Early Development of Pendleton Artificial Reef

JOHN J. GRANT, KENNETH C. WILSON,
ALLEN GROVER, and HEIDI A. TOGSTAD

ABSTRACT—An artificial reef was constructed of 9,100 t (10,000 tons) of quarry rock, in southern California, 1.6 km (1 mile) offshore of Camp Pendleton. The reef was arranged in eight high-relief modules covering 2.8 hectares (7 acres) of sand substrate in 13.1 m (43 feet) of water. Management techniques are being utilized in an effort to accelerate and direct successional changes on the reef. These have included transplanting giant kelp, Macrocystis *spp., and red abalone,* Haliotis rufescens. *Successional changes and the impact of management operations on the reef were monitored. After 1 year 19 species of fishes and 26 species of invertebrates were observed.*

Introduction

Construction of the Pendleton Artificial Reef (PAR) (Grove, 1982) offered the California Department of Fish and Game (CDFG) and Southern California Edison (SCE) an opportunity to utilize several techniques in an attempt to enhance an otherwise relatively unproductive environment and to investigate the potential of such reefs as a mitigation measure for potential damage to the nearshore marine environment by a coastal power plant. Of particular interest is the transplantation of giant kelp, *Macrocystis pyrifera* and *M. angustifolia*, to the reef. Establishment of a stand of giant kelp will increase the aspect-ratio of the reef and provide "substrate to surface" habitat for fish and invertebrate species.

Site Selection

Several criteria were used to determine the location for PAR construction. Water depth was chosen as being adequate for *Macrocystis* growth and recruitment in that section of coast. This decision was based upon experience gained in kelp restoration work and dives in nearby kelp forests to assess local conditions. Sites that were heavily influenced by terrestrial runoff were rejected in an effort to avoid excessive turbidity, siltation, and substrate burial. Since the reef was to be constructed on sand, excavations and probes were made to determine if a solid base was present. A site which was mutually agreeable to CDFG and SCE was selected; however, this was changed since the presence of an artificial reef in that location could impact ongoing studies to determine the effect of San Onofre Nuclear Generating Station (SONGS) on local biota. The site was moved further down the coast to its present location 5.5 km (3.4 miles) southeast of SONGS in 13.1 m (43 feet) of water (Fig. 1).

Design and Construction

Many materials have been used to construct artificial reefs. Turner et al. (1969) concluded that concrete shelters attracted the greatest number of fishes. However, they also found that man-made reefs caused continual bottom sediment disturbances with alternate "sanding in" and scouring of the lower edge of the reef. This effect is somewhat lessened on quarry rock reefs, and allowances for this scouring action were incorporated into our reef design. After considering all facts, including lower cost and ease of handling, we designed the reef to be constructed of quarry rock.

Many Japanese reef designs have served to attract, or centralize, finfish assemblages for harvest by achieving high relief or "high-aspect ratios." While increasing the potential for exploitation of finfish populations is not the main purpose of PAR, we did incorporate high relief into the design to provide habitat above the effects of siltation for settlement and growth of *Macrocystis*. The aspect-ratio will be further enhanced by growth of *Macrocystis*.

A phenomenon known as the "edge effect" (Odum, 1971) is also incorporated into the design of this reef. Turner et al. (1969) suggested that reef design should incorporate large open spaces 50-60 feet (16-18 m) in diameter. The horizontal configuration of the reef as designed is presented in Figure 2. The reef was designed to consist of eight modules, each 27 m (90 feet) long, 12 m (40 feet) wide, and 3.1 m (10 feet) high, placed 18 m (60 feet) apart. The sandy areas are expected to enhance the edge effect wherever they adjoin the rock piles and the spacing is such that the piles will act as one large reef rather than eight discrete reefs.

Recent work by Tegner[1] indicates that abalone, *Haliotis* sp., recruitment may be enhanced by the presence of cobble-sized rock. Consequently, four of the modules received a "topping" of such

The authors are with the California Department of Fish and Game, 350 Golden Shore, Long Beach, CA 90802.

[1]Mia Tegner, Scripps Institution of Oceanography A-001, La Jolla, CA 92093. Pers. commun.

rock. Future abalone recruitment on modules with and without the topping can thus be compared.

The reef was constructed of 9,100 t (10,000 tons) of rock from the Connolly-Pacific[2] quarry near Avalon on Santa Catalina Island. Although rocks ranged from 0.3 to 2 m (1-6 feet) in diameter, rocks of 0.6-1.3 m (2-4 feet) diameter form the main body of all modules except Module 3, which is composed entirely of 1.3-2.0 m (4-6-foot) rocks.

