in order to lift inorganic particles high enough in the water mass to be carried to the artificial reef on a falling tide. The particulate organic particles being less heavy would stay in suspension longer and require less force to mix them with water. Also, some POC may be attributed to plankton that stays higher in the water mass. When values were compared within each day, the turbid water always contained more POC and PIC than clear water.

The turbid water also was richer in net plankton. Tows in turbid waters yielded three times the mass of plankton as those done in clear waters on the same day. The increase of plankton in turbid water was due to an increase in all planktonic forms. However, copepods (calanoid) and algal bits were slightly more abundant.

A third explanation for the massing of fishes in turbid water may be strictly behavioral. That is, certain species of fish may seek areas of low visibility. However, if this were the sole factor, then the fishes would be distributed evenly throughout the more turbid water, which they were not. Another hypothesis is that a reduction in water transparency and the resultant reduction in light intensity brings about the same behavioral phenomenon as experienced at dusk; namely, that of concentration of fishes around the shelters offered by the artificial reef (see following section).

Relationship to Time of Day.

"It is characteristic that several diurnal activities in fishes tend to increase in frequency or intensity both when light is decreasing and also when it is increasing..." (Woodhead, 1966). Starck and Davis (1966) and Hobson (1965, 1968) showed that the behavior and relative abundance of fishes at any particular locale change considerably as night approaches. Other authors have observed changes in fishes as a function of time of day. Fish (1954) and Winn, *et al.*, (1964) observed fish sound production peaks at dawn and dusk. Randall (1961b) cited several instances of spawning of surgeonfishes at dusk in the Society Islands. Hamashima, *et al.*, (1969) stated that fish schools are concentrated around an artificial reef near Nagasaki Port an hour or two before sunset and an hour or two after sunrise. This same phenomenon was noted on the Pokai Artificial Reef. Observations in the morning and late in the evening indicated that the fish biomass was substantially higher at these times when compared to noon censuses.

An attempt was made to quantify these fluctuations of fish biomass on the Pokai Artificial Reef. Three fish censuses (one at dawn, one at mid-day and one at dusk) were conducted on the M-1968 quadrat area to determine fluctuations in the standing crop and species diversity with the time of day. Unfortunately, due to equipment failure, only two days were sampled successfully. On each of these days, the morning census was made as soon as there was enough light to see. All midday counts were made between 10:00 AM and 2:00 PM, and the dusk count was made within approximately 15 minutes of sunset. Table V summarizes the data obtained on two separate days at the M-1968 study area.

TABLE V. Fish abundances on the M-1968 site at different times of the day.

Date	Time	Number per 0.1 a		Biomass (lbs. per 0.1 a)
		Species	Individuals	
7-9-69	dawn	44	325	131
	noon	47	573	227
	dusk	46	727	448
8-29-69	dawn	48	507	270
	noon	51	310	98
	dusk	52	832	1484

The tremendous increase observed in the evenings was due primarily to large schools of <u>Naso</u> <u>brevirostris</u>, <u>N.</u> <u>hexacanthus</u>, and <u>Acanthurus</u> <u>olivaceus</u>, although other fish such as Acanthurus sandvicensis, Scarus dubius, Monotaxis grandoculis, Mulloidichthys samoensis and Caranx melampygus were also more abundant.

Generally, the herbivores and carnivores that fed primarily during the day retreated in shelter during the night. Those fish that fed at night, such as holocentrids, apogonids, etc., and those that fed primarily upon invertebrates (e.g., crustaceans) left the shelter of a reef during the nighttime hours.

At dusk all species milled around behaving much differently than during the day. Coloration began to change from daytime to nighttime patterns. As night approached, the Acanthuridae, Scaridae, Labridae, Chaetodontidae and Pomacentridae became restless and later could be seen in the shelter of the pipes. The Apogonidae, Holocentridae and Priacanthidae became more active and ventured further from the pipes. These observations agree with those of Hobson (1956, 1968), and Starck and Davis (1966). Breder (1948) observed that the pomacentrid Abudefduf and certain species of the genus Acanthurus rest near the bottom at night.

These data suggest that the artificial reef had the important function of providing night cover for diurnal fishes and day cover for nocturnal fishes in the area. The activity observed at dusk resulted from an intermixing of fishes leaving the pipes and those arriving for shelter. The fact that large piscivorous fishes were attracted to this concentration also adds to fish abundance at this time. Aschoff (1964) points out that an ecological niche has too often been viewed as a niche in space, whereas there are also niches in time. Thus, competing species may become sympatric in space by being allopatric in time. This certainly seems true on the Pokai Artificial Reef where a niche may be occupied by one species in the daytime and another species at night.

The question may arise as to why the biomass in the early mornings was not higher. The answer probably lies in the fact that the census were not conducted until there was enough light to see the various species of fish without having to use an artificial light. Hobson (1968) pointed out that the use of an underwater light biases data towards those fishes which are attracted to light. Evidently, the fishes which came onto the reef the previous night had already departed into the surrounding area. This would seem to be the case as the nocturnal feeders, holocentrids, apogonids, and priacanthids, had already returned to their pipe shelters.

The high biomass obtained at noon on July 9, 1969, was the result of a large school of Heniochus acuminatus that swam into the transect area. Generally, the biomass at noon was less than that of morning and evening. Three studies, for which no quantitative data were retained on the tapes due to malfunction of the tape recorder, illustrated noticeably greater biomass during morning and evening observations. The data for August 29, 1969, therefore, gave a more realistic representation of fish biomass fluctuations since it seemed to corroborate the three unrecorded observations.

Visual observations at other times of the day indicated that fish populations on the reef were relatively stable between 9:00 AM and 3:00 PM. This, of course, varied with length of day at different times of the year and water transparency.

Relationship to Pipe Configuration.

Observations on other artificial reefs have shown that the arrangement of the substrates is a decisive factor in the attraction of fishes and mobile invertebrates to the reefs (Unger, 1966; Randall, 1963; Ogawa, 1966; Walford and Clark, 1967). Configurations of pipe which included variations in numbers and spatial relationships were studied at the Pokai Artificial Reef with respect to the numbers and biomass of important biota. Censused were single pipes, various arrays of two pipes, and a larger group of 11 pipes (Plate 24 A). Numbers of fishes and mobile invertebrates, and approximate fish biomass associated with specific pipe groups was recorded on an underwater writing slate. Whenever possible, individual pipes of approximately the same size were sampled.

Plate 24

Some simple pipe configurations evaluated for their effect on fish abundance.

A

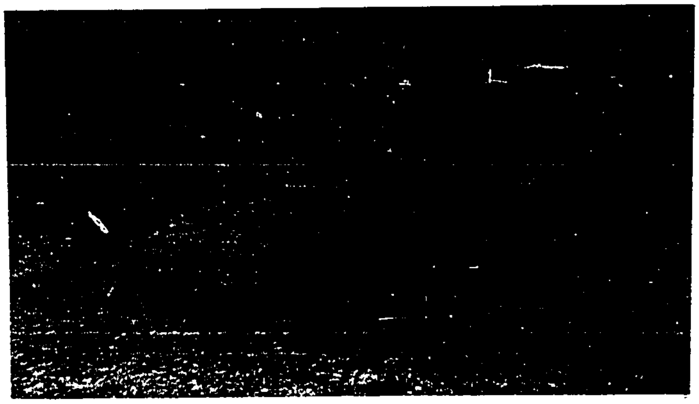
Single pipe.

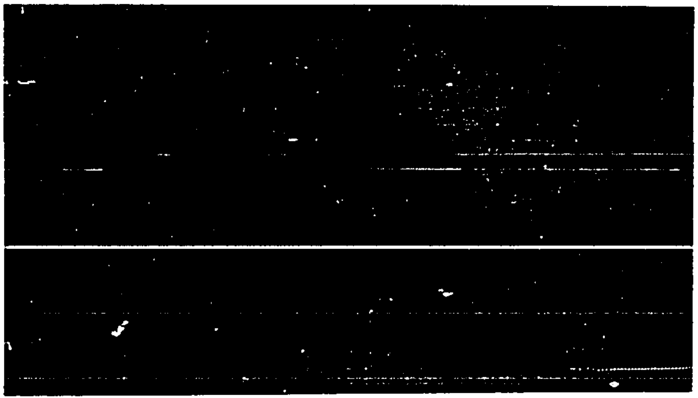
B

Parallel and perpendicular pipes.

C

Nested pipes.





Finding pipes adequately separated from surrounding pipes and ones that fitted into the configurational categories was very difficult. Because of this and the great differences in pipe sizes as well as the variation of surrounding natural substrates, statistical analyses were not attempted. As a result, this section is meant only to give an indication of the influence pipe configuration has on biotic concentrations.

One difficulty in counting involved separating migrant from resident fishes. Even species observed to wander widely would sometimes remain near particular pipe groupings during the course of a day. Fishes actively seeking shelter in or under the pipes being censused were considered to be associated with that respective pipe community.

Nine individual pipes (Plate 24 A) were sampled by direct observation to determine the abundance of fishes and invertebrates. Three pipes were examined on the A-1964 site, five on the M-1968 site and one on the D-1966 site. An assumption was made that there would be no difference in the attractive qualities of individual pipes between stations.

Two pipes could be oriented to each other in a variety of ways. The most common arrangements on the reef were parallel, perpendicular and nested (one within another) (Plate 24 B, C). Three censuses were made for each of these arrangements, and their averages were expressed on a unit pipe basis to enable comparison with the average values for the nine single pipes. These data appear in Table VI.

