COMPARISON OF COMMUNITIES ON ARTIFICIAL AND NATURAL REEFS IN SOUTHERN CALIFORNIA, WITH EMPHASIS ON FISH ASSEMBLAGES

FINAL REPORT

Richard F. Ambrose
Principal Investigator

Contributing Staff:

Susan L. Swarbrick
Staff Research Associate

and

Keli C. McKay
Tamara L. Sasaki

Marine Science Institute
University of California, Santa Barbara

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Marine Review Committee, Inc.
531 Encinitas Blvd., Suite 105
Encinitas, CA 92024

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EXECUTIVE SUMMARY

The relationship between artificial and natural reefs must be understood in order to assess the feasibility of using artificial reefs to replace resources that have been lost from natural reefs. This report evaluates the ecological similarities of artificial and natural reefs in Southern California, and assesses information about (1) aspects of artificial reef design that maximize the standing stock of fish, and (2) the size of artificial reef needed to compensate for the loss of resources from a natural reef.

Communities on artificial and natural reefs were surveyed in Fall 1986. Ten artificial and 16 natural reefs were sampled between San Diego and Santa Barbara. Two types of artificial reefs were sampled. "Traditional" artificial reefs were usually small, isolated, completely submerged, and with moderate to low height. Breakwaters were larger, steeper, emergent (i.e. projected above the surface of the water) and tall. Natural reefs ranged from small, high-relief reefs composed of boulders and bedrock to large, low-relief reefs composed of cobbles. Sites near the San Onofre Nuclear Generating Station that were sampled include the San Mateo Kelp bed (including Two-Man Rock), San Onofre Kelp bed (both Main and North portions), Pendleton Artificial Reef, Box Canyon, Las Pulgas Reef, and Barn Kelp.

On each reef, the densities of algae, invertebrates and fish were estimated. Fish were sampled near the benthos and in the water column. The densities of young-of-year fish were estimated in order to compare recruitment on artificial and natural reefs. Biomass density and standing stock were also estimated for each reef.

Physical characteristics

There were substantial differences in physical characteristics between the artificial and natural reefs sampled. Artificial reefs were smaller than natural reefs. Since most artificial reefs were constructed of large rocks and boulders, these substrate types were more prevalent than on natural reefs. In contrast, small rocks and cobble were more common on natural reefs, and bedrock was sometimes extensive. Artificial reefs, especially breakwaters, generally had steeper slopes than natural reefs. A few natural reefs had slopes that were comparable to artificial reefs, but many natural reefs were virtually flat. Two artificial reefs were constructed from concrete.

Algal and invertebrate characteristics

The algal communities found on natural and artificial reefs were quite different. Percent cover or density of most groups of algae was greater on natural reefs than on artificial ones. The density and size of giant kelp (*Macrocystis pyrifera*) plants also tended to be greater on natural reefs. Higher cover of foliose algae and higher density of kelps resulted in a greater mean algal height on natural compared to artificial reefs.

The percent cover of sessile invertebrates, particularly bryozoans, tended to be higher on artificial reefs. Larger invertebrates were generally not abundant, and total density was not significantly different between the two reef types. The gorgonian *Lophogorgia* was the only species with higher densities on artificial reefs. Anemones, bivalves, the snail *Kelletia kelletii* and the red urchin *Strongylocentrotus franciscanus* had higher densities on natural reefs.

Fish assemblages

In general, the same species of fish were found on both reef types but the relative abundances of some of the common species were different. Rock wrasse, senorita, sheephead and garibaldi comprised a higher proportion of the fish seen on natural reefs than artificial reefs. In contrast, blacksmith made up a much higher proportion of the fish on artificial reefs. The proportion of fish in the water column that were young-of-year was about the same on artificial and natural reefs. However, a greater proportion of fish near the benthos were young-of-year on artificial reefs than on natural reefs. The size distributions of a few species also differed between artificial and natural reefs. In particular, larger sheephead and kelp bass tended to occur on natural reefs. Cluster analyses indicated that the fish assemblages on artificial reefs in general were about as similar to natural reefs as they were to each other.

The densities of fish near the benthos were much higher on artificial reefs than natural reefs. This pattern was driven in part by high densities of blacksmith on artificial reefs, but both young-of-year and all lifestages of sport fish (which do not include blacksmith or gobies) were also more abundant on artificial reefs. Almost all individual species studied had higher densities on artificial reefs. Only all lifestages combined for garibaldi, senorita and rock wrasse tended to be more abundant on natural reefs. The densities of young-of-year of most species were quite low but the trend for all species was toward higher density on artificial reefs. The density of young blacksmith was often very high, particularly on artificial reefs.

Densities of fish in the water column on artificial and natural reefs were highly variable. High densities in the water column were usually the result of high densities of blacksmith, atherinids or senoritas. Young-of-year ("young") comprised most of the fish seen in the water column on 35% of the reefs with high densities. Most young were blacksmith or senorita, although young atherinids were found on Pitas Point Artificial Reef. There were no significant differences between mean densities on artificial and natural reefs, but blacksmith were about 4 times more abundant on artificial reefs while senoritas were 4 times more abundant on natural reefs.

Total biomass density (kg/m^3) of fish near the benthos was higher on artificial than natural reefs. For most individual species, benthic biomass density was higher on artificial reefs. However, biomass density of a few species, particularly garibaldi and sheephead, was almost twice as high on natural reefs. Biomass density in the water column was slightly higher on natural reefs than artificial reefs. For a few species, notably kelp bass in the water column and sheephead near the benthos, there seemed to be a higher proportion of larger individuals on natural reefs.

Standing stock estimates were based on the size of the reef and the biomass density of fish on the reef. The area of artificial reefs averaged 2.2 ha (excluding breakwaters and Rincon Oil Island, artificial reefs averaged only 0.85 ha), while natural reefs averaged 124 ha, about two orders of magnitude larger. The mean biomass density of benthic fish was 0.452 metric tons (MT)/ha on artificial reefs and 0.286 MT/ha on natural reefs. The average standing stock of fish near the benthos on artificial reefs was 0.94 MT (range: 0.12 to 2.77 MT). On natural reefs, average standing stock was 45.32 MT (range: 2.22 to 276.05 MT). Since biomass density was much lower in the water column than near the benthos, standing stocks of fish in the water column were also much lower. Average standing stock in the water column was 0.017 MT on artificial reefs and 0.032 MT on natural reefs.

Factors influencing fish assemblages

The data on species richness and density on reefs provide a basis for comparing artificial and natural reefs. However, this information alone provides little insight into the mechanisms underlying the observed patterns or features of an artificial reef that might influence the fish assemblage on the reef. These problems were addressed by examining the relationships between physical and biological characteristics of the reefs with fish richness and density using regression analyses.

Most regressions between species richness and physical characteristics were significant only for artificial reefs. The number of species near the benthos was not related to the area of artificial reefs, but the number of species in the water column was, indicating that larger artificial reefs had more water column species. Similarly, the number of species near the benthos was not related to the height of artificial reefs, but the number of species in the water column was, indicating that higher artificial reefs had more water column species. The relationship with reef depth was somewhat more complicated. Deeper artificial reefs had more species with juveniles & adults near the benthos, but fewer species with young-of-year near the benthos and fewer species of all lifestage categories in the water column. Thus, more species recruited to shallow artificial reefs, and these reefs also had more species in the water column, but deeper reefs had more species with juveniles & adults represented.

The presence of *Macrocystis* had a strong positive effect on species richness of water column fish on both artificial and natural reefs. There was also a positive relationship between species richness of fish in the canopy and the mean height of all algae. Understory kelp appeared to have had no effect on richness, either near the benthos or in the water column.

The densities of fish in the water column were also positively related to algal characteristics of the reefs. This relationship was particularly strong for *Macrocystis*, where the regression explained as much as 80% of the variation in fish densities. However, all algal characteristics tested had at least some significant regressions with water-column fish densities, and these were always positive. Thus, the abundance of algae, even benthic algae, seems to enhance the assemblage of fish in the water column.

In contrast to fish in the water column, the relationship between the density of fish near the benthos and algal characteristics was not consistent, but varied according to life stage and species. The densities of young-of-year near the benthos were, in general, positively related to algae on the reefs; the only negative relationship was for young blacksmith. For all life stages combined, barred sand bass was negatively related to algal characteristics. The density of blacksmith near the benthos was also sometimes negatively related to algal characteristics. The density of garibaldi was positively related to algae on the reefs.

Summary

In general, the same species of algae, invertebrates and fish occurred on both artificial and natural reefs, albeit with somewhat different relative abundances. Nevertheless, there were a number of crucial differences between the two reef types, including aspects of reef size, isolation, complexity, algal abundance, and the fish community. Some of these differences may have important implications regarding the amount of fish produced on artificial reefs.

Algae, especially giant kelp, may be very important for fish production on reefs in Southern California. Algae provide food, shelter and recruitment sites for fish. Our data indicate the importance of *Macrocystis* for water-column fish. Yet one of the most conspicuous differences between artificial and natural reefs is the relative lack of algae on artificial reefs. The scarcity of algae on artificial reefs may significantly reduce their potential for enhancing fish production.

Higher densities of fish occurred on artificial reefs compared to natural reefs, at least near the benthos, but biomass densities were similar. Fish richness and diversity on artificial reefs were equal to or higher than natural reefs. Estimates of fish recruitment to the two reef types, based on young-of-year densities, were also comparable, with generally higher recruitment on artificial reefs in Fall 1986.

The most fundamental question about the use of artificial reefs in mitigation, the amount that fish production can be increased through the construction of an artificial reef, remains unanswered. The results of this study demonstrate that artificial reefs contribute to one important aspect of production, recruitment, since the densities of young-of-year were generally higher on artificial reefs than natural reefs during our survey. But there are no data concerning survivorship and growth, so the overall contribution of artificial reefs to fish production cannot yet be determined.

If an artificial reef is to be used in mitigation, one of the most critical decisions about the reef is the size that will be required. The size of reef needed to mitigate a particular impact depends on (1) the resources lost by the impact, and (2) the resources provided by the reef. The resources lost by the impact can usually be estimated, but because of the uncertainty about fish production on artificial reefs, it is very difficult to estimate the resources provided by a reef.

A rough estimate of the resources provided by an artificial reef can be made under the assumption that the standing stock of an artificial reef (i.e. the biomass of fish on the reef) is produced entirely on the reef. As discussed above and in Ambrose (1986a), this assumption is likely to considerably overestimate the true fish production, but it can serve as a starting point for calculating necessary reef size.

Estimates of standing stock indicate that, in spite of higher biomass densities, the standing stock of fish on artificial reefs is considerably lower than on natural reefs because of the small size of existing artificial reefs. For example, the average standing stock of benthic fish on artificial reefs in our survey was 0.94 MT, compared to 45.32 MT for natural reefs. These data indicate that, even under the liberal assumption that all fish on an artificial reef are produced by the reef, the size of a reef needed to replace lost natural resources may be substantial.

One serious criticism of the use of small artificial reefs to mitigate for resource losses is that many of the fish found on the reef may simply be attracted to it. For example, midwater Fish Attracting Devices (FADs) provide no resources to fish, yet large numbers of fish aggregate around them; attraction may also account for a large proportion of the fish on small artificial reefs. On the other hand, a large, complex artificial reef constructed from a natural substrate, such as quarry rock, would offer many different habitat and microhabitat types. Placed in an appropriate location, it could support a rich assemblage of algae and associated invertebrates, thereby providing food for a number of fish species. An artificial reef on such a scale has never been built in the United States, but by supplying an abundance of appropriate features, it seems likely that it would increase fish production. Although small artificial reefs may have limited mitigative value, a large-scale artificial reef that duplicated the size and complexity of natural reefs could be appropriate for mitigating resource losses.

PREFACE

The Marine Review Committee (MRC) has been charged with determining the effects of the cooling system of the San Onofre Nuclear Generating Station (SONGS). The MRC began investigating mitigation measures in 1980, following recognition by the California Coastal Commission (Fischer 1979) that, in addition to changes in the cooling system, "operational changes or mitigation measures might adequately compensate for any marine life damages resulting from the operation of Units 2 and 3. The Commission, therefore, requests the MRC to study the feasibility and effects of selected promising mitigation measures, including construction of an artificial reef, as suggested by Southern California Edison. The MRC should recommend what measures might be taken to assure there would be no net adverse effect on the marine environment from operation of SONGS Units 2 and 3."

The overall objective of the Mitigation Program is to evaluate the feasibility of techniques that might be used to mitigate the effects of SONGS on marine communities. One mitigation technique, artificial reefs, has been recognized by the MRC as potentially valuable, and several studies have been commissioned to evaluate this alternative (Sheehy 1981, Thum *et al.* 1983, Ambrose 1986a). In addition, Ambrose (1986b) presented an overview of options available for mitigation at SONGS, evaluating the appropriateness of each option.

This report presents the results of a survey of communities on a variety of artificial and natural reefs in Southern California. The purpose of this survey was to compare the communities, especially the fish assemblages, on artificial and natural reefs. A number of artificial and natural reefs with a wide range of physical and biological characteristics were surveyed to avoid the limitations resulting from sampling at one site and to accommodate the variation in ecological communities. On each reef, the densities of algae, invertebrates and fish were estimated. Particular care was taken to determine the density of young-of-year fish in order to estimate fish recruitment to the reefs; for this reason, all reefs were surveyed in Fall, following the major recruitment season. The data from this study provide a good description of the communities occurring on artificial reefs and how they compare with those on natural reefs. The data are also used to evaluate the influence of reef characteristics on fish assemblages on reefs. This information is needed to evaluate the feasibility of using artificial reefs in mitigation. The data also provide information about aspects of reef design that maximize the standing stock of fish, and the size of artificial reef needed to compensate for the loss of resources from a natural reef.

There are two chapters in this report. The first chapter presents the results of the survey of artificial and natural reefs. The data on the diversity and abundance of algae, invertebrates and fish are used to assess the similarity between communities on the two reef types. In addition, factors that might influence fish assemblages are examined in order to identify reef characteristics that should be considered if an artificial reef is used in mitigation.

The second chapter discusses the results of this study on artificial reefs as they apply to using artificial reefs in mitigation. The problem of fish production on artificial reefs, discussed at length in Ambrose (1986a), is not resolved by the data collected during this project, but the data do provide some new information regarding fish production that is evaluated. In addition, new insights into the possible effects of reef depth, height and size on fish communities are discussed. Chapter 2 is not intended to be a final analysis of the feasibility of using artificial reefs in mitigation, but it does summarize some of the important issues.

Appendices supporting the data presented in Chapter 1 are provided in a separate volume, submitted with the Draft Report in September 1987. One Appendix, E, is included at the end of this volume. Also included at the end of this volume are corrections to errors in the separate Appendix volume.