The construction contractor was unable to place the rock exactly as planned due to adverse seas occurring during construction. However, the resultant configuration (Fig. 3) has proven adequate.

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

Establishment of Ecological Studies

Considerable time was spent setting up transect lines for ecological surveys. Lead-core 30 m (98.4-foot) lines marked at 1 m intervals were laid out along longitudinal and latitudinal axes of all eight modules (Fig. 2). These 1 cm (3/8-inch) diameter lines are permanent transect markers. Physical parameters such as depth and substrate composition were noted at 5 m (16.4-foot) intervals along all lines. Movement of permanent transect lines has been minimal even under conditions of heavy surge. The only losses have apparently been related to the settling of rocks during heavy seas in winter 1980-81 and to the dragging of boat anchors.

Preliminary diving surveys to determine species composition and abundance of fishes were conducted in November and December 1980 using rapid-visual survey techniques (Jones and Thompson, 1978). Qualitative observations of species composition and relative abundance of fishes have been made frequently during all diving activities on PAR.

Quarterly studies, beginning in August 1981, included random 0.25 m^2 quadrat surveys of all biota and 30 × 1 m band surveys of selected invertebrates and algae along the permanent lead-core lines.

Preliminary analysis of data collected from random 0.25 m^2 surveys indicated that the variance of fauna sampled was such that our sampling effort would have to be much greater if our data were to have statistical validity. Consequently we initiated a sampling program utilizing an 0.125 m^2 Random Point Contact (RPC) method. This technique, popular in terrestrial plant ecology (Winkworth, 1955), was adapted to subtidal-sampling needs by personnel of Lockheed Ocean Science Laboratories[3] and modified to fit the requirements of our program.

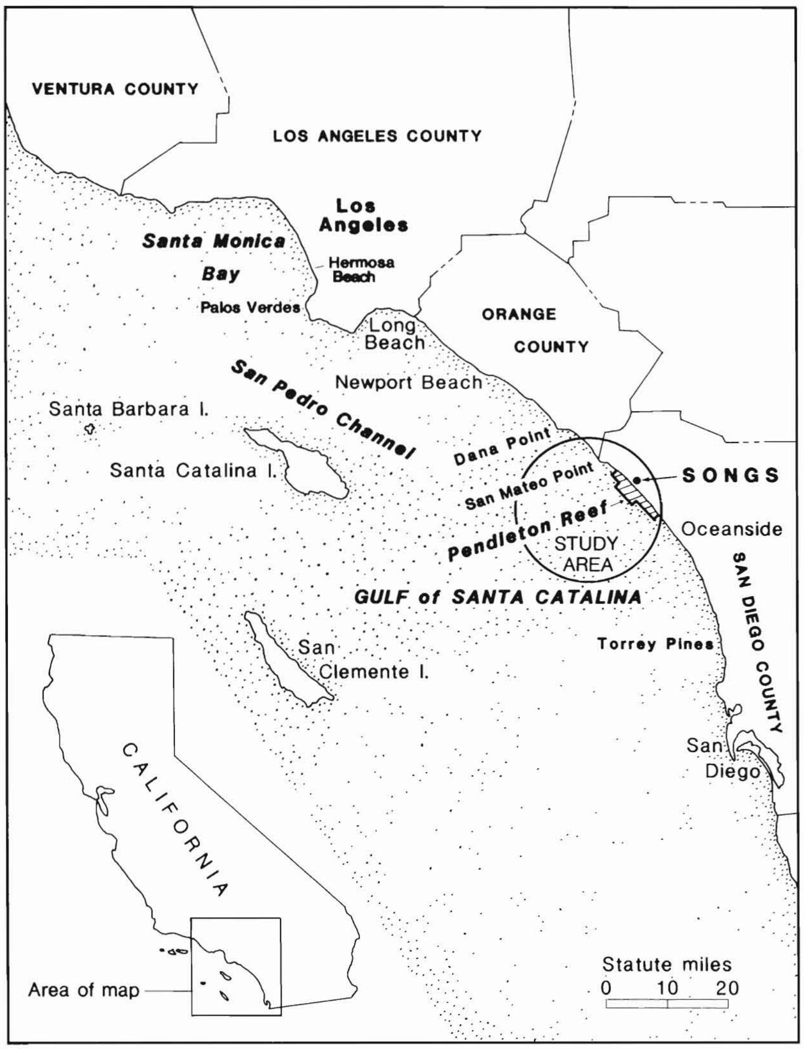

Figure 1.—Location of the Pendleton Artificial Reef.