Mobile invertebrates consisted primarily of hermit crabs *Dardanus* sp.; a grapsid crab *Percnon planissium*; a banded shrimp *Stenopus hispidus*; urchins *Echinothrix*, *Eucidaris*, *Tripneustes*, *Chondreocidaris* and *Heterocentrotus*; gastropod mollusks *Cerithium*, *Cypraea*, *Conus*, *Mitra* and *Thais*; and the starfishes *Linckia* and *Culcita*. Most of these were located in the crevices where the pipes met the substrate or in the enclosed spaces between adjoining pipes. Unfortunately, many of the small shrimps and xanthid crabs, important to the food web of the reef, were too small to be observed easily in the field and were not included. The most common fishes generally associated with the pipes were *Holocentrus*, *Myripristis*, *Apogon*, *Canthigaster*, *Dascyllus*, *Ctenochaetus*, *Paracirrhites*, *Gymnothorax*, *Forcipiger* and *Zebrasoma*.

The most productive configuration (Table VI) was the nested pipe design. However, the parallel pipe arrangement proved to be a close second in desirability for fishes. The number of fish species increased as the complexity in pipe arrangement increased. The number and biomass per pipe was three to five times greater for nested and parallel pipe designs than for solitary pipes. The values for pipes perpendicular to one another did not differ significantly from the single pipe determinations. There were actually fewer fishes associated with the perpendicular pipe design

TABLE VI

BIOTA ASSOCIATED WITH SINGLE AND DOUBLE PIPE CONFIGURATIONS

Parameter	Single pipe	Two Pipes Parallel	Two Pipes Perpendicular	Two Pipes Nested
No. of fishes per pipe	6.0	16.3	3.2	19.0
Biomass of fishes per pipe (pounds)	0.5	2.2	0.2	2.4
No. of fish species per pipe design	2.8	6.7	3.7	8.3
No. of invertebrates per pipe	3.6	2.6	4.3	5.1

than with single pipes, but this could be due to the small sample size.

The invertebrates do not show well-defined trends, perhaps because they seemed more dependent upon the natural substrate around the pipes than the actual configuration of the pipes. Wherever the substrate under the pipe had many small holes, a large quantity of algae, etc., there were more invertebrates. Furthermore, greater difficulty was encountered in locating many of the invertebrates as pipe configuration increased in complexity.

The degree of protection offered to the biota was the primary difference between the various designs. Single or perpendicular pipes did not provide good protection. The large exposed interior of a pipe offered no seclusion. Only when one pipe was placed within another, or when two pipes lay in parallel contact to form a third enclosure between them and the bottom, was there a good retreat gradient with consequent diversity and abundance of fishes.

The most productive artificial reef consisted of many pipes stacked together and within one another so as to provide the maximum diversity in habitat area. A census of 11 pipes stacked close to one another showed 71 fishes of 25 species (12.1 lbs.) occupying an area 30 feet long by 10 feet wide. In comparison, two pipes within approximately the same area showed 6 fishes of 4 species (0.47 lbs.). Forty-three mobile invertebrates were also tallied within the area containing the 11 pipes. This high diversity and abundance within a small area was indicative of the complexity of habitats offered when pipes were concentrated rather than spread widely over the bottom.

Summary.

An important point to be gained from the above information is that any comparisons of fish populations must take into consideration factors such as time of day and behavioral characteristics of fish populations with different water conditions. Fish censuses at different times of the day showed large fluctuations in fish biomass. Evening estimates were at least twice those of noon, and there also appeared to be more fish in the early morning. An inverse relationship was found to exist between water clarity and fish abundance. The attraction of fish to the Pokai Artificial Reef during turbid water conditions appeared to be due to an increase in available food (plankton) and/or a behavioral characteristic where fishes approach shelter under reduced light conditions. Approaching areas of shelter under low light conditions may also be related to diel behavior patterns of some species.

The pipe configuration study demonstrated the importance of complexity of habitat as an influence on the standing crop of fishes and species diversity. When the pipes were arranged so as to provide maximum diversity in habitats, there was a substantial increase in the number of fishes associated with the area. The artificial reef had approximately 25 times more biomass than natural area in the same vicinity. The natural area had a larger percentage of juvenile fishes which may indicate that the larger habitats offered by the artificial reef or the presence of more predators, among other factors, may limit the numbers of juveniles on the artificial reef.

CHAPTER VII

HERBIVORE GRAZING STUDY

Randall (1961a) observed that the sparse algal growth in deeper waters around Hawaii may be due to the heavy grazing intensity by fishes. He constructed one-inch wire mesh cages to keep grazers off selected substrates and noted that algal growth was two to four times greater in the cages than on surrounding substrates. In another study in the Virgin Islands, Randall (1965) demonstrated that the lack of sea grasses at the fringes of most coral reefs may be the result of heavy grazing by fishes. The greatest grazing intensity was at these areas, because the proximity to coral would offer the herbivores protection. Observations of Pokai Artificial Reef pipe surfaces showed evidence of grazing both on algae and encrusting invertebrates (Plates 25 and 26), and large concentrations of grazers were occasionally observed (Plate 14). The following study was initiated to determine to what extent this grazing influenced the species composition and standing crop of algae on the reef substrate.

Fragments of pipe and cement blocks were placed inside three cages of varying wire mesh size ($\frac{1}{4}$ inch, one inch, and two inch). Each cage had a flap of wire which could extend over another pile of substrate to act as a control (Plate 27). Each control substrate was therefore subject to the same overhead lighting conditions and accessibility for

Plate 25

Marks where Acanthuridae have grazed algal growth on the surface of a pipe.

Plate 26

Marks where Scaridae have grazed the black, encrusting bryozoan *Holoporella pilaefera* (in center foreground).

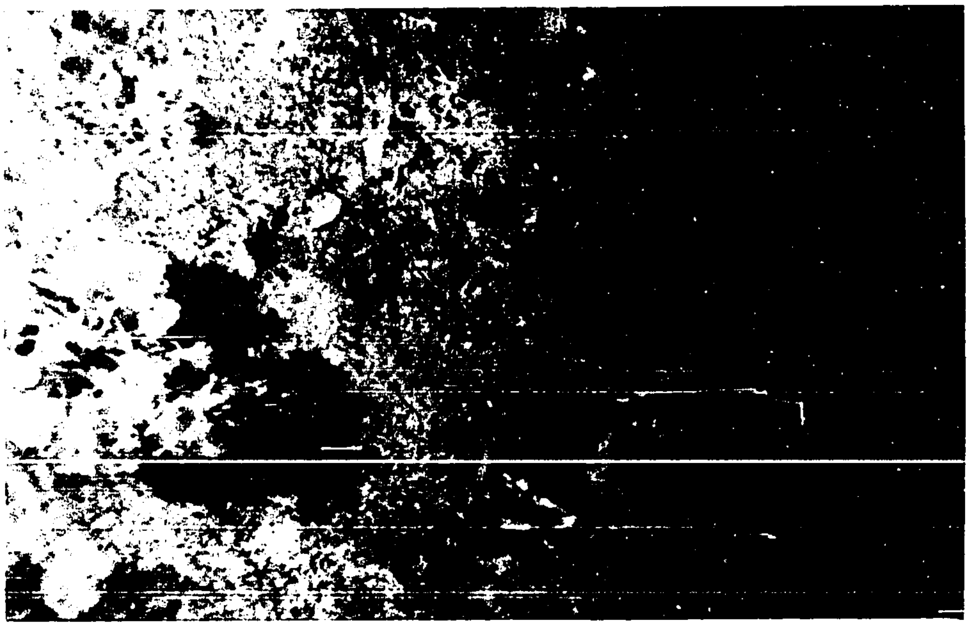
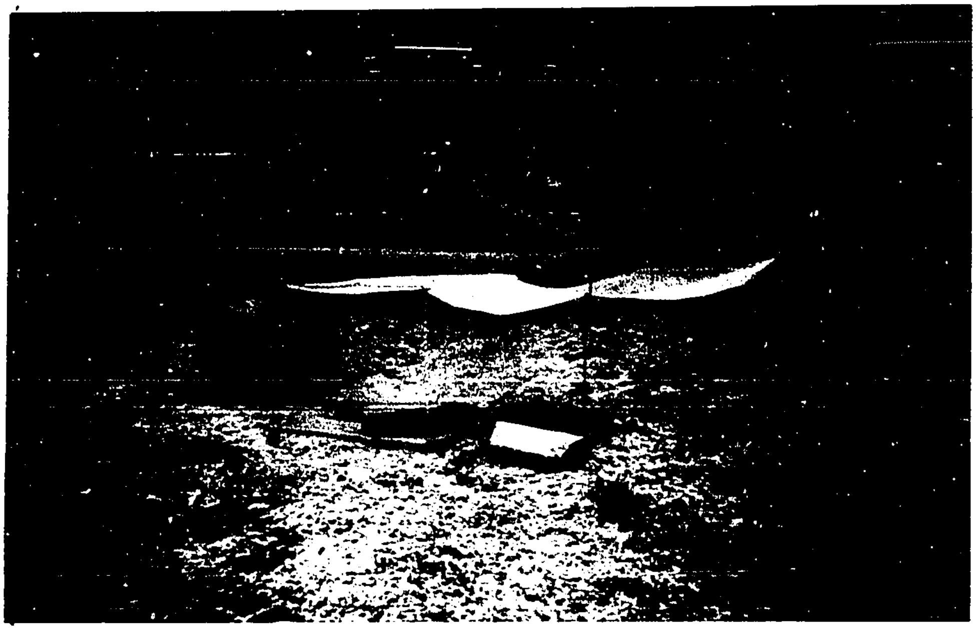