Previous MRC studies on artificial reefs and mitigation

Several other MRC reports discuss the feasibility of using artificial reefs to mitigate SONGS effects. Sheehy (1981) primarily summarized various techniques used in Japan to enhance marine fisheries, although he also discussed how these techniques could be applied to mitigate losses that might be associated with SONGS. Thum *et al.* (1983) provided a brief overview of state and federal requirements for proper mitigation, a case history of mitigation of the environmental effects of intertidal dredging and filling of estuaries in Oregon, and a review of mitigation legislation in California. Thum *et al.* also discussed the results of the Pendleton Artificial Reef project and suggested some alternative methods for utilizing artificial reefs as a means of mitigation. Ambrose (1986a) reviewed information on artificial reefs specifically to evaluate the feasibility of using artificial reefs as a mitigation technique. A major portion of Ambrose (1986a) was devoted to summarizing evidence regarding fish production on artificial reefs.

The MRC also undertook a study of the biological development of Pendleton Artificial Reef, an artificial reef constructed 5 km downcoast from SONGS in 1980.

Results of this study are summarized in three Lockheed Ocean Science Laboratories (LOSL) reports (LOSL 1983a, 1983b, 1983c). Although these reports do not deal directly with mitigation, it is discussed in LOSL (1983c).

CHAPTER 1

SURVEY OF ARTIFICIAL AND NATURAL REEFS DURING FALL 1986

1.1 Introduction

Artificial reefs have been purposefully constructed since at least the 1700's in Japan (Ino 1974) and the 1800's in the United States (Stone 1974, 1985), although their widespread use has only taken place in the last 20-30 years. Throughout their history, the primary goal of artificial reefs has been to enhance fishing success, and this goal still predominates. However, there has recently been considerable interest in using reefs in mitigation, as a means of producing fish to compensate for fish losses resulting from human developments.

One of the most controversial aspects of artificial reefs revolves around the question of whether they actually increase the production of fish, or simply attract fish. The question of fish production is important because attraction alone would not be acceptable on artificial reefs used to compensate for or offset a loss of resources. The simple redistribution of biomass occurring when fish are attracted to an artificial reef would not compensate for a loss of resources, since no new resources would be provided. For this reason, determining the extent to which artificial reefs contribute to fish production is a critical step towards evaluating the feasibility of using artificial reefs in mitigation.

The ability of artificial reefs to attract fish, and hence increase fishing success, is well established (Turner *et al.* 1969, Fein and Morganstein 1974, Russell *et al.* 1974, Russell 1975, Molles 1978, Bohnsack and Talbot 1980, Gascon and Miller 1981, Ranasinghe 1981, Tubb *et al.* 1981, Wilson *et al.* 1981, Matthews 1985, Walsh 1985). It is not clear that the reefs actually produce fish, (i.e., cause an overall increase in fish biomass). Fish production can potentially be increased by higher recruitment, higher growth or greater survival of fish. A review of the literature indicates that increased fish production on a marine artificial reef has never been demonstrated (Ambrose 1986a). A brief review of these studies is given below; but first, some basic terms that are used in this report are defined.

Fish production as used here refers to the increase in fish biomass. Currently, the most generally accepted definition of production is: the total elaboration of fish tissue during any given time interval, including what is formed by individuals that do not survive to the end of the time interval (Ivlev 1966); the elaboration of new tissue can be by the growth of existing fish, increased fecundity of existing fish, and/or an increase in the number of fish. Productivity refers to the rate of biomass production, while production refers to absolute biomass (Bohnsack and Sutherland 1985). *Standing stock* (or standing crop) refers to the total number or biomass of fish present on a reef at a specific time. *Recruitment* is used to mean the settlement onto a reef of larval or post-larval fish, or the birth of fish without a larval stage.

Many studies have mentioned anecdotally that fish recruit to artificial reefs (Turner *et al.* 1969, Parker *et al.* 1979, Woodhead *et al.* 1982), but few have quantified the amount of recruitment. The most complete study of fish recruitment has been performed on Pendleton Artificial Reef in Southern California. Young-of-year were sampled on the reef two (LOSL 1983c) and four (DeMartini 1985) years after reef construction, with 10-11 species represented and most species present during both censuses. These results indicate that some species successfully recruit to artificial reefs, but it is not possible to estimate the relative importance of recruitment versus immigration in the fish assemblage as a whole, nor is it clear how the pattern of recruitment on artificial reefs compares to that on natural reefs.

Growth rates on artificial reefs have been determined for only one fish species, copper rockfish (Dewees 1970, Dewees and Gotshall 1974); tagged copper rockfish grew an average of 0.14 mm/day. Because copper rockfish were never captured away from the reef, fish growth was directly linked to the artificial reef. The majority of studies have tried to assess growth on artificial reefs indirectly by examining stomach contents to indicate whether the fish consumed organisms occurring on artificial reefs; however, while this technique can demonstrate that fish *could* have foraged on artificial reefs, it does not prove that they did. Gut-content studies have indicated that some fish obtain most of their food from artificial reefs (Pearce and Chess 1968, Prince and Gotshall 1976, Hueckel 1980, Hueckel and Stayton 1982, Davis *et al.* 1982, Buckley and Hueckel 1985). On the other hand, some fish on artificial reefs apparently do not feed on the reefs (Randall 1963, Kakimoto 1982, Russell 1975, Mottet 1981, Davis *et al.* 1982, Hueckel and Stayton 1982, Steimle and Ogren 1982).

Finally, very few studies have assessed survival on artificial reefs. Data from one artificial reef in California indicate that survival of adult fish might actually be lower on artificial reefs because of fishing pressure (Matthews 1983, 1985, Solonsky 1983, 1985).

Few studies have addressed even one of the mechanisms by which artificial reefs could increase fish production, but no study to date has addressed all aspects of fish production simultaneously. Such a comprehensive approach is necessary because gains in one factor, such as recruitment, could be canceled by losses in another, such as survival. In fact, studies by Matthews (1983, 1985) and Solonsky (1983, 1985) indicate that this could happen. Until a comprehensive study of production is completed, we must rely on assessing individual studies. A synthesis of such studies (Ambrose 1986a) suggests that the production of some species probably increases on properly designed artificial reefs, but the extent of the production is unknown.

In addition to the problem of fish attraction vs. production on artificial reefs, the relationship between communities on artificial and natural reefs must be understood before artificial reefs can be used to mitigate losses to natural reefs. Many studies on the effectiveness of artificial reefs have compared communities on artificial and natural reefs (Bohnsack and Sutherland 1985). However, most studies looked only at fish and evaluated only a few reefs. Research on artificial reefs in California conducted by the California Department of Fish and Game (DFG) in the late 50's and early 60's provided information on a few reefs types, but did not compare the artificial reefs with natural reefs (Carlisle *et al.* 1964, Turner *et al.* 1969). Since 1980, DFG (Wilson *et al.* 1981, 1984, 1985, Grant *et al.* 1982, DFG 1983) and the MRC (Lockheed Ocean Science Laboratory [LOSL] 1983a, 1983b, 1983c, DeMartini 1987, DeMartini *et al.* 1985) have been involved in a detailed study of Pendleton Artificial Reef; although these studies have greatly increased our information about artificial reefs, most of the effort has been devoted to only one artificial reef, PAR, and relatively little effort has been expended comparing PAR to natural reefs. Other studies in Southern California concerning artificial reefs include Stephens and Zerba (1981), Stephens *et al.* (1984), and DeMartini and Roberts (1982), who studied fish on breakwaters, and Davis *et al.* (1982) and Duffy (1977), who studied infauna around and epifauna on the Torrey Pines Artificial Reef.

The goal of this report is to evaluate the structure of natural and artificial reef communities in Southern California to determine their similarities, particularly with respect to the fish assemblages that occur on the reefs. By surveying a wide range of artificial and natural reefs, the limitations imposed by sampling at one site are avoided and the natural variation in ecological communities can be accommodated. These data will provide a good indication of the algal, invertebrate and fish assemblages occurring on artificial reefs, and how these assemblages compare with those on natural reefs. This information needed to evaluate the feasibility of using artificial reefs to compensate for the loss of natural reef resources. The results will be used to aid the MRC in evaluating the feasibility of using artificial reefs as a mitigation technique.

1.2 METHODS

1.2.1 Sampling

1.2.1.1 Reefs sampled

More than 25 artificial reefs have been constructed by the Department of Fish and Game in Southern California; however, many of these have deteriorated or were otherwise unsuitable for this study. Ten artificial reefs, including three breakwater sites and one artificial island, were chosen. For comparison, 16 natural reefs were sampled.

The 26 reefs sampled range from San Diego to Ventura (Figure 1-1, Table 1-1). A general description of the reefs is given in Appendix A-1. Eight artificial reefs consisted of one or more discrete piles of quarry rock, while the other two artificial reefs consisted of haphazard piles of concrete slabs and/or pilings. Three of the artificial reefs sampled were breakwaters: inside LA Harbor Breakwater, outside LA Harbor Breakwater, and King Harbor Breakwater. The subtidal slope of one island, the small man-made Rincon Oil Island, was also sampled; because of the physical similarities of the configuration of this island to the breakwaters, it has been included with breakwaters for some analyses. Eleven natural reefs and four artificial reefs had a giant kelp (*Macrocystis pyrifera*) canopy at the time of sampling.

A number of the reefs included in this study have been the subjects of previous studies for the MRC. Pendleton Artificial Reef (PAR), located 5 km downcoast from the San Onofre Nuclear Generating Station (SONGS), has been studied by Lockheed Ocean Science Laboratories (LOSL) and DeMartini, as well as the Department of Fish and Game. Torrey Pines Artificial Reef (TPAR, also known as Bureaucrat Reef) has occasionally been studied in connection with PAR studies. Seven natural reefs around the San Onofre area were surveyed. Barn Kelp, Las Pulgas Reef and Box Canyon (directly offshore from PAR) are south of San Onofre; Barn Kelp has been used as a control for SONGS in some MRC studies, while Las Pulgas Reef and Box Canyon were studied in connection with PAR (LOSL 1983b, 1983c). San Onofre Kelp Main, station 4-1, is in the main kelp bed offshore of SONGS; this station is close to the diffusers at SONGS, and thus is in a part of the bed that may have been influenced by the diffusers. San Onofre Kelp North, station 002, is a small kelp bed just north of the diffusers. San Mateo Kelp is 4.5 km upcoast from SONGS, and has also served as a control for SONGS; Two Man Rock is a site within the larger San Mateo kelp bed area.

A summary of the common species encountered on the artificial and natural reefs is given in Appendix A-2.

Sampling methodology was the same on natural and artificial reefs. A summary of the sampling protocol is presented below.

1.2.1.2 Physical Measurements

1.2.1.2.1 General measurements

Information concerning the location and general characteristics of the surveyed area was collected at each site. This information included Loran coordinates, distance from shore (measured by radar or estimated subjectively when below the radar's resolution), site exposure and local topography. Subsurface information included depth of transects (measured with a diver's depth gauge), and measurements of reef slope, surge and visibility. Dimensions of the reef (length, width, and height) were also estimated. Reef height was measured as the difference between the deepest point on the reef (at the sand/rock interface) and the shallowest point. Areas of large reefs were estimated from California State Department of Oceans and Navigation Bathymetry charts using a planimeter. For surge measurements, a diver-held device measured the angle of deflection of a sphere by moving seawater (see Foster et. al. [1985] for a detailed description). Floats that were 7.5 cm in diameter and fitted with half inch bolts and 20 cm lanyards were used to estimate underwater horizontal visibility. These floats were painted a dull green-brown to more closely approximate the color of fish. Visibility was recorded as the mid-point between the distance where the bolt head could be clearly distinguished when approached from afar, and the distance where the bolt head first became indistinguishable as a diver swam away from the float. Visibility readings were taken twice for each set of four transects.

1.2.1.2.2 Substrate characterization

Substrate was categorized by particle size (Table 1-2) and recorded at 2-m intervals along each of the eight 30-m benthic transect lines, beginning at the 2-m mark and ending at the 28-m mark. The benthic transects were established during the sampling for fish (see section 1.2.1.5.1).

1.2.1.3 Algae and Invertebrates

Algae and invertebrates were sampled by three different methods: band transects, 1-m^2 quadrats, and random point contacts. These methods are described below. In addition, the height of algae at each sample point on transects used to sample substrate types (see section 1.2.1.2.2) was also measured.

1.2.1.3.1 Band transects

Large conspicuous invertebrates, both motile and non-motile, kelp (including *Pterygophora californica*, *Laminaria farlowii*, *Eisenia arborea*, *Egregia menziesii*, and *Macrocystis pyrifera*), and *Cystoseira osmundacea* were counted in eight band transects 2-m wide by 5-m long (see Table 1-3). One band transect was started at a random location along each of the eight benthic transects initially sampled for fish. The number of stipes per individual was recorded for all *Macrocystis* plants > 1 m tall within the band transect. This stipe count was used to estimate both the mean number of stipes per *Macrocystis* plant and the mean number of stipes per 100 m^2.

1.2.1.3.2 Quadrats

Small motile invertebrates and some conspicuous sessile species were counted in 1-m^2 quadrats (Table 1-3). On each reef, a total of ten quadrats were located randomly on the benthic transect lines, one or two on each transect. On a few occasions invertebrates that were usually counted in quadrats were sampled in band transects instead (Table 1-3).

1.2.1.3.3 Random point contacts

Percent cover of sessile organisms, both invertebrates and algae, was determined using a random point contact (RPC) method (Cowen *et al.* 1982). A 1-m bar was placed diagonally within a 1-m^2 quadrat. A 1.2-m line, containing five knots located at regular intervals, was attached from one end of the bar to the other end. The line was stretched tightly at each knot and the point under the knot was sampled. At each point, organisms from the substrate to a height of 1-m were recorded (see Table 1-3). Five points were contacted on each side of the bar for a total of ten points per quadrat. RPC data were collected from the same quadrats sampled for small motile invertebrates and conspicuous sessile species.

<u>1.2.1.5 Fish</u>

1.2.1.5.1 Benthic Transects

Visual transects were used to estimate the densities of adult, sub-adult, juvenile, and young-of-year ("young") fish. The general procedure was for a diver to swim along a 30-m transect and record all fish within a corridor of specific dimensions. All fish encountered were recorded in appropriate life-stage categories (with lifestage categories based on fish lengths, Table 1-4). The diver swam at a constant rate to minimize counting fish attracted to him or counting fish twice.

Adults

The adult fish transects near the benthos were sampled during the first dive of the day, whenever possible, in order to minimize the influence of diver disturbance. Immediately after descending and attaching the beginning of the first transect line, the diver swam at approximately 25 m/min along a depth contour, counting fish and reeling out the transect line. Total length of the transect line was 30 m. Fish were counted within a 3-m wide by 1.5-m high corridor. Each fish was placed in one of three life-stages: adult, sub-adult or juvenile. However, estimates of only adults and subadults were used in the analyses; estimates of juvenile densities were taken from young-of-year transects.