Reef Biomanipulations and Management

Such operations in 1980-81 included the transplantation of giant kelp and juvenile red abalone, *Haliotis rufescens*, onto PAR. Three separate kelp-transplanting operations were conducted in October-November 1980 and April, May, and June 1981.

During the first operation, subadult and young adult plants were obtained from Neushul Mariculture in Santa Barbara and approximately 36 of these were transplanted onto Module 6 in November 1980. They also provided several bricks

[3]John W. Carter, Lockheed Ocean Science Laboratories, 6350-A Yarrow Drive, Carlsbad, CA 92093.

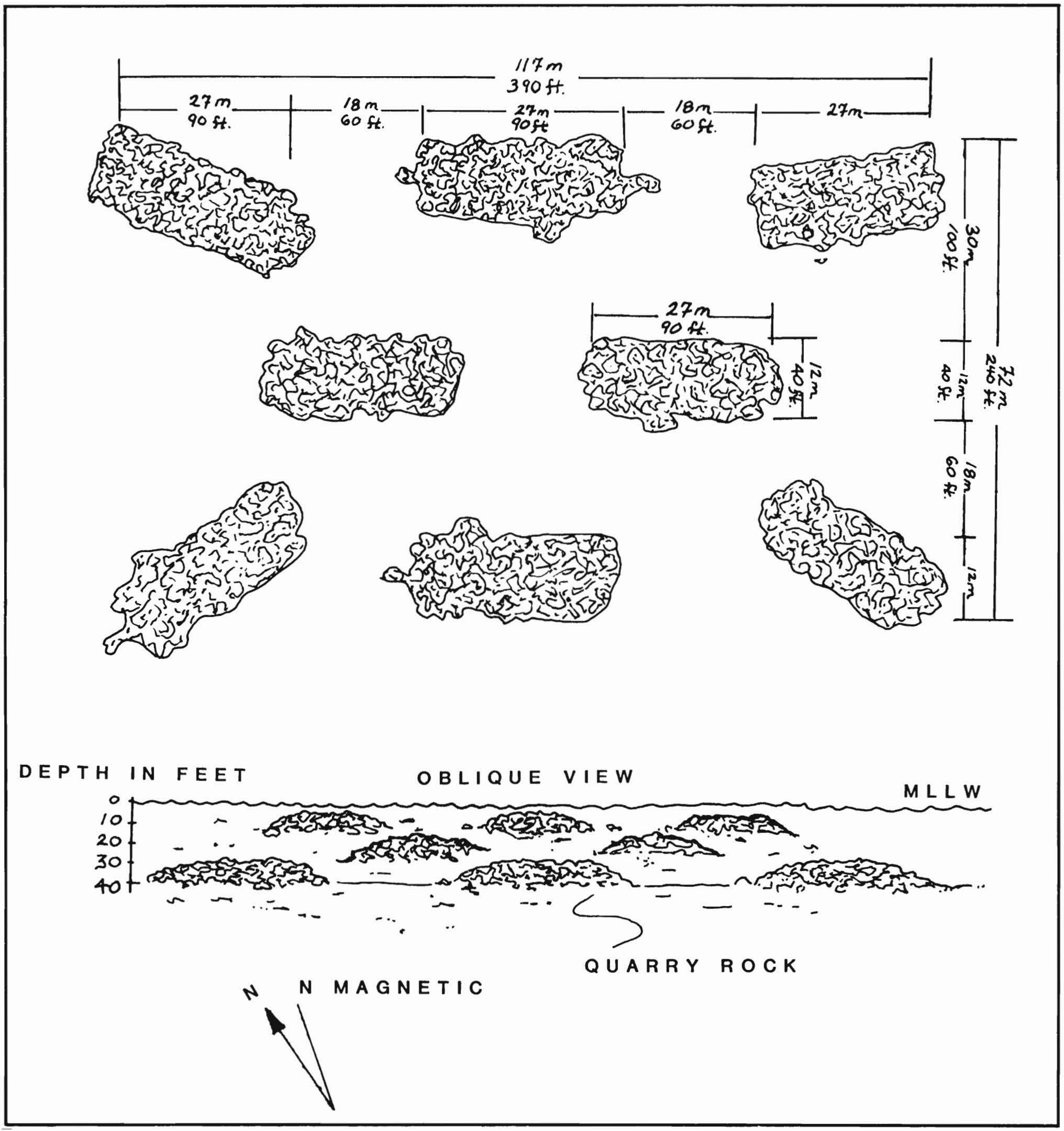

Figure 2.—Pendleton Artificial Reef as designed, 23 June 1980.

filled with Osmocote time-release fertilizer to which young *Macrocystis* plants were attached. These were also placed on Module 6. Twenty-five additional young *Macrocystis* plants were collected from San Mateo Point and SONGS kelp, and transplanted to Modules 6 and 8 in April 1981.