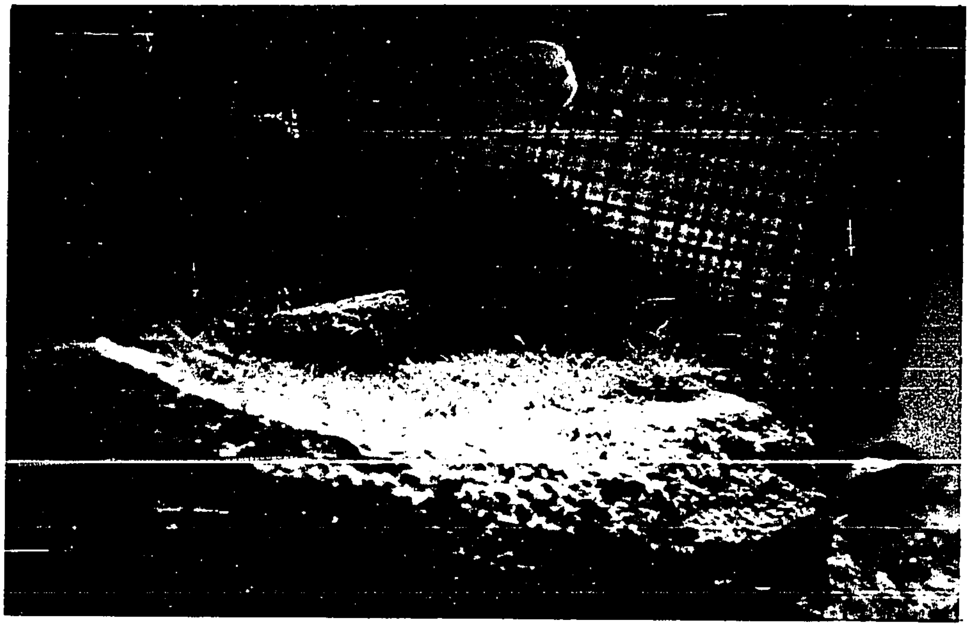
Plate 27

Fresh concrete fragments within and beside exclusion cage used in grazing study.

Plate 28

Algae on protected substrate removed from one-inch mesh, wire cage. Growth for the 6 week period is approximately three times that of either control.





grazing by fishes and invertebrates. In addition, another pile of substrate with no wire cover was placed adjacent to each cage to act as controls for the effect of lighting conditions. Initially, these cages were left on the M-1968 site, June 4 through July 7, 1969, and then photographs were taken and a comparison made between the various substrates. A second immersion of 6 weeks, August 15 through October 3, 1969, was conducted at the D-1966 site with epoxy-coated wire cages. Photographs were taken at two-week intervals and comparisons made between the different substrates. A quantitative measurement was to be made at the conclusion of this test, but the cages were destroyed by large swells after the last photographs were taken on October 3, 1969.

In the first test, results showed poor algal growth within the one-fourth-inch mesh cage, a result of either excessive shading or zinc toxicity from the galvanized wire. The algae on the substrates in the one-inch mesh cage showed increased growth, while those in the two-inch mesh cage showed no significant change. Small fishes, _Acanthurus nigroris_, _Zebrasoma flavescens_, and _Centropyge potteri_ could be seen entering the two-inch mesh cage to graze on the algae. Presumably, the algae remained at the original level due to this grazing.

The second test, utilizing epoxy coated cages to occlude zinc influence gave approximately the same results.

The algal growth in the one-fourth-inch mesh cage was reduced, apparently because of lowered light intensity. Increased algal growth was observed in the one-inch mesh cage, and the two-inch mesh cage showed no difference from its control.

In both tests the control substrates, those under the flaps of screen and those in the open, showed no difference in algal height from the initial levels. Examination of the algal community in the one-inch mesh cage showed the height of algae was approximately three times that of its control or any of the other substrates (Plate 28). The dominant algae were still the blue-greens, *Shizothrix calcicola* and *Lyngbya majuscula*, but scattered throughout were growths of the reds, *Polysiphonia* sp. (previously unrecorded), *Herposiphonia* sp., *Asterocytis ramosa* and *Amansia glomerata*; the brown, *Dictyota divaricata*; and the green, *Neomeris vanbosseae*. All of these thalli were larger than any found on substrates open to grazing. *Polysiphonia* and *Asterocytis* were found only on enclosed substrates. The number of diatoms had also increased to form a heavy coating on all surfaces.

The hypothesis that the species composition and standing crop of algae on the surfaces of pipes was determined by the preferential grazing of herbivores in the area appears to be valid.

In addition to studying the algal community, observations were made of the most common herbivores in the area. The herbivores observed grazing or browsing on the surfaces of the pipes were the fishes: *Acanthurus nigroris*, *Acanthurus nigrofuscus*, *Ctenochaetus strigosus*, *Zebrasoma flavescens*, *Naso lituratus*, *Scaridea zonarca*; and the urchins: *Tripneustes gratilla* and *Echinothrix calamaria* (Plates 13 and 14).

The urchins appeared to be indiscriminatory feeders, and they rasped over large areas of the substrate both inside and outside the pipes. *Tripneustes gratilla* fed on the algal mat on the surfaces of pipes and was seen actively feeding during the day. *Echinothrix calamaria* was observed occasionally on the surfaces of pipes but more often was seen on the interiors of the pipes apparently feeding on bryozoans and tunicates. At night it became more active and moved rapidly over the top surfaces of the pipes, as well as the interiors, rasping off algae and other sessile biota.

Jones (1968) stated that *Acanthurus* and *Zebrasoma* rely on fine filamentous algae while *Naso* tends to feed on the larger algal species. He also found that at the generic level only 38% of the available browns, 33% of the greens, 15% of the reds and 8% of the blue-greens were eaten. This indicates selective feeding, and by process of elimination, the most abundant, observable algae would be those considered undesirable by the herbivore population. On the pipes at Pokai Artificial Reef these are the blue-greens (Cyanophyta).

The fact that more algae grew when grazing intensity was reduced is indicative of the herbivore community's dependence on this source of food. The pipes offered more grazing area to herbivores than was originally present on the natural substrate. This was especially true if pipes were located over sand areas where epilithic algae was unable to grow on the natural substrate. The additional grazing area provided by the pipes probably made it possible to support a higher population of herbivorous fishes.

CHAPTER VIII

DISCUSSION AND CONCLUSIONS

This study reinforces previous information that artificial reefs can effectively increase the standing crop of marine biota on a selected area. The fish biomass on the Pokai Artificial Reef increased 25 times or more within one month after establishment. Several factors interacted to bring about this greater abundance. First, observations showed that faunal biomass increased as the pipes became more concentrated, suggesting that physical complexity of habitat may be the most important parameter in increasing the abundance and diversity of marine fauna. Second, there is evidence (i.e., the concentration of itinerant fishes around the reef on turbid water days) that fishes are orienting to the topographical relief provided by the reef. However, there was difficulty in separating this orientation from the attraction that shelter provides, and as a result, no firm conclusions were drawn. A third factor to consider is that artificial reefs provide food for many fish species. The herbivore exclusion study demonstrated that pipe surfaces provided additional amounts of algal material for the herbivorous fishes as well as sessile and mobile invertebrates for carnivorous fishes. The carnivorous fishes were observed feeding on the small shrimps and crabs which were found in the crevices and holes associated with the pipe substrates. Scarids were observed grazing on encrusting Bryozoa. Larger predators such as carangids were also observed feeding on various small fishes associated with the reef.

All of the foregoing points bring out the important role that artificial reefs play in the increase of fish abundance. Factors influencing fluctuations in fish abundance were also revealed in this study. In the study on fish biomass in relation to time of day, itinerant, diurnal fishes, presumably wide-ranging in the surrounding area, were found in the shelter of pipes at night. Nocturnal fishes were found in the pipes during the daylight hours. The artificial reef was, therefore, acting as a central orientation and shelter point from which the various species of fish radiated into the surrounding areas in search of food. This resulted in higher fish populations at dawn and dusk.

Turbid water caused by high surf and the resulting low visibility brought an increase in abundance of fishes around the artificial reef. Observations showed that there was not an abundance of fishes over natural areas in the vicinity of the artificial reef during the turbid water conditions. The behavior of fishes at this time was similar to that observed at dusk (i.e., approaching shelter and increasing activity). This suggests that some factor common to both conditions, such as low light intensity, may induce this behavior.

For further study on fish abundance, natural reef areas along the Waianae Coast were compared to the Pokai Artificial Reef. The fishes were two to four times larger, and the biomass was 25 times greater on the artificial reef than the average for the random counts on the natural areas. There also was a greater percentage of juvenile fishes on natural reef. These differences were probably the result of the variety in the habitat available. Increase in number and size of shelters on the artificial reef provided habitats for larger and more fishes, while the smaller holes and crevices on the natural reef appeared to be better suited for juvenile habitation. Possibly, the larger fishes associated with the artificial reef tended to prey upon juvenile fishes and thereby reduce their numbers.

Invertebrates and algal abundances were more difficult to quantify than fish abundance. The additional niches and substrates provided by the artificial reef, censused by a variety of means, all showed significant increases in the amounts of flora and fauna. Floristic abundance seemed to depend upon the availability of hard substrate exposed to adequate sunlight as well as grazing intensity. Invertebrate abundance was dependent primarily upon small crevices and holes for shelter, hard substrates for attachment, and grazing intensity.

The study on the recruitment of fishes showed that movement onto the Pokai Artificial Reef was entirely random with no particular area contributing more fishes than another. Resident species of fishes in the natural areas adjacent to an artificial reef did not necessarily migrate to the new area. The majority of these fishes remained in the area where they were tagged. Migratory fishes were more likely to be the first colonizers of a reef while resident fishes generally fell into the category of delayed-colonizing species. Graphs on average individual fish weight for most of the delayed-colonizing species indicate that a significant portion recruited were juveniles that later matured on the site. However, certain adult fishes were occasionally found in the transect areas prior to the time that the juvenile recruits had obtained full size. This would indicate an overflow of adult fishes from the surrounding natural areas. The increased biomass on the reef, therefore, would be due to a combination of growth of fishes on the reef as well as concentration of itinerant and "overflow" fishes from the surrounding reef areas.