At the end of the first transect, the diver tied off the end of the transect line, then continued swimming for approximately 5m before beginning the second transect, which was sampled in the same manner as the first. At the end of the second transect, the diver swam at right angles to the transect for at least 5m before establishing the start of the third transect. The third and fourth transect lines, which were laid down along the opposite heading from the first two transects, were sampled in the same manner as the first two. The fifth through eighth transects were sampled by a second diver, with the transects laid down in a mirror image from the first set of transects. All transect lines were left attached to the substrate for use in subsequent sampling for fish, invertebrates and algae. In some cases, such as deep reefs, it was necessary to sample a reef over two days. In these situations, transect lines were left down overnight, a marker buoy was attached, and Loran readings were recorded to allow divers to return to the same location the next day.

Young-of-year

The young-of-year and juvenile sampling near the benthos followed the same transect lines as the adult sampling, but only after a period of at least one-half hour to allow the fish to recover from the disturbance of the initial sampling of adult fishes.

Because a more detailed search was necessary for young-of-year sampling, the young-of-year corridor was only 1-m wide. To ensure that young occurring off the substrate (such as *Chromis punctipinnis*) were included, the corridor was 2-m high. Only young and juvenile fish encountered within the sample space were counted. Life-stage classification was based on the lengths shown in Table 1-4. Swimming speed was slower than the speed for the adult transects to allow for a thorough search of the substrate.

The date of sampling could influence the estimate of young density because recruitment may be seasonal; for example, a species that recruited only in November would not have been encountered on any reefs sampled during October. To avoid bias due to the time samples were taken, the sample dates for artificial and natural reefs alternated. We have also evaluated this potential bias by regressing the density of young-of-year against sample date; this analysis was performed on the nine species of fish that occurred on four or more reefs. None of the species showed a significant relationship between density of young and sample date (Table 1-5).

Fish lengths

To determine the size frequency distribution of fish, divers swam around the reef estimating the length of all fish seen. Swims usually lasted at least 10 min on each reef. If fish were in schools, the total number of individuals in the school and the proportions of individuals in each size-class present in the school was estimated. To allow for greater attention to less common species, fish lengths of only the first 100 or so individuals encountered of each species were estimated.

1.2.1.5.2 Water column transects

Adults

Adult, sub-adult and juvenile fish occurring in the water column (and under the kelp canopy when present) were sampled by video; however, estimates of only adult and subadult densities were used in the analyses. The diver shooting the video swam at a depth of approximately 3 m for approximately of 1 min and 25 sec, which was about the time necessary to cover 30 meters. In the narrative that accompanied the video, the diver identified the species and age class of each fish seen. The actual counting of fish was done later, when the videotape and narrative were reviewed. (Unfortunately, technical problems with the underwater microphone resulted in no narrative for a number of samples.) Eight transects were usually sampled at each site. In addition, horizontal visibility was measured by the diver and recorded on the video. The relationship between visibility and the area sampled using the video camera had been calibrated previously and was used to determine the width and height of each video sampled. The volume of the transect was calculated by multiplying the area by the length of the transect (as determined from the swim time).

Young-of-year

Young-of-year and juveniles were sampled by visual transects in the same area as the adult video survey. Swim times were approximately 2 min/30m transect. The corridor sampled was 2-m high by 1-m wide, originating at the plane of the diver.

Transect characteristics

Several characteristics of the water column transects, including distance of the transect from the bottom, duration of the transect swim, visibility, and *Macrocystis* density, could influence the estimates of fish density; these characteristics have been compared below for artificial and natural reefs.

The water column fishes were sampled at a distance from the bottom that varied between 1.8 and 19.8 m on artificial reefs, and from 6.1 and 14.9 m on natural reefs (Table 1-6). The mean time for the transect swim varied from 71 to 122 sec on artificial reefs and from 63 to 135 sec on natural reefs, while the mean visibility in the water column was from 0.8 to 4.6 m on artificial reefs and from 1.8 to 4.4 m on natural reefs (Table 1-6). Distance from the bottom, mean swim time, and visibility were not significantly different for artificial and natural reefs (Table 1-7).

1.2.1.5.3 Influence of environmental conditions on samples

To determine whether prevailing environmental conditions might bias our analyses, visibility and surge were regressed against fish densities and species richness on both the benthic and water column-transects.

Visibility in benthic fish transects varied from 1.6 to 9.5 m, while visibility in water-column transects varied from 0.8 to 4.6 m. Regression analysis indicates that the density of fish and the number of fish species on the benthic transects were significantly related to benthic visibility (Table 1-8 a and b). In addition, the density of juvenile and adult fish in the water column was significantly related to visibility in the water column; however, there was no significant relationship between species richness of fish in the water column and visibility (Table 1-8 a and b). The significant relationships between density and richness versus visibility raises the possibility of bias in our comparison of fish on artificial and natural reefs. However, there was no significant difference in either the benthic visibility (t-test, $t=1.288$, $P=0.21$) or the water column visibility (Table 1-7) on artificial versus natural reefs, indicating that our comparison will not be biased.

Surge, measured as an angle of deflection (see above), varied from 0.5° to 58.3°. There was no significant relationship between either fish density or species richness and surge in either the benthic or water column transects (Table 1-9 a), and there was no significant difference in surge on artificial versus natural reefs (t-test, $t=-0.905$, $P=0.37$).

1.2.2 Analysis

Diversity indices were calculated to describe the fish assemblage and also types of substrates and algal heights sampled on reefs. Three diversity measures were used. They were: (1) richness, the number of species or types sampled; (2) Shannon-Wiener index, $H' = -\Sigma p_i \log_{10} p_i$; and (3) Simpson index, $1/\Sigma p_i^2$, where p_i is the proportion of the total that is comprised of a particular species or type. The latter two indices were both used because the Shannon-Wiener is sensitive to rare species whereas the Simpson index is sensitive to common species.

1.2.2.1 Algae

The abundance of encrusting, filamentous, and foliose red and brown algae as well as erect corallines and algal turf was estimated as percent cover. The algal groups sampled were placed into larger morphological categories (encrusting, filamentous, foliose and erect corallines) for analyses. Encrusting reds and browns, including encrusting corallines, were summed. Filamentous reds and browns were also summed as were foliose reds and browns. However, erect corallines remained in a separate category.

The abundance of all other algal groups was estimated as number of plants per 100 m^2. All kelps, except *Macrocystis pyrifera*, were included in the "understory kelp" category; *Cystoseira osmundacea* was also included in this category. *Macrocystis* remained in a separate group.

An independent estimate of algal abundance on a reef was calculated using the measurements of algal height taken at regular intervals along the substrate transects. If algal height was 0, it was assumed that algae were absent under that point; algae were present if algal height was greater than 0. These presence-absence data were used to estimate algal percent cover. This estimate excludes encrusting algal species since they usually have a very low profile.

1.2.2.2 Invertebrates

Many of the invertebrate species sampled were encountered only rarely. A number of species were grouped into larger categories (e.g. snails or colonial tunicates) for the analyses. Sometimes the most abundant species included in larger categories were also analyzed separately. For example, snails were summed over all species but analyses were also done on *Kelletia kelletii* separately.

Abundance of sessile invertebrates that were sampled using the RPC method was estimated as percent cover. Density estimates for taxa counted in quadrats or band transects was estimated as the number of individuals per m^2. However, for statistical analyses densities were scaled to 100 m^2.

Occasionally, some of the taxa that were usually counted in quadrat samples (Table 1-3) were counted in band transects instead. For these groups, if the mean density from the quadrat sample was 0 and the density from the band transect was not 0, then the band transect estimate was used.

Total percent cover, total density of invertebrates, and total density of gorgonians on a reef were calculated by summing the mean percent cover, the mean density of all groups sampled on the reef or the mean density of species of gorgonians, respectively; as a result, there is no estimate of variability for the totals.

1.2.2.3 Fish density

Density was calculated as the number of fish per 1000 m^3. Fish were placed into 1 of 3 lifestages based on length (Table 1-4). The densities of young and adult fish were estimated from the young-of-year and adult transects.

For the analyses presented in this report, the juvenile lifestage included both juvenile and subadult fish. When the young-of-year transects were sampled, the length range used to define the juvenile lifestage also included the subadult lifestage for some species. For these species, juvenile densities are calculated from the counts done on young-of-year transects only. For the other species, the juvenile length range for the young-of-year transects did not include the subadult lifestage. For these species, density of juveniles was calculated as the sum of the juvenile density from the young-of-year transects and the subadult density from the adult transects. The same fixed line was used for benthic samples of both the young-of-year and the adult transects, so juvenile and subadult densities were added on each transect before the mean and standard error was calculated. In contrast, the same transects were not used for both young-of-year and adult samples in the canopy samples, so densities could not simply be summed as in the benthic samples. Therefore, the mean densities of juveniles and subadults on a reef were calculated first and then summed, and there is no estimate of variability.

Analyses of fish density in the water column focused on either young-of-year or the total of all lifestages. Due to the method described above for determining juvenile densities, the variability in mean density of all lifestages of fish in the water column was not estimated.

1.2.2.4 Fish biomass density

For each species of fish, the estimate of biomass density on a reef was calculated using three factors: (1) the length frequency distribution of fish estimated from the fish lengths data; (2) the relationship between length and weight shown in Appendix B-1 and B-2; and (3) density.

To calculate the biomass density of each species of fish sampled on each reef, the fish lengths data were first separated into the three lifestage classes (adults, juveniles and young). Then, for each lifestage, the length data were used to determine the length-frequency distribution of fish within the lifestage. The length-frequency distribution was estimated using two methods. If the length-frequency distribution within a lifestage was based on measurements of at least 10 fish on a particular reef, then the distribution was determined for that reef separately and was based only on fish sampled on that reef. However, if fewer than 10 fish were measured within the lifestage on a reef, the length-frequency distribution used to estimate biomass density was based on fish sampled on all reefs.

Once the length-frequency distribution within a lifestage was determined, a fish weight was calculated for each length in the distribution using the equations listed in Appendix B-1 and B-2. Then for each length, this weight was multiplied by the proportion of fish of that length. These proportional weights were summed to determine the average weight of a fish within the lifestage.

The biomass density within a lifestage was calculated by multiplying the average weight of a fish by its density in the lifestage. Total biomass density of benthic and water column fish was determined by summing over all lifestages.

The only departure from the method described above occurred when a species was sampled in transects on a reef but was not sampled in the fish lengths sample on any reef. As a result, there was an estimate of the density of fish on a reef but no estimate of the length-frequency distribution. In this case, the midpoint of the length range for young-of-year and juveniles or the shortest length for an adult was used as a conservative estimate of the average length of a fish within a lifestage. This average length was used to calculate the average weight of a fish within the lifestage.

For both density and biomass density of fish, data from the benthic and water column transects were always analyzed separately. Benthic and water column estimates were not combined because the relative proportion of each type of habitat on a reef was not estimated quantitatively. Therefore, the relative contribution of benthic and water column fish to the total density or biomass density of fish on a reef is not known.

1.2.2.4 Standing stock estimate

The standing stock of fish was estimated for each of the reefs we sampled in Fall 1986. DeMartini (1987) has calculated the standing stock of fish on Pendleton Artificial Reef and in San Onofre Kelp Bed; his estimates are based on many samples of fish density at the two sites. In addition, DeMartini has carefully quantified the abundance of different habitat types at the sites, and has sampled within each of the major habitat types. Our estimates are not as refined as DeMartini's, since they are based on rough estimates of reef sizes and very simple estimates of fish biomass density; no effort was made to sample all habitats on a reef, or estimate the relative abundance of different habitats, or insure that the sampled areas on very large reefs were representative of the reef as a whole. Our estimates are probably least accurate for large reefs, since these reefs are most likely to have a variety of habitat types that were not sampled. In spite of the approximate nature of the estimates, they indicate general trends in standing stocks.

Standing stock of fish near the benthos and in the water column were calculated separately from benthic and water column biomass density estimates. The sampling methods we used did not allow us to combine the biomass density estimates because we have no quantitative measure of the relative proportion of benthic vs. water-column habitat. To determine the standing stock on a reef, biomass density estimates were converted from kg/1000 m^3 to MT/ha and multiplied by the area (in hectares) of the reef. Biomass density, which was originally based on the volume of water sampled, was converted to a density estimate based on area by dividing the standardized volume (1000 m^3) by the height of the transect corridors sampled on a reef. The height of the benthic transect corridors sampled on all reefs was 1.5 m. The height of corridors sampled with the video camera in the water column varied among reefs and depended on visibility. The relationship between visibility and corridor height of the video transects was calibrated by divers under controlled conditions and is closely approximated by: Height = (0.57)·(Visibility).

1.2.2.6 Statistical tests

Data were usually transformed for comparisons of means on artificial and natural reefs. Percent cover data were converted to proportions and the arcsine transformation ($p' = \arcsin p^{1/2}$) was used (Zar 1984). Densities and biomass data were scaled so that non-zero values were greater than 1 and the logarithmic transformation ($\log_{10}(x+1)$) was used (Zar 1984). For the comparison of mean algal height on artificial and natural reefs, $\log_{10}(x+0.1)$ was used because mean height values were sometimes less than 1.0.

All statistical tests were done using the SAS software system for data analysis (SAS Users Guide, Version 5 Edition, SAS Institute Inc., Cary, N.C.).

The ecological similarity of artificial and natural reefs was assessed through the use of cluster analysis. The analysis was based on the 10 species that were most abundant over all benthic samples and the 5 most abundant species in the water-column samples. Similarity was calculated as the squared Euclidean distance, and an average linkage algorithm was used to determine the clusters.

T-tests were used to compare means on artificial and natural reefs. If variances were not equal, a Wilcoxon rank-sum test was also done to compare with the results of the t-test.

Regression analyses were done using ranked as well as raw data since relationships may be non-linear. Multiple linear regressions were done using the following 7 independent variables in the model: *reef type* (1=artificial, 2=natural), *reef area*, *reef height*, *reef depth*, *Macrocystis*, *algae*, and *gorgonians*. Reef area was measured in m^2 and the data were $\log_{10}(x+1)$ transformed. *Macrocystis* density was measured as No. of plants/10 m^2 and transformed to $\log_{10}(x+0.1)$. Algal height was measured in cm and the data were $\log_{10}(x+0.05)$ transformed. Gorgonian density was determined from the 1 m^2 quadrats, and the data were $\log_{10}(x+0.01)$ transformed. For the multiple regressions analysis, the assemblage of understory algae was characterized by a principal components analysis, which combines a number of different measurements into one variable describing the algal assemblage. This variable, "algae," is the first principal component from an analysis that included the density of understory kelp, the percent cover of foliose red and brown algae, the percent cover of erect coralline algae, the total percent cover of algae, and mean algal height, and explains 70.2% of the variation in the original variables. The variable "algae" was used in the multiple regression analysis as a measure of the understory algal assemblage on a reef.