To further increase the standing crop of *Macrocystis* plants on the reef to provide parent stock, and to protect offspring from fish-grazing damage, one additional kelp transplanting effort was made at the end of May and early June 1981. A total of 300 kelp plants was collected from Abalone Cove on Palos Verdes Peninsula in Los Angeles County and transplanted to the remaining six

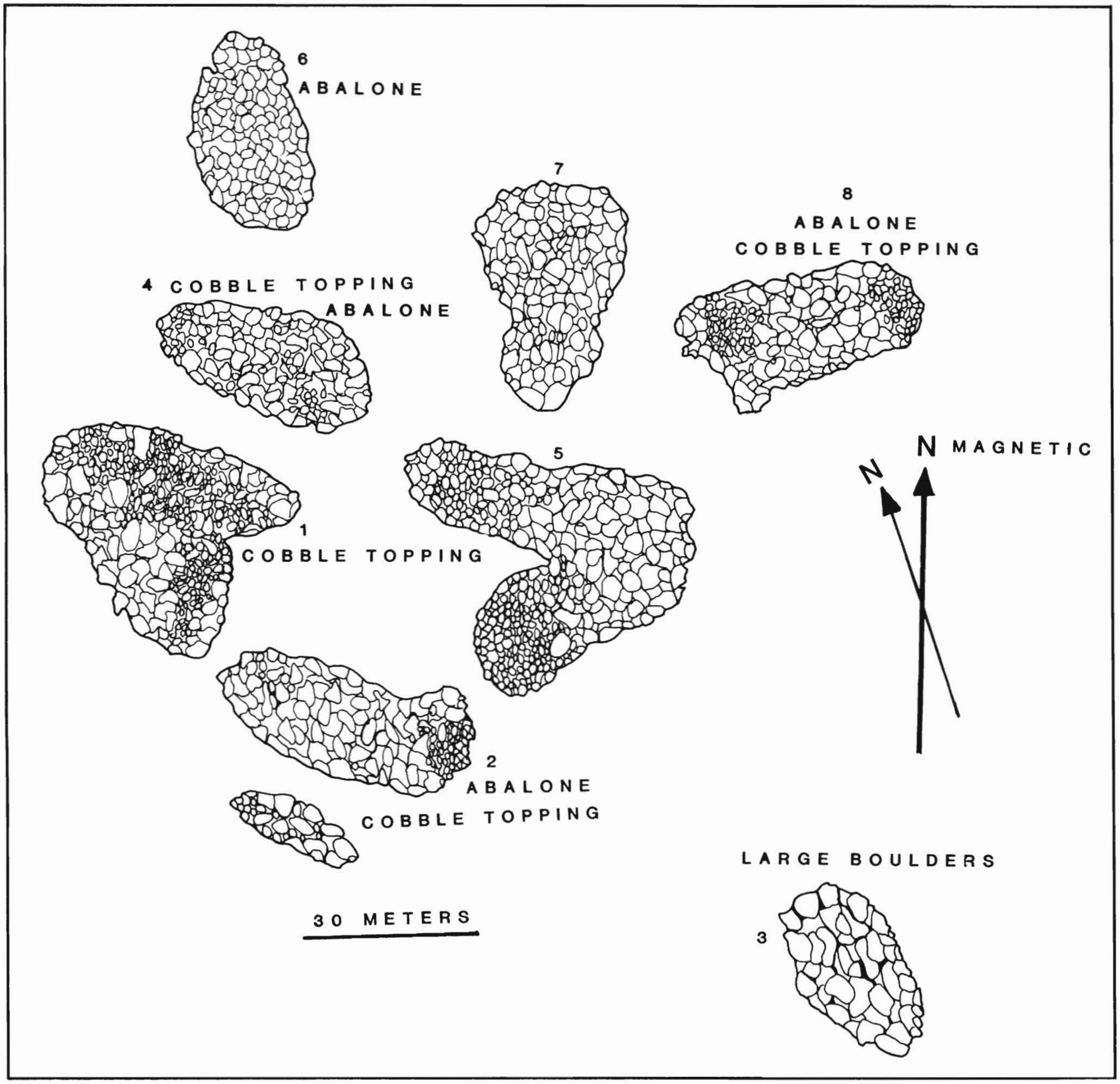

Figure 3.—Pendleton Artificial Reef as constructed, 24 September 1980.

modules, 1 through 5 and 7, during 3 days of field operations.