The factors responsible for increasing fish biomass (i.e., substrate complexity, orientation of fishes to topographic relief and availability of additional food) also interacted to influence the succession of biota onto the Pokai Artificial Reef. Initially, fishes were probably attracted solely to the protection offered by the reef. Their biomass, composed primarily of itinerant fishes, doubled within the first three days. This was long before the sessile biota had developed enough to provide food. Next, large numbers of herbivores appeared (within two weeks). Biomass estimates one month after the M-1968 pipes were deposited were approximately 100 times that of the original census. At this point, the additional food offered was the primary reason for increase. However, the herbivores quickly grazed the long algal growth, and within two to three weeks after the biomass peak, an equilibrium was reached where the number of herbivores was in apparent balance with algal production.

A herbivore exclusion study not only demonstrated that more algae is available on the pipes for herbivores, but it showed that the herbivores determined the species composition of observable algae on the pipes. Fishes grazed selectively, leaving mainly blue-green algae on the surface of the pipes.

The majority of resident carnivores did not appear on the reef for 4 to 5 months. The complexity of invertebrate communities would take at least this long to develop so that resident carnivores could find additional food. Among those that appeared later were planktivores such as Myripristis, Priacanthus and Chromis. These genera did not depend heavily on the development of sessile communities, however, they did need diurnal shelter. Their time of arrival coincided with the period when most juveniles were available for recruitment.

The succession of algae and invertebrates was studied for a period of 30 months. However, dated surfaces up to 69 months in age were available for comparisons. Generally, an equilibrium of all biota was obtained by the time the sessile invertebrate communities reached the climax condition characteristic for the Pokai Artificial Reef area. This usually took about 18 months. The climax condition for the sessile invertebrate communities on pipe exteriors consisted primarily of a mat of blue-green algae intermixed with small colonies of the corals Pocillopora meandrina and Porites lobata, mesogastropod limpets, vermetids and occasional oysters. The relative abundance of these biota may change depending upon predation or environmental conditions, but the constituents remained the same. The interior roof of the pipe had a climax community consisting primarily of oysters with bryozoans, tunicates, and calcareous and siliceous sponges scattered in the crevices between oysters.

The sequence of events leading to climax communities in pipe zones is as follows: The first noticeable biota on the exteriors of pipes were diatoms. Thereafter, the algae most available in the plankton settled on the pipes. If these species were favored fish food, they were grazed down and eventually the blue-green algae, which were not generally selected by fishes, became predominant. Invertebrates, such as corals, mesogastropod limpets, vermetids and oysters, took up to a year before they became a noticeable part of the exterior community.

On the interiors of the pipes the hydroids were the first to appear, and they formed a matrix that caught organic detritus. Microscopic observation of glass slides that were attached for various intervals to the insides of pipes showed large numbers of protozoa associated with the organic material adhering to the hydroids. After this initial phase, which only took about two weeks, oysters, bryozoans and tunicates were seen on the surfaces. The calcareous and siliceous sponges became evident after the aforementioned organisms were well established.

This study of the succession of invertebrates onto pipe surfaces showed a definite sequence of events leading to the climax condition. Fluctuations of invertebrate abundance appeared to be due primarily to predation.

A comparison of the concrete pipe artificial reef with the automobile artificial reefs in Hawaii showed a higher standing crop of fishes around the concrete shelters. The car body reefs are subject to corrosion; and after a few years they disintegrate into low profile rubble, while the concrete pipes are relatively permanent. These factors made the concrete pipe reef preferable in Hawaiian waters.

A selection of a depth optimum for placement of artificial reefs in Hawaiian waters would be difficult. A shallow reef would be desirable in that it would be located close enough to the surface so that photosynthetic activity would be high. The high production of algae associated with the shallow reef would attract large numbers of herbivores, and in turn, these should attract carnivores. It was noticed that certain fishes (i.e., *Mulloidichthys samoensis* and *Acanthurus olivaceus*) were more common on the M-1968 site (60 feet) than the deeper A-1964 site (85 feet). Variations in the distribution of fishes with depth have been noted in earlier studies. Gosline (1965) stated that *M. samoensis* is an inshore goatfish, while *Mulloidichthys auriflamma* is next in depth, and *Mulloidichthys pflugeri* is considered a deep water goatfish. If specific fish species are desired, then the depth at which they most frequently occur should be chosen for the placement of an artificial reef.

One argument for placing artificial reefs in deeper water is that the strong surge present in Hawaiian waters would disrupt most substrates located shallower than 100 feet. This was evidenced by the movement of large pipes in 85 feet of water on the Pokai Artificial Reef. Therefore, if permanency is an important factor in establishing a Hawaiian artificial reef, depths over 100 feet would be preferable.

Depth is not the only consideration for placement of an artificial reef. The original topography and habitat diversity of an area are important for maximum success of an artificial reef complex. As already mentioned, Randall

(1963) and Wass (1967) made the observation that fish populations are greatest when good habitat is surrounded by large expanses of poor habitat. Artificial substrates deposited far from suitable natural reef shelters may, therefore, prove more productive. Observations on the Pokai Artificial Reef indicated that there were higher populations of fishes when pipe substrates were placed beside natural rises in bottom topography. Predatory fishes were also observed following such ledges when moving over an area. Therefore, advantageous placement of artificial substrates would be along ledges having no natural holes and crevices to provide shelter for reef fishes.

REFERENCES

Aschoff, J. 1964. Survival value of diurnal rhythms. Symp. zool. Soc. Lond. 13: 79-98.

Bardach, J. E. 1959. The summer standing crop of fish on a shallow Bermuda reef. Limnol. & Oceanogr. 4(1): 77-85.

Bardach, J. E. 1968. Aquaculture. Science 161: 1098-1106.

Breder, C. M., Jr. 1948. Observation on coloration in reference to behavior in tide pool and other marine shore fishes. Bull. Amer. Mus. nat. Hist. 92(5): 285-311.

Brock, V. E. 1954. A preliminary report on a method of establishing reef fish population. J. Wildlife Mgmt. 18(3): 297-308.

Busby, R. F. 1967. Undersea penetration by ambient light, and visibility. Science 1958: 1179-1179.

Carlisle, J. G. 1962. Marine habitat improvement in California. 581-585. In First National Coastal and Shallow water research conference. Ed. D. S. Gorsline. (Baltimore, Los Angeles, Tallahassee). 897p.

Carlisle, J. G. 1963. Reefs really work. Outdoor Calif. 24(5): 7-10.

Carlisle, J. G., C. H. Turner, and E. E. Ebert. 1964. Artificial habitat in the marine environment. Resources Agency of California, Dept. Fish Game, Sacramento, Calif. Fish Bull. 124. 93p.

Edmondson, C. H. 1944. Incidence of fouling in Pearl Harbor. Occ. Pap. Bishop Mus. 18(1): 3-34.

Ehrlich, P. R. 1968. The population bomb. Ballantine Books. New York. 223p.

Fish, M. P. 1954. The character and significance of sound production among fishes of the Western North Atlantic. Bull. Bingham oceanogr. Coll. 14(3): 1-109.

Gosline, W. A. 1965. Vertical zonation of inshore fishes in the upper layers of the Hawaiian Islands. Ecology 46(1): 823-831.

Gosline, W. A., and V. E. Brock. 1960. Handbook of Hawaiian fishes. University of Hawaii Press, Honolulu. 372p.

Grigg, R. W. 1964. A contribution to the biology and ecology of the black coral, <u>Antipathes grandis</u>, in Hawaii. Master of Science Thesis, University of Hawaii. 74p.

Hamashima, K., I. Mori, and Y. Kuwawa. 1969. Some observations on fish schools and their environment. In Proceedings of the FAO conference on fish behavior in relation to fishing techniques and tactics. (Bergen, Norway. Oct. 19-27, 1967). FAO Fish. Rep. 62(2): 453-461.

Hiatt, R. W., and D. S. Strasburg. 1960. Ecological relationships of fish fauna on a coral reef of the Marshall Islands. Ecol. Monogr. 30: 65-127.

Hobson, E. S. 1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California. Copeia 3: 291-302.

Hobson, E. S. 1968. Predatory behavior of some shore fishes in the Gulf of California. Res. Rep. U. S. Fish Serv. 73: 1-92.

Jones, R. A. 1968. Ecological relationships in Hawaiian and Johnston Island Acanthuridae: surgeonfishes. Micronesica 4(2): 309-361.

Jordan, D. S., and B. W. Evermann. 1905. The aquatic resources of the Hawaiian Islands. Bull. U. S. Bur. Fish. 23(4): 574p.

Kami, H. 1960. Sea sled and SCUBA reconnaissance of inshore areas and studies on effect of artificial shelters on standing crop of fishes. Proj. No. F-5-R-9, Job No. 13. Div. Fish and Game. Honolulu, Hawaii. 10p.

Klim, D. G. 1969. Interactions between sea water and coral reefs in Kaneohe Bay, Oahu, Hawaii. Hawaii Inst. Geophys. Publ. No. HIG-69-19. 56p.

Laevastu, T., D. E. Avery, and D. C. Cox. 1964. Coastal currents and sewage disposal in the Hawaiian Islands. Hawaii Inst. Geophys. Publ. No. HIG-641. 101p.

Leipper, D. F., and E. R. Anderson. 1950. Sea temperatures, Hawaiian Islands area. Pacif. Sci. 4: 228-248.

Long, E. R. 1969. Oceanographic cruise summary marine biofouling studies off Oahu, Hawaii. IR No. 69-86. Naval Oceanographic Office, Washington, D. C. 13p.

Longley, W. H., and S. F. Hildebrand. 1941. Systematic catalogue of the fishes of Tortugas, Florida. Pap. Tortugas Lab 535. 34: 1-331.

Mahi, C. A. 1969. The food and feeding habits of the Kumu, *Parupeneus porphyreus*. Directed research report, Zoology Department, University of Hawaii. 54p.

Mathews, H. H. 1966. Primary production measurements on an artificial reef. Master of Science Thesis, Florida State University. 34p.

Menzel, D. W., and R. F. Vaccaro. 1964. The measurement of dissolved organic and particulate carbon in sea water. Limnol. & Oceanogr. 9(1): 138-142.