1.2.3 Databases

The date collected on artificial and natural reefs are contained in 16 original data bases, described in Appendix E. These data bases were constructed from the raw field data with the help of the MRC contractor, Titan Systems, Inc. The secondary data bases that were created from the original data bases and were used in analyses are also described in Appendix E, along with a list of the SAS programs used to construct the secondary data bases.

In addition, Appendix E includes a list of all the Tables found in the main report and in Appendices B and D. For each table, there is a list of the SAS program(s) used either to construct the table from data contained in the primary or secondary data bases or to do the analyses that are reported in the table.

1.3 RESULTS

1.3.1 Physical characteristics of the reefs

The area of the reefs surveyed varied tremendously. Most artificial reefs were relatively small, on the order of hundreds of meters on a side (Table 1-10), with a mean area of 0.022 km^2. Breakwaters (including the Rincon Oil Island) were larger than the other artificial reefs sampled; without breakwaters, the mean size of artificial reefs was only 0.009 km^2. In contrast, natural reefs were much larger (Table 1-10), with an average area of 1.85 km^2. The sizes of artificial and natural reefs were significantly different (Table 1-11). Natural reefs were, on average, two orders of magnitude larger than artificial reefs.

Artificial reefs were located in water depths of 9 to 24 m. The depths of natural reefs ranged from 11 to 24 m (Table 1-10). The depths of artificial and natural reefs were not significantly different: means were 15.3 m and 16.5 m, respectively, (Table 1-11). Because breakwaters were relatively shallow, the mean depth of artificial reefs excluding breakwaters was 18.0 m, but the depths of artificial and natural reefs were still not significantly different.

The height of artificial reefs, measured as the distance from the reef base to reef crest, varied from 2 to 16 m, with a mean of 6.6 m (Table 1-10). The highest artificial reefs were breakwaters or man-made islands with slopes that reached the surface of the water; excluding these reefs, the greatest height for a traditional artificial reef was only 5 m, and the mean was 3.5 m. The height of natural reefs varied from 1 to 13 m; however, only 3 reefs were more than 5 m high, and the mean was 4.4 m. There was no significant difference in the heights of artificial and natural reefs, regardless of whether or not breakwaters were included (Table 1-11).

The slope of the artificial reefs ranged from 1.3° to 47.5°, with a mean of 28.3° (Table 1-10). The slope of natural reefs ranged from 0° to 39.6°, with a mean of 11.1°. With all reefs included, the slopes of artificial and natural reefs were significantly different (Table 1-11). However, all breakwaters were relatively steep, with slopes greater than 30°. If breakwaters are excluded, the mean slope of artificial reefs decreases to 20.7°, and there is no significant difference between artificial and natural reefs. Although differences in slope were not significant, 10 natural reefs did have slopes less than 15° (six were 0°), while only two artificial reefs had slopes this shallow.

Table 1-12 presents the percentages of different substrate types on the surveyed reefs (see Table 1-2 for the classification of substrate types). Artificial reefs were generally constructed from medium rock, large rock or boulders, with a few reefs containing considerable amounts of sand. Two artificial reefs were constructed from concrete blocks or pilings. Natural reefs consisted of a greater variety of substrate types; some reefs had more of the smaller size substrate types while others had more large rock, boulders and bedrock. The percentages of four substrate types, small rocks, large rocks, boulders, and bedrock, were significantly different on artificial versus natural reefs (Table 1-13). Large rocks and boulders were more prevalent on artificial reefs, while small rocks and bedrock comprised more of the substrate on natural reefs. Bedrock was only found on natural reefs.

The diversity of substrate types on a reef was measured using richness and the Shannon-Wiener and Simpson diversity indices. Richness, the number of different substrate types on a reef, varied from 2 to 6 on artificial reefs and from 3 to 8 on natural reefs (Table 1-12). The Shannon-Wiener and Simpson indices describing substrate diversity on artificial and natural reefs were also similar. Mean Shannon-Weiner diversity was 0.444 on artificial reefs and 0.513 on natural reefs, while mean Simpson diversity was 2.472 and 2.971, respectively. Mean diversity for artificial and natural reefs was not significantly different for any of the three indices (Table 1-13). Note that the ranges of both diversity indices were greater on natural reefs than on artificial ones (Table 1-12); about 1/3 of the natural reefs sampled had higher substrate diversity than any artificial reef. However, some natural reefs had very low substrate diversity. Bedrock generally predominated on the least diverse natural reefs, whereas boulders or concrete predominated on the least diverse artificial reefs.

The substrate characteristics of the reefs have also been described by adapting a standard sedimentological technique for describing particle sizes (e.g. Leeder 1982). Each substrate category was assigned a phi value (determined by the $-\log_2$ of its diameter in cm), and the mean and standard deviation (or sorting) of these particle sizes calculated. This is an inverse scale with the smallest number indicating the largest mean particle size. The two artificial reefs constructed of concrete blocks and pilings were not included in this analysis. Mean particle size ranged from 1.98 to -7.56 for all reefs (Table 1-12), with no significant difference between artificial and natural reefs. The standard deviation of particle size was somewhat lower on artificial reefs, indicating better sorting of sizes (i.e. more similar sizes), but this difference was not significant.

Cluster analysis was used to determine the similarity in heterogeneity of substrate types among reefs. The technique used, average linkage cluster analysis, was based on mean and standard deviation of particle size on reefs. Reefs cluster into two main groups (Figure 1-2). One group was comprised of 1 artificial and 8 natural reefs; in general, these reefs were characterized by small size substrate types such as small to medium rock, cobble and sand. The second group contained 7 artificial and 8 natural reefs that were primarily composed of large rock, boulders and (for natural reefs) bedrock. Thus the substrate heterogeneity of artificial reefs was very similar to a subset of the natural reefs sampled in this study.

In summary, there were a number of qualitative differences in physical characteristics between the artificial and natural reefs sampled. Artificial reefs were smaller than natural reefs. Because most artificial reefs were constructed as high piles of rocks and boulders, they generally had steeper slopes than natural reefs. A few natural reefs had slopes that were comparable to artificial reefs, but many natural reefs were virtually flat. Since artificial reefs were generally constructed of large rocks and boulders, these substrate types were more prevalent than on natural reefs. In contrast, on natural reefs, small rocks and cobble were more common and bedrock was sometimes extensive. Two artificial reefs were constructed from concrete; not only does this material not occur on natural reefs, but the shape of the substrate on concrete reefs (long, thin columns) does not occur on any natural reef.

1.3.2 Algal assemblages

A summary of the percent cover and densities of algal groups sampled on the surveyed reefs is presented in Table 1-14 (detailed results are shown in Appendix

Table C-1). In general, algae were more abundant on natural reefs. While most natural reefs had a substantial cover of at least encrusting algae, this algal group was common on only three artificial reefs. Foliose algae, which add structure to a habitat and harbor small invertebrates that are food for many fish, achieved at least 20% cover on only 40% of the artificial reefs compared to 69% of the natural reefs. Three of the artificial reefs with high cover of foliose algae were relatively shallow, and two of these were breakwaters. The mean cover of encrusting and foliose algae, as well as total percent cover of algae (not including kelps) was significantly different on the two types of reefs (Table 1-15); in each case, natural reefs had approximately twice as much cover as artificial reefs. The cover of turf and erect coralline algae were not significantly different on artificial and natural reefs.

The density of understory kelp species (which included *Cystoseira osmundacea* and all laminarians except *Macrocystis pyrifera*) was much higher on natural reefs than on artificial ones. Only four artificial reefs supported understory kelp, whereas all but two natural reefs had understory kelp (Table 1-14). Densities of understory kelp were extremely high on some natural reefs: five reefs had densities in excess of 150 plants/100 m^2, and the density on one of these was 1660/100 m^2. *Pterygophora* was very abundant on all five of these reefs, but especially at Flat Rock. *Cystoseira* was particularly abundant at SOK North and Box Canyon. The difference between the density of understory kelp on natural reefs was significantly different from the density on artificial reefs; mean density on natural reefs was 186 plants/100m^2 while the mean density was only 11 plants/100 m^2 on artificial reefs (Table 1-15).

Adult giant kelp plants were found on 40% of artificial reefs and 69% of natural reefs (Table 1-14). Three of the artificial reefs with giant kelp were breakwaters or man-made islands; the other was Pitas Point Artificial Reef in Ventura County. *Macrocystis* density varied from 17.5 to 122.5 plants/100 m^2 on artificial reefs, and from 5.0 to 287.5/100 m^2 on natural reefs. Although the mean density of giant kelp on natural reefs was 50.9 plants/100 m^2 compared to 23.8/100 m^2 for artificial reefs, the means were not significantly different (Table 1-15).

In addition to the density of *Macrocystis*, the number of stipes per plant was counted as an estimate of plant size; these data are summarized in Table 1-18. Although the difference in the mean number of stipes/plant on artificial verses natural reefs was not significantly different (Table 1-19), the mean number of stipes/plant was greater than 20 on almost 50% of natural reefs that had *Macrocystis*, while the mean never exceeded 10 stipes/plant on any of the artificial reefs. Thus natural reefs tended to have larger giant kelp plants than artificial reefs. Combining the information on the number of stipes/plant with the density at a site gives the mean density of *Macrocystis* stipes on the reef. The tendency for higher densities and larger plants on natural reefs results in a somewhat higher density of stipes, but the mean density on artificial and natural reefs was not significantly different (Table 1-19).

Juvenile laminarians, which include unidentifiable young laminarian stages as well as *Macrocystis* smaller than 1 m, were present on 20% of the artificial reefs and 38% of the natural reefs sampled. Three natural reefs, all near San Onofre, had very high densities of juvenile laminarians, indicating good kelp recruitment.

However, no recruits were found on the other reef near San Onofre (station 4-1 in the SOK Main bed) that was sampled in this study.

The percent cover of all algae (including laminarians but excluding encrusting species), along with algal height, was also measured along the transect lines (Table 1-16). Three artificial reefs had no algae sampled along the transect lines, whereas algae were sampled on all natural reefs. Algal cover was significantly different on natural and artificial reefs; mean cover was 32.1% and 18.4%, respectively (Table 1-17). The height of algae was greater on natural reefs than artificial ones; means were 5.2 cm and 2.1 cm, respectively, and were significantly different. The diversity of algal heights on artificial versus natural reefs was not significantly different.

In summary, the algal communities found on natural and artificial reefs were quite different; percent cover or density of most groups of algae was greater on natural reefs than on artificial ones. The density and size of *Macrocystis* plants also tended to be greater on natural reefs, although the difference in the means for the two types of reefs was not significant. Higher cover of foliose algae and higher density of kelps resulted in a greater mean algal height on natural compared to artificial reefs.

1.3.3 Invertebrate assemblages

The percent cover of the major sessile invertebrate groups is summarized in Table 1-20. (The occurrence of all species of invertebrates encountered on each reef is shown in Appendix B, Table 2.) All reefs had at least some invertebrate cover.

Sponges, hydroids and colonial tunicates were rarely very common. Bryozoans were common on some reefs, especially artificial ones. Bryozoans covered more than 25% of the substrate on 70% of the artificial reefs but were this abundant on only 31% of the natural reefs. However, mean bryozoan cover was not significantly different on artificial and natural reefs (means of 31.5% and 18.6%,respectively; Table 1-21). High bryozoan cover was found on both breakwaters and traditional artificial reefs. The mean total percent cover of sessile invertebrates was more than 50% higher on artificial reefs compared to natural ones; this difference was nearly significant ($p=0.0569$, Table 1-21).

The density of large invertebrates is summarized in Table 1-22. The total density of large invertebrates was highly variable among reefs, and the mean density on artificial and natural reefs ($33.3/m^2$ and $24.5/m^2$, respectively) was not significantly different (Table 1-23). While densities of most groups of invertebrates were not significantly different on artificial and natural reefs, there were a few exceptions.

Densities of anemones, bivalves, *Kelletia kelletii*, and *Strongylocentrotus franciscanus* were significantly different, with higher mean densities on natural reefs. However, densities of these groups were generally very low on all but a few reefs. For example, the density of *S. franciscanus* was greater than $1.0/m^2$ on only 10% and 31% of artificial and natural reefs, respectively. *Lytechinus anamesus* was found only on natural reefs; on 25% of these reefs, its density exceeded 2 urchins/m^2.

Gorgonians were found on almost all reefs, sometimes in high densities; three artificial and one natural reef had densities greater than $14.0/m^2$. Although mean density was twice as high on artificial reefs, the difference between the densities on the reef types was not significantly different. The density of *Lophogorgia* was generally low, but the difference between the two reef types was significant, with higher mean density on artificial reefs.

Hinnites giganteus and *Styela montereyensis* had estimated mean densities 4-8 times higher on artificial than natural reefs, but the differences were not statistically significant, probably because they were absent from at least 40% of both types of reefs and were only rarely abundant on any reef. *S. montereyensis* was particularly abundant at Pitas Point and Rincon Kelp, where it occurred in densities of 33.2/10 m^2 and 7.2/10 m^2, respectively.

In summary, the percent cover of sessile invertebrates, particularly bryozoans, tended to be higher on artificial reefs, although the differences were not statistically significant. Larger invertebrates were generally not abundant, and total density was not significantly different between the two reef types. The gorgonian *Lophogorgia* was the only taxon with higher densities on artificial reefs. Anemones, bivalves, *Kelletia* and *S. franciscanus* had higher densities on natural reefs.

1.3.4 Fish assemblages

Forty-one species of fish were sampled on the artificial and natural reefs (Table 1-24 and 1-25; see also Appendix C). While most species found on artificial reefs were also observed on at least one natural reef and vice versa, the relative densities and the occurrences of various lifestages of the species found on both reef types differed (Table 1-25). Some species, such as kelp bass, black surfperch, blacksmith, California sheephead, senorita and rock wrasse, were found on virtually all reefs. Few common species were found on predominantly one reef type. Fish species that occurred on a considerably higher proportion of artificial than natural reefs include: spotted scorpionfish, olive rockfish, sargo, black croaker, opaleye, white surfperch, pile surfperch, and rubberlip surfperch; of these, only opaleye and pile surfperch are relatively common. There was a tendency for rockfish and surfperch to occur on a higher proportion of artificial reefs.