The first transplant of red abalone took place in July 1981. A total of 825 juvenile (2-4.5 cm) red abalone was placed on Module 8 during one transplant operation.

Biological Observations

No formal surveys of reef biota were made prior to August 1981. However, early biotic development was noted during general working or reconnaissance dives. Results of these informal observations, discussed below, are given in Tables 1 and 2.

Reef construction began on 27 August 1980. Reconnaissance dives the next day revealed several black perch and white seaperch. Barred sand bass and kelp bass were present. These fishes were not unexpected. Turner et al. (1969) and Carlisle et al. (1964) noted the presence of such fishes within hours of reef construction in Santa Monica Bay. These species are adventitious feeders who characteristically can cover large areas while foraging for food. The dumping of so much rock and subsequent perturbation of the bottom possibly exposed food organisms upon which the fish preyed. Reconnaissance dives made 5 days later, 2 September, showed increased numbers of these fishes. These were joined by California scorpionfish and California halibut. California scorpionfish are primarily rock- and crevice-dwelling fish and were not expected to colonize the reef so early in its development since they had to cross large expanses of sand prior to finding the rocks.

On 17 September the first obvious invertebrates were noted. Large numbers of juvenile barnacles were seen covering most exposed surfaces. Numerous colonies of *Obelia* sp. were also abundant. Identifiable for the first time were the CDFG artificial reef in Santa Monica Bay. Turner et al. (1969) suggested that algae *Ectocarpus* and filamentous diatoms which were growing in abundance on the upper portions of the reef. We observed four adult *Pisaster brevispinus* high on the modules.

During kelp transplanting operations in October 1980, we estimated that 80 percent of the upper surface of most rocks was covered by a 1-2 mm thick layer of a sticky clay-silt-like material. This was later identified as the encrusting ectoproct *Cryptoarachnidium argilla.* This organism was first observed as covering most hard surfaces in the early successional stages of the biota on a thick layers of this organism could inhibit colonization by other species. However, this did not appear to be the case in the Santa Monica Bay reef and, as subsequent observations indicate, it doesn't appear to be an inhibiting factor on PAR.

We noted that many of the barnacles observed earlier had been broken, perhaps either by fish and starfish or by dragged boat anchors.

Several species of new fish were noted around the reef for the first time during kelp transplanting operations. These included California sheephead, pile perch, halfmoon, blacksmith, opaleye, garibaldi, and what appeared to be a juvenile giant sea bass, which are becoming rare in southern California. This apparent sighting, subsequently followed by others on 20 October 1980 and 31 March 1981, suggests juvenile giant sea bass may become residents of the reef. The area from Dana Point to Oceanside has historically been one of the most productive giant sea bass areas in California. A resident population of giant sea bass on PAR would be very valuable and would present significant management implications in view of their decreasing numbers.

Garibaldi are generally considered to be a resident species that establish a home territory and tend not to leave unless displaced. Their presence, and the presence of the previously-noted California scorpionfish indicate the beginnings of a resident fish fauna. This has been described by other CDFG biologists in previous artificial reef work. Apparently, the early stages of the reef's fish fauna development are dominated by perches and basses that move in during foraging activity. Later, as a more complex fauna develops and more niches become available, resident-type fishes begin to compose a greater component of the fish assemblage.

The numbers of fish present during early October dives were tremendous. Sublegal kelp and barred sand bass surrounded some modules in numbers that were close to uncountable. Fishes appeared to be most abundant on the northwesterly modules, and became progressively less abundant on modules to the southeast. Sportfishing boats from Dana Point were regularly observed

Table 1.—Fish Observed on Pendleton Artificial Reef (in order of observation).