Morris, D. E. 1965. Sea sled and SCUBA reconnaissance of inshore areas and studies on effects of artificial shelters on standing crops of fishes. Proj. No. F-5-R-13. Job No. 13. Div. Fish and Game. Honolulu, Hawaii. 7p.

Odum, E. P. 1959. Fundamentals of ecology. Second ed. W. B. Saunders Company, Philadelphia. 546p.

Odum, H. T. and E. P. Odum. 1955. Trophic structure and productivity of a windward coral reef community on Eniwetok atoll. Ecol. Monogr. 25: 291-320.

Ogawa, Y. 1966. Experiments on the attractiveness of artificial reefs for marine fishes. Bull. Tokai Fish. Res. Lab. 45: 137-145.

Ogawa, Y. 1967. Experiments on the attractiveness of artificial reefs for marine fishes. Bull. Jap. Soc. sci. Fish. 33(9): 801-811.

Ogawa, Y., and H. Aoyama. 1966. Experiments on the attractiveness of artificial reefs for marine fishes. Bull. Tokai Fish. Res. Lab. 45: 137-145.

Ogawa, Y., and Y. Onoda. 1966. Experiments on the attractiveness of artificial reef for marine fishes. Bull. Tokai Fish. Res. Lab. 45: 155-163.

Ogawa, Y., and Y. Takemura. 1966a. Experiments on the attractiveness of artificial reefs for marine fishes. Bull. Tokai Fish. Res. Lab. 45: 107-113.

Ogawa, Y., and Y. Takemura. 1966b. Experiments on the attractiveness of artificial reefs for marine fishes. Bull. Tokai Fish. Res. Lab. 45: 115-126.

Ogawa, Y., and Y. Takemura. 1966c. Experiments on the attractiveness of artificial reefs for marine fishes. Bull. Tokai Fish. Res. Lab. 45: 127-135.

Oren, O. H. 1968. Artificial reefs, a short review and appeal. FAP Fish. Circ. No. FRs/c 305. 8p.

Oshima, Y. 1964. Housing scheme for fishes (artificial reef for fishes). Fishery Propag. Ser. 8(1): 56.

Randall, J. E. 1955. A revision of the surgeonfish genus Ctenochaetus, family Acanthuridae with descriptions of five new species. Zoologica 40: 149-166.

Randall, J. E. 1956. A new method of attaching Petersen disk tags with monofilament nylon. Calif. Fish Game 42(1): 63-67.

Randall, J. E. 1961a. Overgrazing of algae by herbivorous marine fishes. Ecology 42(4): 812.

Randall, J. E. 1961b. Observations on the spawning of surgeonfishes (Acanthuridae) in the Society Islands. Copeia 2: 237-238.

Randall, J. E. 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Caribb. J. Sci. 3(1): 31-47.

Randall, J. E. 1965. Grazing effect on sea grasses by herbivorous fishes in the West Indies. Ecology 46(3): 255-260.

Riley, F. 1969. Fisheries of the United States. C.F.S. No. 5300. Bureau of Commercial Fisheries, U.S. Dept. Interior, Washington, D. C. 87p.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. Iowa State University Press. Ames. 593p.

Starck, W. A., and W. P. Davis. 1966. Night habits of fishes of Alligator Reef, Florida. Icthyologica 38: 313-356.

Stephens, W. M. 1969. Bimini's concrete wreck. Oceans 2(1): 20-27.

Stevenson, R. A. 1963. Life-history and behavior of <u>Dascyllus</u> <u>albisella</u> Gill, a pomacentrid reef fish. Ph. D. Dissertation, University of Hawaii. 221p.

Stroud, R. H. 1961a. The utility and location of artificial fishing reefs in coastal marine waters. Rep. Atlant. St. Mar. Fish. Comm. 11: 17.

Stroud, R. H. 1961b. Artificial saltwater fishing reefs. Sport Fish. Inst. Bull. 121: 1-3.

Stroud, R. H. 1964. Guide to Texas fishing reefs. Sport Fish. Inst. Bull. 150: 4.

Stroud, R. H., and R. M. Jenkins. 1961a. Artificial reef criteria. Sport Fish. Inst. Bull. 118: 5.

Stroud, R. H., and R. M. Jenkins. 1961b. Concrete components for marine fishing reefs. Sport Fish. Inst. Bull. 121: 1-2.

Stroud, R. H., and M. H. Massmann. 1966. Artificial reefs as tools of sport fishery management in coastal marine waters. Sport Fish. Inst. Bull. 170: 1-8.

Sunn, Low, Tom and Hara, Inc. 1962. Report on oceangraphic survey and study relative to sewage disposal for Waianae, Oahu. Report to city and county of Honolulu. Sunn, Low, Tom and Hara, Inc. Honolulu. 36p.

Swerdloff, S. N. 1970. The comparative biology of two Hawaiian species of the damselfish genus <u>Chromis</u> (Pomacentridae). Ph. D. Dissertation, University of Hawaii. 192p.

Tinker, S. W. 1958. Pacific sea shells. Revised ed. Charles E. Tuttle Company, Rutland, Vermont. 240p.

Tinker, S. W. 1965. Pacific crustacea. Charles E. Tuttle Company, Rutland, Vermont. 133p.

Turner, C. H. 1961. Apartment for rent. Outdoor Calif. 22(1): 10-12.

Turner, C. H. 1962a. Test block studies. 619-623. In First National Coastal Shallow Water Research Conference. Ed. D. S. Gorsline. (Baltimore, Los Angeles, Tallahassee). 897p.

Turner, C. H. 1962b. Seascapes from car. Outdoor Calif. 23: 11-13.

Unger, I. 1966. Artificial reefs. American Littoral Society, Highland, New Jersey. Publ. No. 4. 74p.

Van Name, W. G. 1945. North and South American ascidians. Bull. Amer. Mus. nat. Hist. 84: 1-476.

Walford, L. A., and J. R. Clark. 1967. Artificial reefs. Oceanology Int. 2: 27-30.

Wass, R. C. 1967. Removal and repopulation of the fishes on an isolated patch coral reef in Kaneohe Bay, Oahu, Hawaii. Directed research report, Zoology Department, University of Hawaii. 77p.

Winn, H. E., J. A. Marshall, and B. Hazlett. 1964. Behavior, diet activities and stimuli that elicit sound production and reactions to sounds in the longspine squirrelfish, <u>Holocentrus</u> <u>rufus</u>. Copeia 2: 413-425.

Woodhead, P. M. J. 1966. The behavior of fish in relation to light in the sea. 4: 337-403. <u>In</u> Oceanography and marine biology. Ed. H. Barnes. Hafner Publication Company, New York. 505p.

Woods Hole Oceanographic Institute. 1952. Marine fouling and its prevention. United States Naval Institute, Annapolis, Maryland. 338p.

APPENDIX

TABLE Ia. Taxonomic summary of organisms found on the Pokai Artificial Reef

Major Taxon	Number of recognized species
Bacillariophyta	7
Other algae	22
Porifera	3
Coelenterata	
Anthozoa	13
Hydrozoa	2
Bryozoa	45
Mollusca	85
Echinodermata	19
Crustacea	26
Annelida	5
Tunicata	7
Hemichordata	1
Pisces	142
Total	377

TABLE IIa. Taxonomic catalogue of the Pokai Artificial Reef biota.

KEY

-	Rare
+	Common
++	Abundant
SP	Sessile on pipes.
MP	Mobile, associated with pipes.
N	Associated with natural substrates in vicinity of artificial reef.
R	Resident of the artificial reef area.
I	Itinerant. Passing over the pipes occasionally.
[ ]	Old taxonomic designations.
( )	Common names

TABLE IIa. Catalogue of biota on the Pokai Bay artificial reef.

ALGAE

Bacillariophyta (diatoms)		
Biddulphia mobiliensis	++	SP, N
Climacosphenis moniligera	++	SP, N
Coscinodiscus sp.	++	SP, N
Fragilaria sp.	++	SP, N
Nitzschia closterium	++	SP, N
Synedra undulata	++	SP, N
Thallasiothrix sp.	++	SP, N
Naviculoid diatoms	++	SP, N
Chlorophyta (green algae)		
Dictyosphaeria cavernosa	-	N
Halimeda discoidea	-	SP, N
Microdictyon japonicum	-	N
Microdictyon setchellianum	-	N
Neomeris annulata	+	SP, N
Valonia aegagropila	-	N
Cyanophyta (blue-green algae)		
Lyngbya majuscula	++	SP, N
Lyngbya sp.	++	SP, N
Schizothrix calcicola	++	SP, N
Phaeophyta (brown algae)		
Dictyota divaricata	+	SP, N

Ectocarpus indicus	+	SP, N
Pocockiella variegata	-	N
Polysiphonia sp.	-	SP, N
Zonaria hawaiiensis	-	N
Rhodophyta (red algae)		
Amansia glomerata	++	N
Asparogopsis taxiformis	+	N
Chondrococcus ambigua	-	N
Herposiphonia sp.	++	SP, N
Jania sp.	+	SP, N
Laurencia sp.	+	N
Peysonnelia rubra	++	SP, N
Tolypiocladia sp.	-	N
PORIFERA		
Calcarea (calcareous sponges)		
Leucetta sp.	+	SP, N
Demospongiae (siliceous sponges)		
Pellina sp.	-	SP, N
Spirastrella sp.	++	SP, N
Tedania sp.	++	SP, N
COELENTERATA		
Anthozoa (corals)		
Caelastrea tenuis	-	SP, N
Calliactis armillatus	-	N
Coscinaraea ostreaeformis	-	N
Dendrophyllia manni	+	SP

Favia hawaiiensis	++	SP, N
Fungia fragilis	-	N
Montipora verrilli	+	SP, N
Montipora verrucosa	++	SP, N
Pocillopora meandrina	++	SP, N
Porites brighami	++	SP, N
Porites compressa	++	SP, N
Porites lobata	++	SP, N
Porites pukoensis	+	SP, N