The cluster analysis based on fish densities (Fig. 1-3a) and relative densities (Fig. 1-3b) indicate that the fish assemblages on artificial reefs were generally similar to the assemblages on natural reefs. Some pairs of artificial reefs were quite similar (e.g. TPAR and PAR, RIAR and LOAR, and MDAR and HBAR), but there was no indication that artificial reefs as a whole segregated into their own cluster at higher levels, as would be expected if the fish assemblages on them were not similar to those on natural reefs. In fact, most of the clusters containing natural reefs also contained some artificial reefs.

1.3.4.1 Species richness and diversity

The number of species of fish sampled on artificial reefs ranged from 13 to 22, while the species richness of fish on natural reefs ranged from 10 to 19. Mean richness was 18.7 and 14.2 on artificial and natural reefs, respectively, and the difference was statistically significant. This difference in total species richness is a result of higher species richness near the benthos on artificial reefs (Table 1-27). This increase in species richness is seen in all lifestages of fish; there were about twice as many species of young fish and an almost 50% increase in adult and juvenile species.

On average, 4.1 young-of-year species were found near the benthos on artificial reefs and only 2.4 species on natural reefs. The mean richness of benthic juveniles & adults was 14.8 and 10.4 on artificial and natural reefs, respectively, while richness of all lifestages combined was 15.3 and 10.9, respectively. In all cases, differences in mean richness between reef types were significantly different. In contrast, relatively few species occurred in the water column (Table 1-26). Many reefs, both artificial and natural, had no young in the water column and no fish at all were found in this habitat on four artificial and two natural reefs. The difference between mean species richness in the water column on the two reef types was not significant for any lifestage (Table 1-27).

Although species richness was higher on artificial reefs, species diversity was not (Table 1-28). For both young-of-year and all lifestages combined, both near the benthos and in the water column, the two diversity indices were generally very similar, and differences between artificial and natural reefs were not significant (Table 1-29).

1.3.4.2 Density of benthic fish

1.3.4.2.1 Total

Benthic fish generally had higher densities on artificial reefs than on natural ones (Table 1-30); mean densities of all lifestages of all species combined were significantly different (Table 1-31). The mean density of all lifestages of benthic fish on artificial reefs was 425/1000 m^3, while on natural reefs it was only 185/1000 m^3. Total fish density exceeded 200/1000 m^3 on all artificial reefs, whereas only four of the natural reefs (25%) had densities that high.

The density of all lifestages of sport fish followed a pattern similar to that of all species combined (Table 1-30). Sport fish included species of commercial or sport fishing importance; these species are noted in Table 1-24. The mean density of sport fish on artificial reefs was 145/1000 m^3, but on natural reefs was only 80/1000 m^3; these densities are significantly different (Table 1-31). The density on 75% of the natural reefs was lower than the lowest density on any artificial reef (89/1000 m^3).

The mean densities of all lifestages of 11 fish species are given in Table 1-30. (Data for all species encountered each reef are included in Appendix C, Table 3.) These 11 species were analyzed separately because they are either important commercial/sport fish species or important forage species. The mean densities of six of the species were significantly different on artificial and natural reefs (Table 1-31). Of these species, kelp bass, barred sand bass, black surfperch, pile surfperch, and blacksmith had densities 2-7 times higher on artificial reefs than on natural ones, while only rock wrasse had higher densities on latter reefs. Blacksmith densities on three artificial reefs were particularly high (697, 529 and 297 fish/1000 m^3 on PAR, TPAR, and NBAR, respectively) and were this high on only one natural reef (300 fish/1000 m^3 on PV). The difference in mean density of blacksmith on artificial and natural reefs accounted for about 60% of the difference in the mean density of all species combined. However, the density of the sport fish group of species, which does not include blacksmith, was significantly higher on artificial reefs. Thus the observed pattern in fish densities is not entirely due to the difference in blacksmith abundance on the two types of reefs.

Densities of the five other fish species (opaleye, halfmoon, garibaldi, sheephead and senorita) did not differ significantly between artificial and natural reefs. When opaleye were present, their densities were similar on artificial and natural reefs; however, they were absent from nine natural reefs but only one artificial reef. Garibaldi tended to occur in higher densities on natural reefs than artificial ones, with a mean densities of 12.1 and 5.0 fish/1000 m^3, respectively. Its density was more than 10/1000 m^3 on only one artificial reef (TPAR) compared to nine natural reefs. Garibaldi were absent from 50% of artificial and 30% of natural reefs.

1.3.4.2.2 Young-of-year

The density of young fish near the benthos was highly variable on both artificial and natural reefs. (Data for all species of young sampled near the benthos are presented in Appendix C, Table 4.) As few as 12.5 young/1000 m^3 were found on artificial reefs while on one natural reef, Rincon kelp, none were seen (Table 1-32). The highest densities of young observed on artificial and natural reefs were 421 and 125 fish/1000 m^3, respectively. Mean density of young of all species combined was 144/1000 m^3 on artificial reefs and only 28/1000 m^3 on natural ones; means were significantly different (Table 1-33). Total density of young fish was at least 30/1000 m^3 on 80% of the artificial reefs but only 25% of the natural reefs sampled.

The high densities of young fish were generally driven by the density of blacksmith; over all, this species comprised about 50% of the young on both artificial and natural reefs. While young blacksmith were found on 80% of artificial reefs, they were present on only 30% of the natural reefs surveyed. However, blacksmith comprised at least 85% of all young fish on 4 of 8 artificial reefs and 3 of 4 natural reefs where the density of young exceeded 30 fish/1000 m^3. On all reefs with more than 100 young fish/1000 m^3, at least 85% and usually more than 90% of the total were blacksmith. When blacksmith were excluded, the mean density of young was 65/1000 m^3 and 14/1000 m^3 on artificial and natural reefs, respectively. Although the mean density on artificial reefs was 4 1/2 times higher than on natural ones, the difference was nearly significant ($P=0.0581$, Table 1-33). In addition, the density of young on the King Harbor Breakwater was unusually high due to a very high density of blue-banded gobies, an annual species. When both blacksmith and gobies were excluded, mean(SE) density of young on artificial and natural reefs was only 27.1 (9.97) and 9.1 (1.92) fish/1000 m^3, respectively; these densities were not significantly different (t-test, $t=1.110$ with 24 df, $P=0.28$).

The density of young of sport fish species tended to be higher on artificial reefs; mean density was 18/1000 m^3 and 3.9/1000 m^3 on artificial and natural reefs, respectively. Although there was, on average, more than 4 times as many young sport fish on artificial reefs as on natural ones, the differences were nearly significant ($P=0.059$, Table 1-33). The three highest densities of sport fish on artificial reefs occurred on the Los Angeles Harbor and King Harbor Breakwaters.

The mean densities of young of five species other than blacksmith are also shown in Table 1-32. Mean densities of four of them, kelp bass, black surfperch, pile surfperch and senorita were at least twice as high on artificial reefs; however, densities on the two reef types were not significantly different for any of these species (Table 1-33). Young kelp bass were found on one artificial reef, PAR, and the three breakwater sites as well as three sites on natural reefs, Box Canyon and both the Main and North beds of San Onofre Kelp. High densities of young black surfperch were observed at the LA and King Harbor breakwaters, but black surfperch were not found on 30% of the artificial reefs and 50% of the natural ones sampled; on most other reefs densities were similar. Pile surfperch occurred on 40% of artificial reefs compared to only 13% of natural reefs. Senorita young-of-year occurred in high densities at the King Harbor Breakwater; they were also common at TPAR, PAR, La Jolla Cove, Box Canyon and SOK (North), all of which are southern sites.

In summary, mean densities of both young-of-year and all lifestages of all species of fish near the benthos were much higher on artificial compared to natural reefs. This pattern was driven in part by high densities of blacksmith on artificial reefs, but all lifestages of sport fish, which do not include blacksmith or gobies, and young-of-year were also more abundant on artificial reefs. Higher densities on artificial reefs were observed for almost all individual species studied. The only exceptions were all lifestages combined for garibaldi, senorita and rock wrasse, which tended to be more abundant on natural reefs, although the difference in density was significant for only rock wrasse. The densities of young-of-year of most species were quite low, but the trend for all species was toward higher density on artificial reefs. The density of young blacksmith was often very high, particularly on artificial reefs.

1.3.4.3 Density of water column fish

1.3.4.3.1 Total

The mean density of fish of all lifestages in the water column is summarized in Table 1-34. (Data for all species of fish encountered in the water column during this study are shown in Appendix C, Table 5.) Mean densities are highly variable on both artificial and natural reefs. No fish were found in the water column on 25% of the artificial reefs and 13% of the natural reefs sampled. When fish were present in the water column, their densities were often quite high; densities exceeded 100 fish/1000 m^3 on all but one of the artificial reefs and 40% of the natural reefs with water column fish. The highest densities on artificial reefs occurred on the breakwaters and Rincon Oil Island; only one other artificial reef, Pitas Point, had a substantial number of fish in the water column. The highest densities on natural reefs were found at Laguna Beach North, Marine Street Reef and Pelican Point. The mean density of all species combined in the water column was 162/1000 m^3 and 122/1000 m^3 on artificial and natural reefs, respectively; the difference between means was not significant (Table 1-35). The mean density of sport fish in the water column was slightly higher on natural reefs compared to artificial ones, but the means were not significantly different.

The mean densities of all lifestages of five species of fish found in the water column are given in Table 1-34. Three species were found on some reefs at densities greater than 100 fish/1000 m^3. Blacksmith were abundant on three breakwaters and two natural reefs. Kelp surfperch were abundant on the outside of L.A. Harbor breakwater and on the natural reef at Laguna Beach. Senorita were abundant on two natural reefs, both supporting *Macrocystis* and both near San Diego. Blacksmith and kelp surfperch had higher mean densities on artificial reefs, while senorita, halfmoon and kelp bass had higher mean densities on natural reefs, but none of the differences were significant (Table 1-35).

1.3.4.3.2 Young-of-year

The density of young fish in the water column is summarized in Table 1-36. (Data for all species of young-of-year fish seen in the water column are shown in Appendix C, Table 6.) Young fish were not found in the water column on 50% of the artificial and 56% of the natural reefs sampled. On 40% of artificial reefs and almost 60% of natural reefs with young fish in the water column, densities were less than 15/1000 m^3. Density was greater than 100 fish/100 m^3 on only one breakwater and two natural reefs. Young on these reefs were blacksmith and/or senorita. The mean density of young of all species combined was 33/1000 m^3 on artificial and 28/1000 m^3 on natural reefs; the means were not significantly different (Table 1-37).

Young-of-year of sport fish were found in the water column on only three artificial reefs and two natural reefs. Pitas Point Artificial Reef had a high density of atherinids but they were the only young fish seen in the water column at that site. L.A. Harbor Breakwater (Inside) had a relatively high density of young kelp rockfish. Although the mean density of sport fish was higher on artificial than natural reefs, the difference was not significant (Table 1-37).

The mean densities of young of four species are given in Table 1-36. Except for senoritas, each species was found on only a few reefs. Senorita young were found on seven natural reefs and one artificial reef; mean density was many times higher on natural reefs, but the difference was not significant (Table 1-37).

In summary, densities of fish in the water column on artificial and natural reefs were highly variable. Almost 25% of the reefs sampled had no fish in the water column. On an additional 25% of the reefs, no young-of-year fish were seen. However, densities of fish in the water column were very high on some reefs. When density was high, it was usually the result of the high density of just one or two species. Blacksmith were predominant on 2 breakwaters, the man-made oil island and a natural reef, while atherinids, either alone or with kelp surfperch, accounted for almost all fish seen on a breakwater, an artificial reef, and a natural reef. Two other natural reefs had high densities of senorita, either alone or with blacksmith. Young-of-year comprised most of the fish seen in the water column on 35% of the reefs with high densities. Most young were blacksmith or senorita, although young atherinids were found on Pitas Point Artificial Reef. There were no significant differences between mean densities on artificial and natural reefs but blacksmith were about 4 times denser on artificial reefs wile the density of senorita was 4 times higher on natural reefs.

1.3.4.4 Biomass density of benthic fish

The biomass densities of all fish sampled near the benthos are shown in Table 1-38. (Data for all lifestages and young-of-year for all species sampled on reefs are given in Appendix C, Tables 7 and 8.) Biomass density exceeded 25 kg/1000 m^3 on 60% of artificial but only about 30% of natural reefs surveyed; on half of the natural reefs, it was less than 15 kg/1000 m^3. Although mean biomass density was higher on artificial reefs than natural ones (30.2 kg/1000 m^3 and 21.8 kg/1000 m^3, respectively) the difference was not significant (Table 1-39).

The biomass density of sport fish followed the same pattern as total biomass density. On artificial reefs, the mean biomass density of sport fish was 22.9 kg/1000 m^3, while on natural reefs it was 16.15 kg/1000 m^3; the difference between means was not significant (Table 1-39).

Biomass density of 11 fish species are given in Table 1-38. Four of these species, opaleye, black surfperch, pile surfperch and blacksmith, had significantly different biomass densities on the two reef types; in every case, the density was higher on artificial reefs. This follows the pattern seen for the numerical densities of these species (Table 1-30). Opaleye were absent from many natural reefs, but when present, biomass density seemed comparable on artificial and natural reefs. Blacksmith biomass density was very high on TPAR, where it also had high densities. Biomass density of the remaining species (kelp bass, barred sand bass, halfmoon, garibaldi, sheephead, senorita and rock wrasse) was not significantly different between artificial and natural reefs, although biomass density of barred sand was much higher on artificial reefs, while garibaldi and sheephead were higher on natural reefs.

For almost all species, the ratio of biomass densities on artificial versus natural reefs was similar to the ratio of numerical densities (Table 1-30). In contrast, the mean density of sheephead was about the same on both types of reefs but the biomass density was twice as high on natural reefs. Therefore, sheephead on natural reefs were, on average, larger than those found on artificial reefs.

Sheephead are large fish and contribute considerably to the total biomass density on both artificial and natural reefs. The difference in the size of sheephead on the two types of reefs probably accounts for the lack of a significant difference in total biomass density when total numerical density was significantly different.

1.3.4.5 Biomass density of water column fish

The biomass density of fish in the water column was much lower than the biomass density of fish near the benthos. A summary of biomass density in the water column is shown in Table 1-40. (Data for all lifestages and young-of-year of all species observed on reefs is given in Appendix C, Tables 9 and 10.) The biomass density in the water column of artificial reefs was by far the highest on L.A. Harbor breakwater and Rincon Oil Island. On natural reefs, relatively high biomass densities were found on Laguna Beach North, San Mateo Kelp, Don't Dive There and San Onofre Kelp (Main, 4-1). Mean biomass density was 1.73 kg/1000 m^3 on artificial reefs and 2.35 kg/1000 m^3 on natural reefs; means were not significantly different (Table 1-41).