Scientific Name	Common name	Date of first observation
Embiotoca jacksoni	Black perch	28 August 1980
Phanerodon furcatus	White seaperch	28 August 1980
Paralabrax nebulifer	Barred sand bass	28 August 1980
Paralabrax clathratus	Kelp bass	28 August 1980
Scorpaena guttata	California scorpionfish	2 September 1980
Paralichthys californicus	California halibut	2 September 1980
Semicossyphus pulcher	California sheephead	17 October 1980
Rhacochilus vacca	Pile perch	17 October 1980
Medialuna californiensis	Halfmoon	17 October 1980
Chromis punctipinnis	Blacksmith	17 October 1980
Girella nigricans	Opaleye	17 October 1980
Hypsypops rubicundus	Garibaldi	17 October 1980
Stereolepis gigas	Giant sea bass	17 October 1980
Anisotremus davidsoni	Sargo	17 October 1980
Halichoeres semicinctus	Rock wrasse	17 October 1980
Scorpaenichthys marmoratus	Cabezon	11 December 1980
Oxylebius pictus	Painted greenling	May 1981
Sebastes auriculatus	Brown rockfish	May 1981
Cheilotrema saturnum	Black croaker	May 1981

Table 2.—Invertebrates Observed on Pendleton Artificial Reef (in order of observation).

Scientific name	Common name	Date of first observation
Megabalanus californicus	Barnacle	17 September 1980
Obelia sp.	Hydroid	17 September 1980
Pisaster brevispinus	Short-spined sea star	17 September 1980
Cryptoarachnidium argilla	Encrusting ectoproct	17 October 1980
Abietinaria sp.		22 October 1980
Pisaster giganteus	Giant-spined sea star	30 October 1980
Spirorbis sp.		11 December 1980
Membranipora sp.		11 December 1980
Panulirus interruptus	Spiny lobster	12 December 1980
Styela montereyensis	Stalked tunicate	16 January 1981
Aglaophenia struthionides	Ostrich-plume hydroid	16 January 1981
Pododesmus cepio	Abalone jingle	16 January 1981
Chaetopterus variopedatus	Parchment tube worm	16 January 1981
Salmacina tribranchiata		31 March 1981
Loxorhynchus crispatus	Sheep crab	31 March 1981
Diplosoma macdonaldi		21 April 1981
Cystodytes lobatus		21 April 1981
Dendrobeania laxa		20 May 1981
Serpulorbis squamigerus	Scaled worm shell	20 May 1981
Corynactis californica	Strawberry anemone	20 May 1981
Tubularia crocea		20 May 1981
Octopus sp.	Octopus	20 May 1981
Chelyosoma productum	Ascidian	August 1981
Plumularia sp.	Hydroid	August 1981
Hinnites giganteus	Purple-hinged scallop	August 1981
Notoacmaea sp.	Limpet	August 1981

fishing the reef.

Sargo were first noted on the reef on 21 October 1980. Commercial lobstermen were working PAR, with two individuals working nine traps. We observed the first rock wrasse the following day. Also noted for the first time was a lone *Abietinaria* sp. colony. The dive on 30 October 1980 produced our first sighting of *Pisaster giganteus*, a starfish common on most southern California rocky substrate out to 18 m (60 feet) deep.

On 11 December, a reconnaissance of Module 7 revealed the presence on occasional rock surfaces of an encrusting bryozoan, *Dendrobeania* sp. A minute prostrate polysiphonous red algae with a finely-divided thallus was observed forming numerous 2.5-5 cm (1-2 inch) diameter patches on upper rock surfaces. *Enteromorpha* was noted on the upper 1.5 m (5 feet) of Module 7. A reconnaissance of the *Macrocystis* transplants on Module 6 indicated that 26 of the original 36 plants had survived. Most were in poor condition with *Spirorbis* and *Membranipora* heavily epiphytic on the blades. Little new frond growth was evident on any plants except those attached to the Osmocote-filled bricks. Of the 26 remaining transplants, 16 had some hapteral attachment to the rock. Poor growth of plants, except for those on the Osmocote bricks, was probably the result of high temperatures and low nutrient levels. Plants on the bricks constantly bathed in nutrients escaping from the Osmocote did better than other transplants. One large kelp plant, with 12 fronds, greater than 1 m in length and with sporophyll development, was lodged in the lower reaches of the reef. The holdfast of this plant had several large cobbles attached to it. The next day the first observations of a cabezon and a California spiny lobster were made.

The 6 January 1981 dive revealed that transplanted *Macrocystis* had produced new blades. Patches of red algae had become more dense and conspicuous with some areas up to 0.6 cm (¼ inch) thick. Incidental observations made on 16 January revealed several additional species. Good numbers of juvenile stalked tunicates were noted in many locations. They were particularly evident on our transect leadlines. The ostrich-plume hydroid, *Aglaophenia struthionides: Pododesmus cepio;* and a serpulid tube were also noted for the first time. Parchment tube worms, *Chaetopterus variopedatus*, were common under rocks.