Hydrozoa (hydroids)

Campanularia sp.	++	SP
Pennaria tiarella	-	SP

BRYOZOA

Cheilostomata

Antropora granulifera	-	SP, N
Benea discodermiae	-	SP, N
Crepidacantha zelancia	-	SP, N
Colletosia radiata	-	SP, N
Disporella californica	+	SP, N
Fenestrulina malusi	-	SP, N
Floridinella arculifera	-	SP, N
Hippopodina feegeensis	-	SP, N
Hippoporella calyciformis	-	SP, N
Hippoporina porcellana	-	SP, N
Hippothoa distans	-	SP, N
Holoporella aperta	+	SP, N

Holoporella fusca	-	SP, N
Holoporella honolulensis	++	SP, N
Holoporella pilaefera	+	SP, N
Holoporella vagans	-	SP, N
Labioporella crenulata	-	SP, N
Lagenipora cylindrica	-	SP, N
Margaretta opuntoides	-	SP, N
Mastigophora pesanseris	-	SP, N
Microporella orientalis	-	SP, N
Parasmittina aegypitaca	++	SP, N
Parasmittina marsupialis	++	SP, N
Parasmittina tropica	-	SP, N
Parellisina curvirostris	-	SP, N
Penetrantia parva	-	N
Phidelopora sp.	++	SP, N
Rhamphostomella argentea	-	SP, N
Rhynchozoon nudum	+	SP, N
Rhynchozoon new species	-	SP, N
Schizonavella torquata	-	SP, N
Schizoporella puntigera	-	SP, N
Steginoporella lateralis	-	SP, N
Steginoporella magnilabris	++	SP, N
Tetraplaria ventricosa	-	SP, N
Thalamoporella delicata	-	SP, N
Thalamoporella hawaiiana	+	SP, N
Trypostega venusta	-	SP, N

Velumella americana	-	SP, N
Cyclostomata		
Lichenopora violacea	++	SP, N
Lichenopora new species	-	SP, N
Tervia jellyae	-	SP, N
Tubulipora concinna	+	SP, N
Tubulipora flexuosa	-	SP, N
Tubulipora pulcherrima	-	SP, N
MOLLUSCA		
Cephalopoda (octopus)		
Octopus ornatus	+	MP, N
Gastropoda (snail)		
Amaltheidae (Hipponycidae)		
Hipponix pilosus	++	SP
Apolodonidae		
Modulus tectus	-	MP, N
Architectonicidae		
Heliacus variegatus	-	N
Bursidae		
Bursa affinis	-	N
Bursa siphonata	-	N
Buccinidae		
Pisania tritonoides	-	N
Calyptraeidae		
Calyptraea spinosum	-	MP, N
Cassididae		

Casmaria erinaceus	-	N
Cassis cornuta	-	N
Cerithiidae		
Cerithium echinatum	++	MP, N
Cerithium sinense	++	MP, N
Cerithium sp.	+	MP, N
Cerithium thaanumi	+	MP, N
Colubrayiidae		
Colubraria muricata	-	N
Columbelliedae		
Mitrella margarita	-	MP, N
Conidae		
Conus abbreviatus	++	N
Conus bullatus	-	N
Conus distans	-	N
Conus flavidus	+	N
Conus imperialis	+	N
Conus leopardus	++	N
Conus lithographis	+	N
Conus marmoreus	++	MP, N
Conus miles	++	N
Conus obscurus	++	MP, N
Conus penaceus	-	N
Conus pulicarius	++	N
Conus quercinus	-	N
Conus striatus	++	MP, N

Conus textile	-	MP, N
Conus vexillum	-	N
Conus vitulinus	-	N
Cymatidae		
Charonia tritonis	-	N
Cymatium gemmatum	-	N
Cymatium nicobaricum	-	MP, N
Cymatium pileare	-	N
Distorsio anus	-	N
Cypraeidae		
Cypraea fimbriata	+	MP, N
Cypraea gaskoini	-	MP, N
Cypraea granulata	-	MP, N
Cypraea helvola	++	MP, N
Cypraea isabella	++	MP, N
Cypraea leviathan	-	MP, N
Cypraea poraria	+	MP, N
Cypraea schilderorum	-	MP, N
Cypraea sulcidentata	+	MP, N
Cypraea talpa	-	MP, N
Cypraea teres	+	MP, N
Cypraea tessellata	-	MP, N
Cypraea tigris	-	N
Eulimidae		
Balcis cumingii	-	MP, N
Fasciolariidae		

Fusinus sandwichensis	-	MP, N
Latirus nodatus	++	MP, N
Fissurellidae		
Diodora octagona	-	N
Mitridae		
Mitra astricta	+	N
Mitra exasperata	-	N
Mitra faveolata	-	N
Mitra mitra	++	N
Mitra newcombii	+	N
Mitra olivaeformis	++	N
Mitra papalis	++	N
Mitra peasei	+	MP, N
Mitra strictica	+	N
Mitra tusa	+	N
Muricidae		
Drupa vicina	-	MP, N
Drupa rubusidaeus	++	MP, N
Nassariidae		
Nassarius dermestina	-	N
Nassarius papillosus	++	MP, N
Olivadae		
Oliva sandwichensis	++	N
Strombidae		
Strombus maculatus	-	N
Strombus tridentatus	-	N

Terebridae		
Terebra crenulata	-	N
Terebra guttata	+	N
Terebra lanceata	-	N
Terebra maculata	++	N
Turridae		
Daphnella sandwicensis	-	N
Xenoturris kingae	-	N
Trochidae		
Trochus intextus	-	N
Turbinidae		
Turbo intercostalis	-	MP, N
Vermetidae		
Dendropoma platypus	++	SP
Opisthobranchiata (nudibranchs)		
Dorid		
Chromodoris petechialis	+	MP, N
Hexabranchus aureomarginata	-	MP, N
Eolid		
One unidentified species		
Pelecypoda (bivalves)		
Ostreidae		
Ostrea hanleyana	++	SP
Pteriidae		
Pinctada galtsoffi	+	SP, N

ARTHROPODA--Crustacea

Cirripedia--Thoracica (barnacles)

Balanus amphitrite	+	SP
Amphipoda--Caprellidea		
Caprella sp.	++	MP, N
Decapoda--Natantia (shrimps)		
Crangon sp.	++	MP, N
Crangon sp.	++	MP, N
Hymenocera picta	-	MP
Stenopus hispidus	++	MP, N
Stenopus sp.	-	MP, N
Decapoda--Reptantia--Macrura (lobsters)		
Enoplometopus occidentalis	-	MP, N
Panulirus japonicus	++	MP, N
Parribacus antarcticus	-	MP, N
Scyllarides squammosus	+	MP, N
Decapoda--Reptantia--Anomura (hermit crabs)		
Aniculus maximus	+	MP, N
Dardanus gemmatus	+	MP, N
Dardanus megistos	+	MP, N
Decapoda--Reptantia--Brachyura (crabs)		
Actaea sp.	+	MP, N
Calappa bicornis	-	N
Carpilius maculatus	+	MP, N
Carpiloides sp.	++	MP, N
Charybdis hawaiiensis	++	MP, N
Conchodytes meleagrinae	-	MP, N
Coralliocaris mammillata	+	N

Lissocarcinus orbicularis	-	N
Percnon planissimum	++	MP, N
Platypodia sp.	++	MP, N
Ranina ranina	-	N
Trapezia maculata	-	MP, N
ECHINODERMATA		
Asteroidea (starfish)		
Acanthaster planci	+	MP, N
Asterope carinifera	-	N
Culcita novaeguineae	+	MP, N
Linckia guildingii	++	MP, N
Linckia multiflora	+	MP, N
Mithrodia bradleyi	-	N
Echinoidea (urchins)		
Brissus latecarinatus	-	N
Chrondreocidaris gigantea	-	MP, N
Diadema paucispinum	+	MP, N
Echinometra mathaei	+	MP, N
Echinometra oblonga	-	MP, N
Echinothrix calamaria	++	MP, N
Eucidaris metularia	++	MP, N
Heterocentrotus mammillatus	+	MP, N
Metalia spatangus	-	MP, N
Tripneustes gratilla	++	MP, N
Holothuroidea (sea cucumbers)		
Holothuria atra	-	MP, N

Stichopus tropicalis	-	MP, N
Ophiuroidea (brittle stars)		
Ophiocoma insularia	++	MP, N
TUNICATA		
Ascidiacea		
Ciona intestinalis	+	SP, N
Didemnum candidum	++	SP, N
Didemnum sp.	+	SP, N
Didemnum sp.	+	SP, N
Didemnum sp.	+	SP, N
Didemnum sp.	+	SP, N
Hemichordata		
Enteropneusta		
Ptychodera sp.	++	N
PISCES		
Acanthuridae		
Acanthurus achilles	-	R
Acanthurus dussumieri	+	R
Acanthurus nigrofuscus	+	R
Acanthurus nigroris	+	I
Acanthurus olivaceus	++	I
Acanthurus sandvicensis	+	I
Acanthurus thompsoni	-	I
Ctenochaetus strigosus	++	R
Naso brevirostris	++	I
Naso hexacanthus	++	I

Naso lituratus	+	I
Naso unicornis	++	I
Zebrasoma flavescens	++	R
Antennariidae		
Antennarius moluccensis	-	R
Apogonidae		
Apogon snyderi	++	R
Apogon waikiki	+	R
Aulostomidae		
Aulostomus chinensis	++	R
Balistidae		
Melichthys niger [*M. buniva*]	++	R
Melichthys vidua	++	R
Sufflamen bursa [*Balistes bursa*]	++	R
Xanthichthys mento [*X. ringens*]	-	R
Bothidae		
Bothus mancus	+	R
Brotulidae		
Brotula multibarbata	-	R
Canthigasteridae		
Canthigaster coronatus [*C. cinctus*]	++	R
Canthigaster jactator	++	R
Carangidae		
Carangoides ajax	-	I
Carangoides ferdau	+	I
Caranx helvolus	-	I