The biomass density of sport fish in the water column followed the same pattern. Mean biomass density was higher on natural versus artificial reefs (1.9 kg/1000 m^3 and 0.4 kg/1000 m^3, respectively), but the difference was not statistically significant (Table 1-41).

The biomass densities of five individual species are presented in Table 1-40. Biomass density of all species was very low; none of the fish that were abundant in the water column are very large species. The largest biomass density, 7.67 kg/1000

m^3, was contributed by kelp bass in the San Onofre Kelp Bed. Only one species, halfmoon, showed a significant difference in biomass density between the two reef types; its numerical density was also significantly higher on natural reefs. Otherwise, biomass density tended to be higher on natural reefs for kelp bass and senorita and higher on artificial reefs for kelp surfperch and blacksmith.

The ratio of mean biomass density on artificial and natural reefs is the reverse of the ratio for numerical density; mean biomass density was higher on natural reefs while numerical density was higher on artificial reefs. This reversal is driven in part by the differences in kelp bass on both types of reefs. Although the mean numerical density of kelp bass was lower than some other species found in the water column on the reefs sampled (particularly kelp surfperch and blacksmith, which have higher numerical densities on artificial reefs), kelp bass grow much larger than these other species and therefore contributed proportionally more to the total biomass on a reef. Not only were kelp bass more abundant on natural reefs, but more than 95% of the kelp bass seen on natural reefs were juveniles and adults; in contrast, one-third of the kelp bass seen on artificial reefs were young-of-year.

In summary, total biomass density of fish was much higher near the benthos than in the water column on all reefs except San Onofre Kelp (Main 4-1), where it was about equal in both habitats. For most species, biomass density of fish in the benthos was higher on artificial compared to natural reefs, but the difference was significant for only 4 species. However, the biomass densities of a few species, particularly garibaldi and sheephead, were almost twice as high on natural reefs, although the differences were not significant.

The pattern of higher mean numerical density of all fish near the benthos on artificial versus natural reefs was also seen for biomass density, although the difference was not statistically significant for biomass density. However, the pattern of higher mean numerical density in the water column on artificial reefs was reversed for biomass density; biomass density was higher on natural reefs, although differences were not significant for either type of density estimate. For a few species, notably kelp bass in the water column and sheephead near the benthos, a higher proportion of larger individuals occurred on natural reefs.

1.3.4.6 Standing stock

The estimate of standing stock is based on the size of the reef and the biomass density of fish on the reef. The area of artificial reefs averaged 2.2 ha (excluding breakwaters and Rincon Oil Island, artificial reefs averaged only 0.85 ha), while natural reefs averaged 124 ha (Table 1-42), about two orders of magnitude larger. The mean biomass density of benthic fish was 30.2 kg/1000 m^3 on artificial reefs and 21.8 kg/1000 m^3 on natural reefs (Table 1-39). When these data are converted to MT/ha (Table 1-42), the mean(SE) on artificial reefs was 0.452 (0.061) MT/ha, and on natural reefs 0.286 (0.045) MT/ha.

Standing stocks of fish near the benthos on artificial reefs varied from 0.12 to 2.77 MT (Table 1-54), with a mean(SE) of 0.941 (0.304) MT. On natural reefs, estimated standing stocks varied from 2.22 to 276.05 MT, with a mean(SE) of 45.320 (23.893) MT. The estimates for PAR and SOK, although independently derived, are similar to DeMartini's (1987) estimates.

Since biomass density was usually much lower in the water column than near the benthos, standing stocks of fish in the water column were also much lower. The mean biomass density of all fish in the water column was 1.73 kg/1000 m^3 on artificial reefs and 2.35 kg/1000 m^3 on natural reefs (Table 1-41). Standing stock in the water column on artificial reefs varied from 0 to 0.33 MT (Table 1-54), with a mean(SE) of 0.017 (0.008) MT. On natural reefs, standing stock varied from 0 to 222.04 MT, with a mean(SE) of 0.032 (0.014) MT.

1.3.5 Factors influencing fish communities

The data on species richness, density and biomass density of fish on reefs provide a basis for comparing artificial and natural reefs. However, these data alone provide little information on why certain patterns exist, or how particular features of an artificial reef might influence the community that occurs on the reef. The latter question is particularly important for designing new artificial reefs to meet particular criteria. We have addressed these problems in this section by examining the relationships between select physical and biological characteristics of the reefs with fish richness and diversity and fish density.

Because fish on artificial and natural reefs could respond differently to a particular factor, we have analyzed artificial and natural reefs separately. Separate analyses for artificial and natural reefs, along with the number of factors examined, resulted in a large number of regressions. Caution should be exercised in ascribing importance to significant ($P<0.05$) regressions, since 5% of the regression can be expected to be "significant" due to chance alone. All regressions were performed on both raw (transformed) data and ranked data. Only significant ($P<0.05$) or nearly significant ($P<0.10$) regressions, and only the results of regressions based on ranked data, are presented in the main body of this report, with the complete analyses, including regression plots, presented in Appendix D.

1.3.5.1 Species richness

1.3.5.1.1 Physical characteristics of the reefs

Regression analyses were performed to examine the relationship between species richness and the physical characteristics of the reefs. Three physical parameters were examined: reef area, depth and height.

Reef area was positively related to the number of species in the water column of artificial reefs, but not natural reefs (Table 1-43, Fig. 1-4). Larger artificial reefs had more species with young-of-year ($R^2=.65$, $P=0.0048$) and juveniles & adults ($R^2=.59$, $P=0.0093$) in the water column. There was no relationship between the number of species near the benthos and the size of reef. The total number of species sampled on natural reefs (including species near the benthos, in the water column, and in the fish length samples) was positively related to reef area, although the regression was not significant ($R^2=0.23$, $P=0.0582$).

Note, however, that the species richness measured during this study is not an estimate of the total number of species on a reef, because a limited volume of water was sampled and no effort was made to sample all habitats on a reef. Thus, our estimates of richness may underestimate the true species richness, especially for large reefs or reefs with a large number of different habitat types. Our regression of species richness versus reef size does not test island biogeographical concepts.

In general, species richness was positively related to reef height. There were no significant relationships among benthic fish, although young-of-year richness on natural reefs was nearly significantly related to height ($P=0.0806$ for ranked data, and $P<0.05$ for raw data), with a positive slope and an $R^2=0.20$ (Table 1-43, Fig. 1-6). Among the fish in the water column, young-of-year, juvenile & adults, and all lifestages combined were positively related to the height of artificial reefs, with R^2 equal to 0.42, 0.47 and 0.47, respectively.

Reef depth was both positively and negatively related to fish species richness (Table 1-43). For young fish near the benthos, the relationship was positive but not significant on natural reefs ($P=0.0781$ for ranked data, $P<0.05$ for raw data), and negative but not significant on artificial reefs ($P=0.0809$). The richness of juveniles & adults (and all species combined) on artificial reefs was positively related to reef depth. The richness of water column fish was negatively related to the depth of artificial reefs. This relationship was significant for young-of-year ($R^2=0.63$), juveniles & adults ($R^2=0.55$), and all lifestages combined ($R^2=0.55$). There was no relationship between reef depth and the richness of water column fish on natural reefs.

In summary, few regression analyses of species richness vs. physical characteristics of reefs yielded similar results for both artificial and natural reefs, and most significant regressions involved artificial reefs. The number of species near the benthos was not related to the area of artificial reefs, but the number of species in the water column was: larger artificial reefs had more water column species. Similarly, the number of species near the benthos was not related to the height of artificial reefs, but the number of species in the water column was: higher artificial reefs had more water column species. The relationship with reef depth was somewhat more complicated. Deeper artificial reefs had more species with juveniles & adults near the benthos, but fewer species with young-of-year near the benthos and fewer species of all lifestage categories in the water column.

1.3.5.1.2 Algal characteristics of the reefs

Regression analyses were also performed to examine the relationship between species richness and characteristics of the algae on the reefs surveyed. The algal characteristics examined were: density of large brown algae (including understory kelps, *Macrocystis*, and all kelps combined) and the percent cover and mean height of algae on the reefs.

There were no significant relationships between the density of understory kelp and either benthic or water column fish, for either natural or artificial reefs (Table 1-44).

There was no significant relationship between the richness of any of the lifestages of fish near the benthos and the density of *Macrocystis* (Table 1-44, Fig. 1-8). However, on artificial reefs all benthic lifestages combined were negatively related to *Macrocystis* density, although the regression was not significant.

There was a strong positive relationship between the richness of fish in the water column and *Macrocystis* density, both on artificial and natural reefs (Table 1-44, Fig. 1-8). For young-of-year, the regression of ranked data against *Macrocystis* density explained 77% of the variance on artificial reefs and 42% on natural reefs. For juveniles & adults, the regression explained 76% of the variance on artificial reefs and 53% on natural reefs, with a similar result for all lifestages combined. High *Macrocystis* densities were consistently associated with larger numbers of species in the water columns of both artificial and natural reefs.

When the densities of *Macrocystis* and understory kelps are combined, only the richness of juveniles & adults near the benthos (and all benthic lifestages combined) was significantly related (Table 1-44); the regression had a negative slope. The density of all kelps was positively related to the richness of all lifestage categories in the water column of artificial reefs. On natural reefs, the only significant regression was a positive association with young-of-year in the water column.

There were no significant regressions with the percent cover of algae on artificial or natural reefs.

The mean height of algae was positively related to the number of species in the water column on artificial reefs (Table 1-44). This relationship was significant for all lifestage categories on artificial reefs.

In summary, algae generally appeared to have a positive effect on species richness of water column fish. For *Macrocystis*, this relationship was evident on both artificial and natural reefs. For the other algal categories, the relationship with species richness was more apparent on artificial reefs. The only significant relationship with the richness of fish near the benthos was negative. It appears that fewer species of benthic fish, especially juveniles & adults, occur where kelp density is high.

1.3.5.1.3 Multiple Regression Analysis

In the multiple regression analysis, seven physical and biological variables are considered simultaneously: reef type, area, height and depth, *Macrocystis* and gorgonian density, and "algae" (a variable derived from a number of measures of understory algae; see Methods for more details). Artificial and natural reefs were considered together in the multiple regressions.

Several variables appeared to have similar influences on the richness of fish near the benthos and in the water column, although the magnitude of the effects differed (Table 1-45). The slope for reef type was negative for young-of-year and all lifestages combined for both habitat types, indicating that more species were found on artificial reefs than natural reefs. Reef area had positive slopes for oth young-of-year and all lifestages combined for both habitat types, indicating that more species were found on larger reefs. For both reef type and reef area, the magnitude of the slope was greater for benthic samples.

The multiple regressions also indicate that the influences of some variables differed near the benthos vs. in the water column. Reef depth had a large positive slope for all lifestages near the benthos, but a large negative slope for all lifestages in the water column. *Macrocystis* density had negative slopes for fish species richness near the benthos, but positive slopes for richness in the water column. There were also minor differences with reef height, algae, and gorgonians.

1.3.5.2 Density of fish

1.3.5.2.1 Physical characteristics of the reefs

Regression analyses of the density of fish were performed on the same physical characteristics (reef size, depth and height) as for species richness.

When all the species or sport fish species are considered, there was no relationship between reef area and the density of fish near the benthos (Table 1-46, Fig. 1-5). The densities of a few individual species (black surfperch and pile surfperch) were significantly related to reef area. The density of young kelp bass near the benthos was also positively related to the area of artificial reefs, with $R^2=0.667$ for ranked data. In addition, the benthic density of young-of-year of all sport fish species combined was positively related to reef area on both artificial and natural reefs.

For all species combined and sport fish species, the density of fish in the water column was positively related to the area of artificial reefs (Table 1-46). The densities of kelp bass, black surfperch and kelp surfperch in the water column were also positively related to the area of artificial reefs. There were no significant relationships between water column density and area of natural reefs. Among young-of-year in the water column, the density of all species combined was nearly significant (P=0.0523) and positively related to area of artificial reefs.

There was little relationship between the density of benthic fish and reef height, with the few significant relationships generally being positive (Table 1-47, Fig. 1-7). All lifestages combined of opaleye and garibaldi were positively related to the height of natural reefs. Among the young-of-year near the benthos, sport fish were positively related to reef height, but the regression was not significant. The sole negative relationship with height occurred with young kelp bass on natural reefs; however, young kelp bass on artificial reefs may have been positively related to reef height.

Among fish in the water column, all significant regressions between density and reef height were positive. Significant relationships with all lifestages combined were detected with all species, blacksmith and kelp surfperch on artificial reefs, and (nearly significant) with blacksmith on natural reefs (Table 1-47). The young-of-year of all species combined and of senoritas may have been related to the height of artificial reefs.

There were no significant relationships between reef depth and fish densities near the benthos or in the water column on natural reefs (1-48). There were numerous significant regressions for densities on artificial reefs, and with one exception these were all negative. Among all lifestages combined, both opaleye and black surfperch were negatively related to reef depth. The sole positive relationship was a nearly significant regression with all lifestages of sheephead combined. The young-of-year of sport fish near the benthos were negatively related to reef depth.

In addition, kelp bass and black surfperch were negatively related, and pile surfperch (nearly significant) negatively related, to reef depth.

In the water column, all lifestages combined of all species and sport fish species were negatively related to the depth of artificial reefs (Table 1-48). All lifestages of kelp bass and (nearly significant) blacksmith were negatively related to the depth of artificial reefs. The density of all young-of-year in the water column was negatively related to the depth of artificial reefs, with $R^2=0.724$ and $P=0.0019$. The density of the young-of-year of sport fish species in the water column was negatively related to reef depth, but the regression was not significant.

1.3.5.2.2 Biological characteristics of the reefs

The results of the regression analyses between fish density and the percent cover of foliose algae are presented in Table 1-49. All lifestages near the benthos of barred sand bass on natural reefs and blacksmith (nearly significant) on artificial reefs were negatively related to foliose algae. All lifestages of senorita on artificial reefs and garibaldi on artificial and natural reefs were positively related to cover of foliose algae, but these regressions were not significant. Regressions with young-of-year benthic densities were positive for sport fish and black surfperch on natural reefs.

There were few significant regressions with fish in the water column and cover of foliose algae. Young-of-year of all species may have been related to foliose algae on artificial reefs, and the raw (transformed) density of blacksmith in the water column of natural reefs was positively related to foliose algal cover on natural reefs.

Several categories of fish near the benthos were significantly related to the density of understory kelp on natural reefs, but not on artificial reefs (Table 1-50). Among just the sport fish species, both the juveniles & adults and all lifestages combined were negatively related to the density of understory kelp. All lifestages combined of barred sand bass and black surfperch were also negatively related to understory kelp. The only significant relationship with young-of-year near the benthos was a positive relationship with senoritas.