Several new algal taxa were noted during this dive. These included an unidentified fleshy brown algae (possibly *Taonia* sp. or *Pachydictyon* sp.) an unidentified low-growing green algae, and *Colpomenia* sp.

On 31 March two juvenile giant sea bass were observed. Three small *Salmacina tribranchiata* colonies and a large sheep crab also were noted.

Three days of diving in April were dedicated to transplanting *Macrocystis* taken from San Mateo Point and SONGS kelp beds. In all, 25 plants were attached to the reef during these dives. Most were small with 1 or 2 fronds. About 12 of the original October 1980 transplants had survived. All mature growth was heavily grazed and epiphytized. New growth was no more than 0.3 m (12 inches) high and had few epiphytes. For the first time *Macrocystis* recruitment was observed on PAR by CDFG and Lockheed biologists. Juveniles were growing directly on the rocks at a depth of 10.4 m (34 feet). One area had seven juveniles 2.5-5.0 cm (1-2 inches) in height. This was encouraging since natural recruitment is vital for a stable, self-sustaining kelp bed and these findings indicated *Macrocystis* would recruit on the reef. These plants were subsequently grazed down by herbivorous fishes. This has often occurred in our kelp restoration work and can be overcome by transplanting a large number of adults to provide a sufficient biomass to overcome the detrimental effects of fish grazing.

Other algae had become increasingly obvious on the reef. *Rhodymenia* sp. was abundant on most of the higher rocky areas, as was minute polysiphonious red algae and occasional *Enteromorpha.* One of the Osmocote bricks was covered with juvenile *Eisenia.* These plants were not present during the original transplant operations and the bricks had not been in the water prior to our use. It seems likely, therefore, that the plants recruited in situ. This suggests that survival of these plants was enhanced by the increased nutrients since they were not noted on any other part of the reef. Two colonial ascidians, *Diplosoma macdonaldi* and *Cystodytes lobatus,* were noted.

Four new fishes were observed during May transplant operations. These were the painted greenling, brown rockfish, black croaker, and an unidentified surfperch.

Many fishes were living within the reef, going into crevices and under rock overhangs. In many ways, the rock mix appeared to provide more habitat for fishes than did the concrete shelters in the Hermosa Artificial Reef in Los Angeles County. A 0.6 m (2 foot) long California halibut was observed resting on top of a large, flat, horizontal rock near the crest of Module 3. This was significant since the halibut was more than 3.0 m (10 feet) above its normal habitat on the sand. This was the second occurrence of this behavior noted at PAR.

Of interest was the discovery of two very old and blackened *Macrocystis* holdfasts on bedrock exposed at the base of the reef by scouring action. The bedrock was also pockmarked with holes of boring clams suggesting an extended interval of exposure at some time in the past.

During reconnaissance dives in May, *Serpulorbis squamigerus, Tubularia crocea, Corynactis californica,* and one *Octopus* sp. were observed.

The first formal surveys of reef modules took place during the first two weeks of August 1981. However, preliminary evaluation of data from these surveys suggests that the dominant invertebrate, in terms of substrate covered was *Cryptoarachnidium argilla.* This organism, which incorporates sediment in a tubule network, covered between 70 and 100 percent of rock surfaces. The most conspicuous invertebrates were several species of barnacles, most numerous of which was *Megabalanus californicus.* Small hydroids, notably *Plumularia* sp. and *Obelia* sp. were also common, particularly in protected areas. New species of invertebrates noted during the August sampling period were the ascidian, *Chelyosoma productum;* the purple-hinged scallop, *Hinnites giganteus;* and an immature *Notoacmaea* sp.

Low growing vegetative cover, composed of *Ectocarpus, Gigartina, Polysiphonia,* and *Rhodymenia,* was abundant, covering up to 95 percent of some rock surfaces. Vegetation did not appear to be negatively impacted by the *Cryptoarachnidium* cover because algae were growing on and through this ectoproct/silt layer. *Macrocystis* haptera also appear to penetrate *Cryptoarachnidium* and attach to rock.

Discussion

Pendleton Artificial Reef, 1 year after construction, appears to have developed a complex assemblage of fishes, invertebrates, and algae. The individual modules are very similar to "Toseki" or "artificial shoals" which, in Japan, are designed to enhance production of a variety of species.