Caranx melampygus	+	I
Decapterus maruadsi	+	I
Scomberoides sancti-petri	-	I
Carcharhinidae		
Carcharhinus limbatus	+	I
Chaetodontidae		
Centropyge potteri	++	R
Chaetodon auriga	+	R
Chaetodon corallicola	++	R
Chaetodon ephippium	-	
Chaetodon fremblii	++	R
Chaetodon lunula	+	R
Chaetodon miliaris	++	R
Chaetodon multicinctus	++	R
Chaetodon ornatissimus	-	R
Forcipiger flavisimus [*F. longirostris*]	++	R
Hemitauricthys polylepis [*H. zoster*]	+	R
Heniochus acuminatus	+	I
Holacanthus arcuatus	-	R
Chanidae		
Chanos chanos	-	I
Cheilodactylidae		
Goniistius [*Cheilodactylus*] *vittatus*	-	I
Cirrhitidae		
Cirrhitops fasciatus [*Paracirrhites cinctus*]	+	R
Paracirrhites arcatus	+	R

Paracirrhites forsteri	+	R
Congridae		
Conger marginatus	–	R
Coryphaenidae		
Coryphaena hippurus	–	I
Diodontidae		
Diodon hystrix	++	R
Echeneidae		
Remora remora	–	I
Exocoetidae		
Parexocoetus brachypterus	+	I
Fistularidae		
Fistularia petimba		
Gobiidae		
One unidentified species	–	R
Grammistidae		
Suttonia lineata		
Hemiramphidae		
Euleptorhamphus viridis	–	I
Hemiramphus viridis	+	I
Holocentridae		
Adioryx [*Holocentrus*] *spinifer*	–	R
Adioryx [*Holocentrus*] *xantherythrus*	++	R
Flammeo [*Holocentrus*] *sammara*	+	R
Holotrachys lima	–	R
Myripristis berndti	++	R

Kuhliidae		
Kuhlia sandvicensis	-	
Kyphosidae		
Sectator azureus	-	I
Labridae		
Anampses cuvieri	-	R
Anampses rubrocaudatus	++	R
Bodianus bilunulatus	+	R
Cheilio inermis	+	
Coris ballieui	-	R
Coris flavovittata	-	
Coris gaimardi	+	R
Gomphosus varius	-	R
Halichoeres ornatissimus	+	R
Hemipteronotus pavoninus	-	R
Hemipteronotus taeniourus	+	I
Hemiteronotus umbrilatus	-	I
Labroides phthirophagus	+	R
Macropharyngodon geoffroyi	++	R
Pseudocheilinus evanidus	+	R
Pseudocheilinus octotaenia	+	R
Pseudocheilinus tetrataenia	-	R
Thallassoma duperreyi	++	R
Thallassoma ballieui	+	R
Lutjanidae		
Aphareus furcatus	+	I

Aprion virescens	+	I
Pristipomoides microlepis	-	
Malacanthidae		
Malacanthus hoedtii	+	R
Microdesmidae		
Gunnellicthys sp.	+	R
Monocanthidae		
Alutera scripta	+	
Cantherhines dumerili [*Amanses carolae*]	-	
Amanses sandwichiensis	+	R
Pervagor spilosoma	-	R
Mullidae		
Mulloidichthys auriflamma	-	
Mulloidichthys samoensis	++	R
Parupeneus bifasciatus	+	R
Parupeneus chryserydros	+	I
Parupeneus multifasciatus	++	I
Parupeneus pleurostigma	++	I
Parupeneus porphyreus	++	R
Muraenidae		
Echidna zebra	-	R
Gymnothorax eurostus	+	R
Gymnothorax flavimarginata	+	R
Gymnothorax meleagris	+	R
Gymnothorax steindachneri	+	R
Myliobatidae		

Aetobatus narinari	-	I
Myctophidae		
One unidentified species		
Ophichthidae		
Two unidentified species	-	R
Ostraciontidae		
Ostracion lentiginosus	+	R
Lactoria fornasini	+	R
Pleuronectidae		
Samariscus triocellatus	+	R
Pomacentridae		
Abudefduf abdominalis	-	I
Chromis leucurus	+	R
Chromis ovalis	++	R
Chromis vanderbilti	++	R
Chromis verater	++	R
Dascyllus albisella	++	R
Plectroglyphidodon johnstonianus	+	R
Pomacentrus jenkinsi	+	R
Priacanthidae		
Priacanthus cruentatus	++	R
Scaridae		
Calotomus sandvicensis	+	R
Scaridae zonarcha	+	R
Scarus dubius	+	I
Scarus perspicillatus	+	I

Scombridae		
Acanthocybium solandri	-	I
Euthynnus yaito	-	I
Katsuwonus pelamis	-	I
Scorpaenidae		
Iracundus signifer	-	R
Pterois sphex	-	R
Scorpaenopsis gibbosa	+	R
Taenianotus triacanthus	+	R
Serranidae		
Caesioperca thompsoni	-	R
Sparidae		
Monotaxis grandoculis	++	R
Sphyraenidae		
Sphyraena barracuda	-	I
Sphyraena helleri	+	R
Synodontidae		
Synodus variegatus	+	R
Tetraodontidae		
Arothron hispidus	+	
Arothron meleagris	-	
Zanclidae		
Zanclus canescens	++	R

TABLE IIIa. Numbers and species of fishes tagged in the study of colonizer sources, M-1968 study area.

Species	Number	Species	Number
Acanthurus nigrofuscus	5	Forcipiger flavisimus	23
Acanthurus nigroris	6	Gymnothorax sp.	12
Acanthurus olivaceus	10	Holacanthus arcuatus	6
Acanthurus sandvicensis	23	Macropharyngodon geoffroyi	1
Adioryx xantherythrus	11	Melichthys niger	8
Amanses carolae	4	Mulloidichthys samoensis	4
Amanses sandwichiensis	12	Myripristis berndti	20
Amanses pardalis	1	Naso brevirostris	1
Aulostomus chinensis	3	Naso hexacanthus	1
Bodianus bilunulatus	15	Naso lituratus	8
Calotomus sandvicensis	1	Parupeneus chryserydros	3
Chaetodon auriga	19	Parupeneus multifasciatus	153
Chaetodon corallicola	75	Parupeneus pleurostigma	55
Chaetodon fremblii	102	Parupeneus porphyreus	8
Chaetodon lunula	6	Pervagor spilosoma	7
Chaetodon miliaris	96	Scarus sp.	1
Chaetodon multicinctus	19	Scorpaenopsis gibbosa	2
Cheilio inermis	2	Sufflamen bursa	9
Chromis ovalis	1	Synodus sp.	4
Chromis verater	75	Thalassoma duperreyi	4
Ctenochaetus strigosus	28	Xanthichthys mento	3
Dascyllus albisella	4	Zanclus canescens	22
Flammeo sammara	2	Zebrasoma flavescens	26

TABLE IVa. Salinity of bottom water on the D-1966 study area between March 1968 and March 1969.

Date	Salinity*	Date	Salinity*
1968		July 9	34.57
March 19	34.42	July 16	34.50
March 26	34.59	July 25	34.50
April 2	34.77	August 13	34.20
April 16	35.28	August 20	34.20
April 23	34.27	August 28	34.30
April 30	34.27	September 15	34.50
May 7	33.92	October 2	35.00
May 14	34.66	November 12	34.50
May 21	34.58	December 28	35.00
June 2	34.48	1969	
June 11	35.09	January 12	34.30
June 18	35.10	February 13	34.00
June 25	34.58	March 6	34.00
July 2	34.50	1968-9 Mean	34.53

*Salinity in parts per thousand

TABLE Va

Relative surface covered by various benthic organisms off Maile Point, Oahu
(November 22 and 24, 1968)*

	STATIONS AND DEPTH (METERS)			
Surface Components	1968 Site	1966 Site	1964 Site	Average % Coverage
Dead Reef	66.2	70.1	56.8	64.4
Porites sp.	2.1	1.0	2.0	1.7
Peyssonnelia sp.	2.7	0.8	0.8	1.4
Coralline Algae	29.0	28.0	40.3	32.4
Lithophylleae ?	0.2	0.0	2.6	0.9
Porolithon reinboldi	10.5	5.0	5.2	6.9
Goniolithon breviclavium	18.3	23.0	32.5	24.6

*Table by Mark Littler. Department of Botany, University of Hawaii

SECTION I

CORAL GROWTH ON THE POKAI ARTIFICIAL REEF

Yearly increments of pipes providing substrates of known age offered an opportunity for studying the growth of hermatypic coral. The ten largest colonies of Pocillopora meandrina were removed from the A-1964 and D-1966 sites. These were then dried at 80°C, weighed and measured to determine the amount of growth relative to age and depth of substrate. This species was chosen as it was the only one that could be removed intact.

The largest colony from the D-1964 pipe surfaces weighed 15 gm (average 8 gm) and the largest colony from the D-1966 pipe surfaces weighed 88 gm (average 39.6 gm) (Plate 29). The best growth was obtained on metal reinforcing rods where the coral could grow in all directions. The maximum weight attained under this condition at the D-1966 site was 343 gm, and the average of four colonies was 225 gm (Plate 29). None was found on the older area.