In contrast to the relationship between understory kelp and fish near the benthos, the relationships with fish in the water column were positive (but few), and occurred on artificial but not natural reefs (Table 1-50). All lifestages combined of blacksmith may have been related to understory kelp, and the young-of-year of senoritas in the water column were positively related to understory kelp.

Regressions between *Macrocystis* density (as determined from the benthic transects) and the density of benthic fish indicated both positive and negative relationships (Table 1-51, Fig. 1-9). All significant regressions were positive, including opaleye on artificial reefs and pile surfperch on natural reefs for all lifestages combined, and all sport fish young-of-year on natural reefs. In addition, sport fish young-of-year on artificial reefs and young black surfperch on natural reefs were positively related to *Macrocystis* density, but the regressions were not significant. However, several negative relationships with *Macrocystis* were evident, although the regressions were not significant. The density of all species (R^2=0.378, P=0.0587) and sheephead (R^2=0.380, P=0.0577) near the benthos on artificial reefs, and the density of barred sand bass (R^2=0.243, P=0.0526) near the benthos on natural reefs were negatively (but not significantly) related to *Macrocystis* density. In addition, the regression with young blacksmith on natural reefs was nearly significant.

In contrast to the relationships with benthic fish, fish in the water column were invariably positively related to *Macrocystis* density (Table 1-451). The water-column densities of the combined lifestages of both sport fish and all species combined were positively related to *Macrocystis* on both artificial and natural reefs. All lifestages of blacksmith, senorita and kelp surfperch were positively related to *Macrocystis*; for blacksmith, the regression was significant for artificial reefs only, whereas for senorita and kelp surfperch the regressions were significant for both reef types. All lifestages of kelp bass were positively related to *Macrocystis* density on artificial reefs only, but the regressions were not significant. Young-of-year of all species showed a positive relationship with *Macrocystis* on both artificial and natural reefs; sport fish young-of-year were positively related to *Macrocystis* on artificial reefs only. Senorita young-of-year in the water column were positively related to *Macrocystis* on natural reefs only.

A similar relationship between water column fish and *Macrocystis* is apparent when *Macrocystis* density is estimated from the water column transects rather than the benthic transects (as presented in Table 1-51). Significant regressions are invariably positive (Table 1-52). For all lifestages combined, all species, sport fish, kelp bass, halfmoon, blacksmith, senorita and kelp surfperch show a significant positive relationship with *Macrocystis* density; for kelp bass and halfmoon the relationship is significant for natural reefs only, whereas for blacksmith it is significant for artificial reefs only. The densities of young-of-year of all species, sport fish, and senoritas in the water column were also positively related to the density of *Macrocystis* in the water column.

Results of regression analyses with percent cover of all algae are given in Table 1-53. The density near the benthos of one species, barred sand bass, was negatively related to algal percent cover (on natural reefs only). All lifestages combined of garibaldi near the benthos were positively related to algal percent cover on artificial reefs. The benthic young-of-year densities of sport fish (nearly significant on both artificial and natural reefs) and black surfperch (on artificial reefs) were positively related to algal percent cover.

In general, the densities of fish in the water column were positively related to algal percent cover. All lifestages of all species combined and blacksmith, and young-of-year of all species combined, were positively related to percent cover of algae on artificial reefs. There is also a suggestion of a positive relationship between blacksmith density on natural reefs and algal percent cover, with $R^2=0.190$ and $P=0.0916$ for regressions using raw (transformed) data.

The relationships with mean algal height on a reef followed a similar pattern to percent cover of algae (Table 1-54). The significant regressions with benthic densities of all lifestages combined or juveniles & adults were negative and for natural reefs only; these included all lifestages combined of sport fish and barred sand bass, and juveniles & adults of all species and sport fish. On artificial reefs, all lifestages combined of sheephead and juveniles & adults of all species showed a nearly significant negative relationship with algal height, and all lifestages of garibaldi showed a nearly significant positive relationship with algal height. The benthic densities of young-of-year of sport fish on artificial and natural reefs and black surfperch (nearly significant) on artificial reefs were positively related to algal height.

As with percent cover of algae, all significant regressions between algal height and the density of fish in the water column were positive; all significant regressions also involved artificial reefs only (Table 1-54). Among all lifestages combined, all species, sport fish (nearly significant), kelp bass (nearly significant) and blacksmith showed a positive relationship with algal height. The density of young-of-year of all species in the water column was also positively related to algal height on artificial reefs.

In summary, the relationship between algae and fish density frequently differed between fish near the benthos and fish in the water column. The densities of fish in the water column were positively related to algal characteristics of the reefs. This relationship was particularly strong for *Macrocystis*, where regressions with *Macrocystis* density explained as much as 80% of the variation in fish densities. However, all algal characteristics tested had at least some significant regressions with water-column fish densities, and these were always positive. Thus, the abundance of algae, even benthic algae, seems to enhance the assemblage of fish in the water column.

In contrast, the relationship between the density of fish near the benthos and algal characteristics was not consistent, but varied according to life stage and species. The relationships between algae on the reefs and densities of young-of-year near the benthos were generally positive. This relationship was more important for sport fish species than all species combined. The only negative relationship was for blacksmith young-of-year; the high relative abundance of blacksmith may account for the general lack of any relationship with all species combined as compared to sport fish species.

For all life stages combined, barred sand bass consistently were negatively related to algal characteristics. Barred sand bass generally roam over sandy areas, and occurred almost exclusively at the sand/rock interface of both artificial and natural reefs. The results of the regression analysis may indicate that sand bass actively avoid reefs with high algal density, or it may simply reflect an incidental relationship (such as a preference by sand basses for deeper reefs, which also have lower algal densities). The density of blacksmith near the benthos was also sometimes negatively related to algal characteristics. The density of garibaldi was generally positively related to algae on the reefs.

1.3.5.2.3 Multiple Regression Analysis

The multiple regression analysis based on seven variables (reef type, area, height and depth, *Macrocystis* and gorgonian densities, and understory algae) considered the densities of fish near the benthos (Table 1-56) and in the water column (Table 1-57) separately.

Near the benthos, all species combined (both all lifestages and young-of-year) were negatively related to reef type and *Macrocystis* density and positively related to reef area (Table 1-56). The relationships for reef type and area were in the same direction for most individual species. *Macrocystis* density had both positive and negative slopes in the regression models of individual species; the largest negative slopes were for blacksmith, senorita, and rock wrasse, while the largest positive slope was for pile surfperch.

The influence of algae on benthic fish densities depended on the lifestage considered. For a number of taxa (including sport fish, black surfperch, and to a lesser extent all species and kelp bass), algae had a negative slope in the model for all lifestages, but a positive slope for young-of-year. For senorita, algae was positive for both lifestage categories, while for blacksmith it was negative (but small).

Reef depth was often an important variable in the benthic multiple regression models, although the direction of its influence differed. Depth had a negative slope for many species, especially for young-of-year, including sport fish, kelp bass, sand bass, opaleye, black surfperch and pile surfperch. However, depth had a positive slope for blacksmith and sheephead.

The results of the multiple regressions for the densities of fish in the water column were quite different from the results for benthic densities. The dominant feature was the large positive slope for *Macrocystis*. *Macrocystis* was positive for both lifestage categories for nearly all taxa, including all species and sport fish; the single exception was blacksmith. In further contrast to benthic densities, reef type, area and depth had relatively little importance for water column densities.

constructed by DFG, and is fairly old. In addition, TPAR and PPAR are the only existing traditional artificial reefs that have ever supported kelp beds, although kelp is now virtually absent from TPAR.

Some artificial reefs (but no natural reefs) were virtually lacking in algae. The overall cover of algae was 0% on Newport Beach, Hermosa Beach and Marina Del Rey Artificial Reefs. These reefs were the deepest artificial reefs sampled, with depths of 24, 21 and 21 m, respectively.

The giant kelp, *Macrocystis*, is a valuable component of natural communities; it adds vertical structure, is an important primary producer, is fed on directly by some fish species, and shelters numerous invertebrates that are prey for fish. *Macrocystis* was found on only four artificial reef sites. Three of these are "breakwaters": the inside and outside of the Los Angeles Breakwater, and the Rincon Oil Island. The only traditional artificial reef with kelp was PPAR. PPAR and Rincon Island are quite close (< 0.7 km) to natural kelp beds; they are the only artificial reefs we sampled within 1 km of a natural kelp bed. The kelp on the LA Breakwater was transplanted there; its persistence and expansion on the breakwater represents the only successful attempt in Southern California to establish *Macrocystis* on an artificial structure by transplantation.

Algae are important to fish for a number of different reasons. Many fish feed on small invertebrates (such as amphipods) that are abundant in foliose algae and turf (Ellison *et al.* 1979, Schmitt and Coyer 1982, Laur and Ebeling 1983, Schmitt and Holbrook 1984). Algae serve an important function as refuges from predation for some fish species (Holbrook and Schmitt 1984, Ebeling and Laur

1985, Ebeling *et al.* 1985). Understory algae is also the primary recruitment habitat for some reef fish species (Jones 1984, DeMartini, *personal communication*).

Giant kelp is also important for a number of fish species. Kelp adds vertical structure to the water column, providing a point of orientation for some species (Quast 1968a,b, Bray 1981) and a substrate for numerous invertebrates that are preyed upon by fish (Coyer 1979). Kelp beds function as a nursery for kelp bass (Coyer 1979, Larson and DeMartini 1983, M. Carr, *personal communication*), kelp perch (Coyer 1979), surfperches and rockfish (Miller and Geibel 1973, Carr 1983).

Because algae seem to be so important for fish, it may be desirable to construct artificial reefs to maximize algal communities. Although we have not explicitly evaluated the factors leading to high algal abundance and diversity, light may be a limiting factor, and the data suggest that shallow reefs, where light is presumably higher, support higher abundances of algae.

The age of an artificial reef may also influence the algal community on it. The density of *Macrocystis* was positively related to the age of artificial reefs (R^2=0.414, slope=0.511, P=0.0446). The regression of reef age and all kelps combined was marginally significant (R^2=0.380, slope=0.579, P=0.0579). These regressions suggest that older reefs might be more suitable for giant kelp. However, the relationship is driven by the presence of kelp on breakwaters, which are older than other artificial reefs, but also shallower, steeper, and larger.

1.4.1.1.2 Invertebrates

Overall, the invertebrate assemblages on artificial and natural reefs were quite similar. Artificial reefs had fewer anemones, *Kelletia*, bivalves, and urchins but more bryozoans. Some artificial reefs also had relatively high densities of rock scallops (*Hinnites*). One artificial reef, PPAR, had an extremely high density of solitary tunicates. In spite of these differences, the general appearance of most artificial reefs did not seem grossly different from what might be expected of a natural reef in the same location.

The high density of gorgonians on some artificial reefs was striking. However, since some natural reefs also had high gorgonian densities, no difference in gorgonian densities between reef types was detected. High densities of gorgonians occurred most often at southern sites. PAR and TPAR, south of San Onofre, had the highest densities on artificial reefs, while Barn Kelp and Las Pulgas Reef, which are south of San Onofre, and San Onofre Kelp Bed had the highest densities on natural reefs.

The invertebrates sampled during this study include most of the conspicuous invertebrates found on rocky reefs. However, a number of important invertebrate taxa were not examined. For example, we did not attempt to sample small motile invertebrates such as amphipods and other microcrustaceans. These invertebrates are important food items for many fish (Ellison *et al.* 1979, Schmitt and Coyer 1982, Laur and Ebeling 1983, Schmitt and Holbrook 1984), and their abundance could have a significant impact on the fish populations on rocky reefs. Microcrustaceans frequently occur in foliose algae and turf (Holbrook and Schmitt 1984, Schmitt and

Holbrook 1984), and since foliose algae are much sparser on many artificial reefs, these prey may also be scarcer on artificial reefs.

1.4.1.1.3 Fish

Artificial reefs were generally equal to or higher than natural reefs in species richness, diversity, density and biomass of fish.

The higher species richness of fish on artificial reefs was due to an increase in the number of species near the benthos. The overall density of benthic fish was also higher on artificial reefs. Densities of six species were significantly different on artificial and natural reefs; five of these (kelp bass, barred sand bass, black surfperch, pile surfperch and blacksmith) had higher densities on artificial reefs, while one (rock wrasse) had higher densities on natural reefs. There are no clear ecological characteristics shared by the five species with higher densities on artificial reefs. For example, the two bass species are highly mobile, with kelp bass occurring on rocky reefs and sand bass concentrating at the sand/rock interface. The surfperches are relatively sedentary and closely associated with rocky reefs, while the blacksmith school in the water column. The diets of the five species are varied and include large invertebrates and fish (bass), small crustaceans (surfperch), and plankton (blacksmith). The total biomass density of fish on artificial reefs was not significantly from natural reefs, although four species of fish (opaleye, black surfperch, pile surfperch and blacksmith) had higher biomass densities on artificial reefs.

In contrast to the situation for benthic fish, there were few overall differences in water column fish between artificial and natural reefs; total species richness, density, and biomass density were not significantly different. Numerical density was slightly higher on artificial reefs but biomass density was slightly higher on natural reefs. There seem to be higher densities of small fish (blacksmith and kelp surfperch) on artificial reefs but more of the larger species (kelp bass and halfmoon) on natural reefs, although densities of senorita are also high on natural reefs.

Overall, the fish assemblages on artificial and natural reefs were similar. Several species were found on virtually all reefs, and nearly all common species occur on both types of reefs. Cluster analyses did not indicate that artificial reefs as a whole had similar fish assemblages: although the fish assemblages on some pairs of artificial reefs were very similar, in general fish assemblages on artificial reefs were about as similar to natural reefs as they were to each other.

Other studies comparing artificial and natural reefs have also found a general similarity in the fish assemblages (Randall 1963, Buchanan 1973, 1974, Buchanan *et al.* 1974, Dewees and Gotshall 1974, Nolan 1975, Russell 1975, Jones and Thompson 1978, Molles 1978, Bohnsack 1979, 1983a, 1983b, Parker *et al.* 1979, Smith *et al.* 1979, Stone *et al.* 1979, Gascon and Miller 1981). Matthews (1983) found that the fish species composition on an artificial reef in Monterey Bay, California, was quantitatively similar to several natural reefs in the area within one year of construction.

The generally higher richness and density of benthic fish on the artificial reefs we sampled indicates that the fish are responding to these reefs. Fish abundance and/or biomass is often much higher on artificial reefs than natural reefs (Bohnsack and Sutherland 1985; for an exception, see Burchmore *et al.* 1983, 1985)Examples of increased fish abundance on artificial reefs include Turner *et al.* (1969; 2-3 times the biomass), Fast (1974) and Fast and Pagan (1974; twice the number of individuals and 7-8 times the biomass), Russell (1975; 10-14 times the biomass), Smith *et al.* (1979; 6 times the number of individuals), Walton (1979; 16 times the density but the same biomass), and Matthews (1983; up to 3 times the density).