Maximum enhancement of PAR depends, in our opinion, on establishment of a *Macrocystis* bed on the modules. *Macrocystis* beds are complex communities which have been compared in dimension and complexity to terrestrial rain forests (Foster, 1975a, b). The presence of a *Macrocystis* bed greatly increases the numbers and diversity of fish and invertebrate populations. Quast (1968), referring to *Macrocystis,* stated: "In regions with similar rocky substrates of low or moderate relief, the areas with kelp give estimates of the standing crop of fishes that is two to three times as great as that of similar habitats barren of kelp" (sic). A similar situation has been reported by North (1964). Regarding plant biomass he stated: "The standing crop of benthic algae in an open area may be seven times that existing below a *Macrocystis* canopy, but if *Macrocystis* were included, the standing crop of plant material was three to four times as great within the bed as outside."

The desirability of *Macrocystis* is evident. We designed and situated PAR primarily with the establishment of a *Macrocystis* bed as a desired final result. Attaining a stable bed on an artificial reef has not yet been accomplished. *Macrocystis* recruited naturally to an artificial reef constructed by the CDFG off Hermosa Beach in Los Angeles County. This bed was lost, probably due to poor water quality in the area and excessive depth. *Macrocystis* recruited to Torrey Pines artificial reef in 40 feet of water near La Jolla in San Diego County. This kelp bed was lost to sea urchin grazing, but has since begun to return after removal of the sea urchins.

Shoreline development and activities of the Marine Corps at nearby Camp Pendleton have all contributed to increased erosion along a broad section of that coast. At the reef site, substrate is composed of layers of terrestrial debris, sand, and broken shells approximately 2 feet thick overlaying a firm basement of rock and cobble. The placement of the reef, subsequent scouring around the edges of the modules, and increased movement of water between the modules, has removed large volumes of sand. The presence of numerous old blackened holdfast remains from an extinct kelp forest suggest that the probability of kelp recruiting to the area is excellent. We noted on early dives many *Macrocystis* recruits on the base of several modules. These were probably offspring of adult plants that drifted through and became temporarily entangled in the reef. Several of the plants we placed on the modules produced young, but the plant biomass was insufficient to protect these recruits from fish-grazing mortality.

The year 1981 was characterized by abnormally warm water conditions in the southern California bight which led to a decline in kelp beds along portions of the coast. Consequently, our transplants have not done as well as hoped. Perhaps 30 percent of the original plants survive. These, and transplants in October 1981 will, hopefully, form the nucleus for the 1982 parent stock.

The invertebrate fauna has progressively become more complex. The ubiquitous *Cryptoarachnidium argilla* appears to present little problem to many species. When it matures and thickens, it often becomes dislodged and portions fall away leaving exposed bare rock which can be colonized by other forms. Establishment of substrate-grazing invertebrates, such as sea urchins and sea cucumbers, may also help control the growth of *Cryptoarachnidium.*

Juvenile abalone, transplanted to the reef earlier, have suffered some mortality due to predation. However, recaptured individuals have shown new growth. The development of large brown algae, such as *Macrocystis,* is imperative to provide forage for the growing abalone.

Fish assemblages have, at times, exceeded our expectations. Extremely high numbers of basses and perches have been observed on every dive. There appears to be a cyclical increase in the numbers of large sand bass and kelp bass. The larger individuals of these species appeared in great numbers in September 1980 and August 1981. Similar observations were made at artificial reefs in Santa Monica Bay. Turner et al. (1969) suggested that these movements were related to spawning activities.

It is possible that, in its transitional phases of development, an artificial reef attracts a higher percentage of adventive peregrine fishes than mature reefs. Evidence supporting this is found in Turner et al. (1969) where it is reported that fishes, particularly embiotocids and serranids, appeared within hours after reef construction in Santa Monica Bay, and that these species dominated each reef's fish population during its first year. This dominance decreased during the second and third years as resident "reef species," such as gobies, cottids, and rockfishes, became more numerous and the reefs approached equilibrium. A similar pattern can be observed at Pendleton Artificial Reef. Large numbers of perches and basses were observed immediately after construction. Only later did we observe occasional individuals of species that could be defined as "resident species," such as garibaldi, and brown rockfish. Ideally, the most productive reefs would include elements of both resident "reef fish" and semiresident adventitious populations.

The success of PAR as an environmental enhancement tool could benefit regulatory agencies, utility companies, and sport and commercial fishing interests. Results of the first year of a 5-year study indicate that the diversities of fishes, invertebrates, and algae are increasing. Algal cover is also increasing and naturally-recruited *Macrocystis* sporophytes have been noted. The final measure of the success of PAR will be in its comparison with natural reefs of similar configuration that occur nearby.

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