The larger size of coral colonies on the younger D-1966 substrates could be due to the difference in depth between the two stations. The amount of light available for photosynthesis is reduced as it passes through sea water (Holmes, 1957). The difference in depth between the A-1964 site (85 ft) and the D-1966 site (60 ft) may be enough to influence the amount of light available to the zooxanthellae of

PLATE 29

Representative coral colonies of *Pocillopora meandrina* from dated reef substrates: left--two colonies from A-1964 site (85 feet); center--two colonies from D-1966 site (60 feet); right--single radial colony from reinforcing rod on D-1966 site.

corals. Yamazato (1966) stated that light is an important factor indirectly affecting the rate of calcification in corals by its effect on the photosynthesis of zooxanthellae. Goreau (1959) and Goreau and Goreau (1959) showed that for all species of hermatypic corals tested, the calcification rate was high during sunny weather, lower during cloudy weather and lowest in darkness. Compensation depths for some phytoplankton is estimated at approximately 45 m for clear, coastal waters (Riley, et al., 1949). Good hermatypic coral growth does not occur much below 110 feet (Wiens, 1962).

Abrasion by sediments may also influence coral growth. Wiens (1962) stated that if coral polyps are subjected to great amounts of sediment and sediment abrasion, the growth of colonies can be reduced or colonies actually killed. The A-1964 site showed more pipe movement and a corresponding increase in sediment abrasion than the shallower D-1966 site. It was also more difficult to be sure of the exact age of a coral colony on the older surfaces as the history of pipe movement on that area was not as well known.

Difference in average visibility between the two stations, particulate carbon analyses and plankton tows indicated that the inshore station probably had a richer water mass much of the time. The added nutrient, providing the difference in light intensity in turbid waters proved insignificant, also may have increased the growth of coral.

In summary, the greater coral growth found on the younger and shallower D-1966 station probably can be attributed to the greater amount of solar radiation available for photosynthesis, reduced pipe movement and the richer water mass found over that area.

MOLLUSKS FROM POKAI ARTIFICIAL REEF

E. Alison Kay

Three one-quart samples of coarse sand, one from 45 feet (M-1968 site), one from 65 feet (D-1966 site), and one from 85 feet (A-1964 site) from the Pokai Artificial Reef were analyzed for mollusks. The samples were scrutinized with a dissecting microscope, all whole shells removed, and the shells segregated to species. Three one-quart samples of fine sand from the same areas were also available for study but because a small sample from one of these showed approximately the same species composition as that of the coarse sand sample from the same depth (although more shells per unit volume), they were not further analyzed. Samples of algal mat removed from the pipes at each station were analyzed for comparative purposes.

A total of 2,636 specimens of mollusks was found in the three quart samples, the shells representing approximately 120 species of gastropods and bivalves. The number of specimens from each depth is tabulated in Figure Ia; the number of species appears in Figure IIa. The sand sample from the A-1964 site included the largest number of specimens, with three times as many as was found in the sample from the M-1968 site and twice as many as at the D-1966 site. The number of species from the three depths ranged from 62 to 69, with the greatest number of species recorded

FIGURE Ia

Numbers of mollusk specimens in one-quart samples of sand taken from the three study sites (A-1964, D-1966, M-1968).

FIGURE IIa

Numbers of mollusk species in one-quart samples of sand taken from the three study sites (A-1964, D-1966, M-1968).

FIGURE Ia

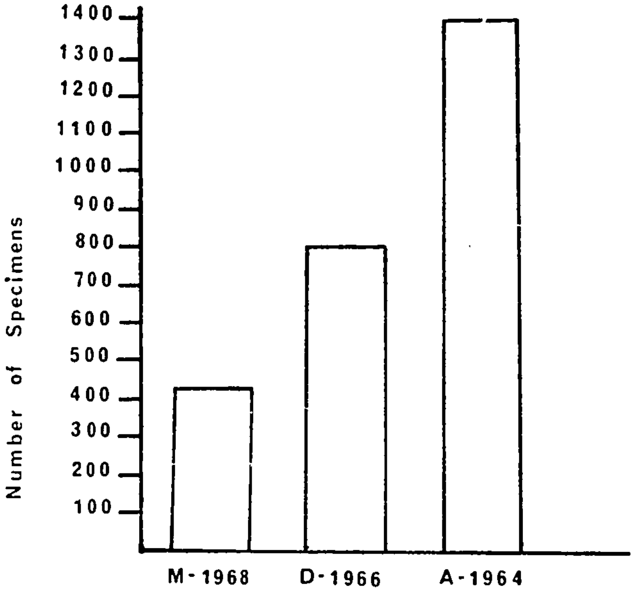
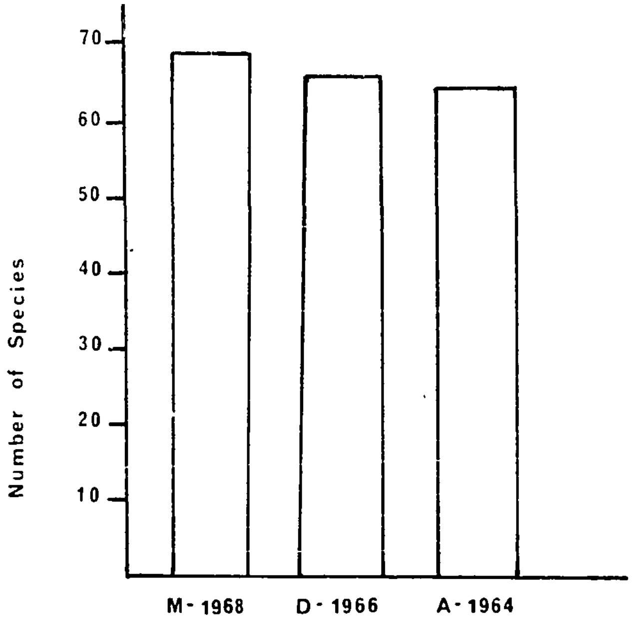


FIGURE IIa



from the M-1968 site. These figures indicate that while molluscan abundance is greatest at the A-1964 site (85 feet), there is a greater variety of species at the M-1968 site (45 feet).

The mollusks found in the samples are not for the most part sand-dwellers but represent epifaunal species washed from coral or rubble in populations of mollusks living epifaunitically rather than representing sand communities at the various depths.

Most of the mollusks in the samples are small, ca. 3 to 7 mm in length. Very few specimens more than 10 mm in length were found.

Of the 120 species found in the samples, at least 30 represent species apparently restricted to subtidal habitats. The remainder appear to be fairly ubiquitous, although a number are predominantly tide-pool forms, and their occurence at even the 45 foot depth may be due to the shells having been transported from shoreline areas.

Perhaps the most interesting aspect of the analysis is the distinctive vertical distribution pattern exhibited by several genera, especially _Rissoina_, _Seminella_, _Obtortio_, and _Diala_.

The rissoinids (family Rissoidae) are consistently dominant at all three stations, comprising roughly 20% of the species composition at each of the stations. At the M-1968 site the two species which are dominant, _Rissoina_ *ambigua* and *R*. *miltozona*, form 74% of the rissoinids; both are common tidepool species. The two remaining rissoinids at the M-1968 site are *R*. *ephamilla* and *R*. *flexuosa*, neither of which have been collected intertidally, but both of which become progressively more important in the species composition at the D-1966 and A-1964 sites, forming 57% and 85% of the rissoinids respectively at these stations. And conversely *R*. *ambigua* and *R*. *miltozona* become less important at the two deeper stations.

Among the cerithids (family Cerithiidae) three genera are noteworthy, "*Lucidestea*," *Diala* and *Obtortio*. Species of these genera represent only 12% of the species composition at the M-1968 site but 41% and 46% respectively of the cerithid composition at the D-1966 and A-1964 sites. While one species of *Lucidestea* is a dominant intertidal organism, that species is not represented in any of the samples but is replaced by another species which becomes progressively more abundant with depth. Neither *Diala* nor *Obtortio* is found intertidally; they are, however, exceedingly important in the species composition of the mollusks at the 65 foot and 85 foot depth stations, one species of *Obtortio* accounting for 28% of all the mollusks from the 85 foot sample.

Less spectacular replacement series were found among the columbellids (family Columbellidae), pyramidellids (Pyramidellidae), and the bivalves. *Mitrella* *fusiformis*, the most ubiquitous and abundant intertidal columbellid forms 35% of the columbellids at the M-1968 site but was not present at all at either the D-1966 or A-1964 stations. Seminella smithii which is not found intertidally forms only 23% of the columbellid sample at the M-1968 station and 62% of the sample at the A-1964 station. Two pyramidellids which are unknown intertidally form the bulk of the representation in the family at all three stations, one becoming obviously more abundant with depth: at the 45 foot station forming 22% of the pyramidellid sample, at the 65 foot station forming 40% of the sample, and at the 85 foot station forming 65% of the sample. And, finally, among the bivalves at least five species which are either uncommon or absent in shallow waters appear to be quite common at the three stations on the artificial reef.

The over-all impression one gets from the analysis is that the 45 foot station (M-1968) appears to be about the limit to which many shallow water species reach, while the 65 foot (D-1966) and 85 foot (A-1964) stations resemble each other more closely and support a deep water fauna.

LITERATURE CITED IN APPENDIX

Goreau, T. F. 1959. The physiology of skeleton formation in corals. Biol. Bull. mar. biol. Lab., Woods Hole. 166: 59-75.

Goreau, T. F., and N. I. Goreau. 1959. The physiology of skeleton formation in corals. Biol. Bull. mar. biol. Lab., Woods Hole. 117: 239-250.

Holmes, R. W. 1957. Solar radiation, submarine daylight, and photosynthesis. 109-128. In Ed. J. W. Hedgepeth. Treatise on marine ecology and paleoecology. Waverly Press, Baltimore. 1,296p.

Riley, G. A., H. Stommel, and D. Bumpus. 1949. Quantitative ecology of the plankton of the Western North Atlantic. Bull. Bingham oceanogr. Coll. 12(3): 1-169.

Wiens, H. J. 1962. Atoll environment and ecology. Yale University Press, New Haven. 532p.

Yamazato, K. 1966. Calcification in a solitary coral, Fungia scutaria Lemarck in relation to environmental factors. Ph. D. Dissertation, University of Hawaii. 130p.