The biomass density and numerical density of fish may be higher on artificial reefs than natural reefs because of the design of the artificial reefs, especially their greater structural complexity (Smith *et al.* 1979), or because of their position in the surrounding habitat (Randall 1963, Russell 1975). Jessee *et al.* (1985) attributed higher fish densities on Pendleton Artificial Reef to the relief and height of the reef, but also noted that the ratio of reef surface area to reef perimeter and the distance to neighboring reefs and hard bottom areas could be important. At present, we know too little about the behavior and population biology of Southern California reef fish to identify for most species the important aspects of reef design. However, two species with particularly strong responses to artificial reefs, blacksmith and barred sand bass, deserve particular mention.

Blacksmith were extremely abundant on a number of artificial reefs. Blacksmith dominated the young-of-year class on artificial reefs, comprising >90% of the recruits on several artificial reefs, and >50% on the majority. (It is interesting to note that the two artificial reefs studied most intensely by the MRC and DFG, TPAR and PAR, support by far the highest densities of blacksmith.

sites the water column biomass is minimal, but at SOK it is relatively high, indicating that our estimate based on benthic biomass is lower than the true biomass density in the kelp bed. Nonetheless, our estimate is very close to Larson and DeMartini's estimate.

The biomass densities estimated for Palos Verdes Reef and King Harbor Breakwater by Stephens *et al.* (1984) are much higher than our estimates for both of these sites, as well as much higher the the biomass densities estimated by Quast (1968b), Larson and DeMartini (1984), and DeMartini (1987). This large discrepancy in estimates is likely to be due to differences in methodologies used. Stephens *et al.* report that the biomass density at King Harbor Breakwater was more than twice the biomass density at Palos Verde Point. In contrast, our estimates indicate that reefs on Palos Verde had twice the biomass density of the King Harbor Breakwater in Fall 1986.

Standing stock refers to the biomass of fish occurring on a reef at a particular time. Standing stock depends on the size of the reef as well as the biomass density. The only detailed estimate of standing stock on a artificial reef in Southern California (besides the estimates in this report) has been made by DeMartini (1987) for PAR; DeMartini (1987) also estimated standing stock at SOK. These two estimates are based on data that were collected using similar methods to those employed in this study, but the sampling was more extensive and more frequent, so the estimates are probably more precise than ours. DeMartini (1987) estimates that several metric tons (MT; 1 MT=1000 kg) of fish were present at PAR during November 1986 to January 1987. Biomass exceeded 0.5 MT/ha over the 1.1 ha of rocks, although it was considerably lower when averaged over the 3 ha of rock-sand complex. The biomass density at SOK was 0.25-0.5 MT/ha (DeMartini 1987). Since the area of SOK was about 100 ha, the total standing stock of fish at SOK (about 30 MT) was greater than the standing stock at PAR by an order of magnitude.

For the reefs surveyed during this study, the standing stock was approximately 2 orders of magnitude higher on natural reefs than on artificial reefs. Even relatively small natural reefs, such as Rincon Kelp and Box Canyon, were larger than artificial reefs, so that in spite of their low biomass densities they had considerably higher estimated standing stocks than most artificial reefs. Larger natural reefs had standing stocks of 30 to 65 MT, while the largest reef complex, Palos Verde Pennisula, had an estimated standing stock of 275 MT.

Four artificial reefs had standing stocks that were notably higher than other artificial reefs. Three of these reefs are breakwaters, including Rincon Oil Island, which due to its large size had the highest standing stock of all artificial reefs. The fourth artificial reef is the Newport Beach Artificial Reef (NBAR); this is the deepest artificial reef surveyed (24 m), and is constructed of concrete pilings. NBAR is quite large, especially for a traditional artificial reef (2.50 ha compared to a mean of 0.52 for the other 5 traditional artificial reefs). NBAR had almost no algae on it, and very few invertebrates; some sponges and a few gorgonians and seastars were the only invertebrates sampled on the reef. In spite of the absence of algae and invertebrates that would provide food and shelter for fish, the standing stock (and density) of fish on NBAR was high (1.958 MT, 501.6 fish/1000 m^3). In the case of NBAR, at least, it seems likely that the unusually high standing stock does not reflect high fish productivity, but rather attractiveness to fish.

As NBAR illustrates, it is important that standing stock not be confused with fish productivity. Standing stock is not necessarily related to productivity; for example, a population with low mortality rates could accumulate a large standing stock, yet the rate of biomass production could be much lower than in another population with a low standing stock but a high turnover rate. For artificial reefs, furthermore, particular aspects of a reef could be attractive to fish, causing a concentration of fish from surrounding areas and hence a high standing stock, and yet the reef could still be deficient in some critical characteristic or resource so that it contributes little to production of new biomass.

Recruitment

Because recruitment of fish is an important component of fish production (Backiel & LeCren 1978), we sampled young-of-year fish on artificial and natural reefs. Artificial reefs had both a higher mean number of benthic species with young-of-year and a higher density of benthic young-of-year. On average, young-of-year were five times more dense on artificial reefs compared to natural reefs. Much of the difference between artificial and natural reefs was due to young-of-year blacksmith, however. When blacksmith and gobies were excluded, the difference in young-of-year densities between the two reef types was less, but young-of-year density on artificial reefs was still slightly higher than on natural reefs.

Young-of-year made up a greater proportion of the fish assemblage on artificial reefs. Young-of-year comprised 34% of all fish sampled on artificial reefs (144.3 young-of-year/425.3 total fish per 1000 m^3), but only 15% on natural reefs (27.7 young-of-year/184.9 total fish per 1000 m^3). This pattern of relatively higher recruitment could be driven by blacksmith, since blacksmith are abundant and recruit well to artificial reefs. However, excluding blacksmith changes the percent of fish that are young-of-year of a reef, but not the difference between artificial and natural reefs. When blacksmith are excluded, the percentage of young-of-year is 27% (65.0 young-of-year/241.1 total fish per 1000 m^3) and 9% (14.3 young-of-year/150.6 total fish per 1000 m^3) on artificial and natural reefs, respectively. Because little is known about the environmental factors influencing the recruitment of most of these species, it is difficult to identify the mechanisms that might be leading to the higher proportion of young-of-year on artificial reefs.

These results demonstrate conclusively that many fish species recruit to artificial reefs. Furthermore, many species appear to reach higher young-of-year densities on artificial reefs, although the variability in recruitment between reefs is large, and except for blacksmith, mean densities were not significantly different. As with total densities of fish, the superiority (in numbers) of artificial reefs stems from fish near the benthos; in the water column, numbers of species and densities are similar. In addition, much of the difference in young-of-year densities stems from one species, blacksmith, since blacksmith comprise 50% of the young-of-year on artificial reefs, but only 20% on natural reefs.

Higher densities of young-of-year on artificial reefs is generally interpreted as a positive effect of artificial reefs, since higher recruitment is assumed to lead to higher overall fish productivity. However, there is one scenario under which high densities of young-of-year could actually be detrimental. Artificial reefs could concentrate a large number of young-of-year that might otherwise disperse to alternative, less crowded, more suitable habitats. Under these conditions, postsettlement growth and survivorship of a cohort of recruits might be lower on an artificial reef than it would be if the reef was not there. Too little is known about recruitment mechanisms to evaluate the likelihood of this scenario. It seems unlikely that concentrating young-of-year on traditional artificial reefs, which are usually located a great distance from other rocky reefs, is a serious problem, but this possibility should be kept in mind when recruitment on artificial reefs is being evaluated.

1.4.2 Factors influencing fish assemblages

Fish assemblages are influenced by many physical and biological characteristics of reefs. The patterns that seem to provide the most insight involve reef area, reef height, reef depth, and the densities of understory kelp and *Macrocystis*.

Reef area was, in general, positively related to the richness or density of fish on the reef. On natural reefs, for which a wide range of reef areas was sampled, none of the bivariate regressions with species richness was significant, and only a few regressions with density were significant. In contrast, there were many significant regressions between richness and density and the area of artificial reefs, particularly in the water column. The situation with artificial reefs in the present study is complicated by the fact that area covaries with a number of other potentially important factors. The positive regressions are driven by breakwaters (especially the LA Breakwater, Inside and Outside, and Rincon Oil Island), which have high densities of fish and are large, but are also shallow, emergent, support giant kelp, have high algal densities, etc. The importance of reef area is somewhat separated from these other factors in the multiple regression analyses. These analyses showed reef area to be important for benthic species richness and the benthic densities of many taxa, including all species combined, but not for fish in the water column.

Reef area could be important to fish on artificial reefs for at least three reasons. First, large reefs may be more easily detected by fish than small reefs. Second, the reef perimeter of large reefs may serve to buffer the interior of the reef from adverse environmental conditions, including sand scouring, high sedimentation, and currents. Small reefs might not buffer these effects, so that fish living on them might be subjected to more stressful conditions. Finally, island biogeography suggests that large reefs might be able to support more species than small reefs (see Bohnsack 1979, Bohnsack and Talbot 1980). Molles (1978) has found a positive correlation between species richness and reef area, although his reefs were very small (max. 60 m^2), and Japanese studies have indicated that the size of a fish school associated with a reef increases with increased reef area (Grove and Sonu 1985).

A number of aspects of the fish community were positively related to reef height. The number of species with young-of-year on natural reefs was greater on taller reefs (Fig. 1-5). Water column fish seemed to be more influenced by reef height than benthic fish for both richness and density, at least for artificial reefs. As with reef area, the positive regressions are driven by breakwaters (LA-Inside, LA-Outside, and King Harbor Breakwaters, and Rincon Oil Island), so height is confounded by other potentially important factors. In the multiple regression analyses, height was important for species richness and the density of blacksmith in the water column, but for little else.

Reef height has been suggested to be important in a number of other studies on artificial reefs (Molles 1978, Walton 1979, Mottet 1981). Japanese researchers believe that reef height affects the length of time fish stay in the vicinity of a reef and the number of fish attracted by the reef (Gyosho Sogo Kenkyu-dai 1976). Some researchers have suggested that for the optimal "aspect ratio", reef height should be 10% of the water depth (Gyosho Sogo Kenkyu-dai 1976). However, other studies suggest that height may not be as important as horizontal spread of the reef. Grove and Sonu (1985) suggest that height may be more important for migratory fishes and horizontal spread may be more important for demersal fishes. Walton (1979) concluded that medium-high reefs were the optimal height.

Patton *et al.* (1985) related fish density to the height of natural reefs at 127 sites. They concluded that the species richness and abundances of the fish studied were "saturating functions" of height. As height increased, the abundances of these species changed rapidly, then ceased to change (or at least changed much more slowly). Their Fig. 6 suggests that species richness begins to level off at about 2 m, and maximum species richness is reached at a height of about 5 m. The results from the present study do not indicate that species richness is a saturating function of reef height (Fig. 1-5). It is possible that density of fish, especially in the water column, is a "saturating function" of reef height, although the pattern is not very clear (Fig. 1-6); if saturation did occur on the reefs we sampled, it probably occurred higher than 5 m. Therefore, our data do not support Patton *et al.*'s suggestion that a low reef may be as good for fish production as a high reef.

Most of the significant regressions of richness and density of fish with reef depth occurred with artificial reefs. The general pattern was for higher fish density or species richness on shallower artificial reefs. This was the pattern for young-of-year near the benthos and for all lifestages of fish in the water column. For benthic young-of-year, greater richness and density may have resulted from settlement preferences. For water-column fish, the negative relationship was probably due to the large distance from the reef to just below the surface of the water, where the water-column samples were taken. Most fish species seem to stay within a certain distance from the substrate on reefs without kelp (Larson and DeMartini 1984); on deep reefs, these species would not have been sampled. Beyond a certain depth, fish near the surface may not respond to the presence of a reef below unless there is a *Macrocystis* canopy.

Although most regressions indicated that fish richness and density was higher on shallow reefs, there were some exceptions. The richness of juveniles and adults near the benthos, and (marginally) with the density of sheephead near the benthos were positively related to reef depth. Thus, deeper reefs had more older individuals near the benthos than shallower reefs.

The densities of some lifestages of benthic fish were negatively related to the density of understory kelp on natural reefs. This relationship was significant primarily for older fish; with young-of-year densities, the relationship either was not significant or was positive. Understory kelp provides a refuge for young-of-year (Ebeling and Laur 1985), so it is understandable that young-of-year would be associated with it. Understory kelp may not be so valuable to older lifestages; Ebeling and Laur (1985) found that thinning or removing understory kelp did not affect the abundances of adult surfperch, and Holbrook and Schmitt (1984) found that the abundance of black surfperch was negatively correlated with the occurrence of foliose algae. Adult surfperch mostly choose to forage in patches of low turf rather than among tall understory plants (Holbrook and Schmitt 1984). Very high densities of understory kelp, such as occurred on some of the reefs we sampled (up to 17 plants/m^2), may interfere with the foraging of older fish. Thus, juveniles & adults, but not young-of-year, may avoid high densities of understory kelp.

The presence of *Macrocystis* on a reef resulted in more fish species and higher densities in the water column (Figs. 1-7 and 1-8). This pattern was one of the strongest detected in this study, occurring on both artificial and natural reefs, with both young-of-year and all lifestages combined, and in the multiple regression analysis. Not surprisingly, up to 80% of the variation in the density of kelp surfperch, a species that is known to depend on kelp, was explained by *Macrocystis* density. But *Macrocystis* density also appeared to be important to all sport fish species, and the young-of-year of all species. In the multiple regression analysis, all lifestages of all species except one, blacksmith, were positively related to *Macrocystis* density. These results indicate that *Macrocystis* strongly influences the assemblage of fish above reefs, and thus is a key factor in determining the overall fish community on a reef.

Although these data clearly indicate the importance of *Macrocystis*, many aspects of the relationship between fish and *Macrocystis* must still explored. Our data cannot precisely identify how fish density responds to *Macrocystis* density; the relationship we have identified relies more on the presence or absence of *Macrocystis* than the density of *Macrocystis* on a reef. In addition, precise quantification of the increase in density or biomass resulting from the presence of *Macrocystis* would require a much more extensive sampling of the water column.

Nonetheless, our data indicate that *Macrocystis* is a fundamental factor influencing the distribution and abundance of reef fishes in Southern California.

1.4.3 Conclusions

In general, the same species of algae, invertebrates and fish occurred on both reef types, albeit with somewhat different relative abundances. Nevertheless, there were a number of crucial differences between the two reef types. These differences include aspects of reef size, isolation, complexity, algal abundance, and composition of the fish community. Some of these differences may have important implications for the potential for fish production on artificial reefs.

Algae, especially giant kelp, may be very important for fish production on reefs in Southern California. Algae provide food and shelter to fish, and hence have tremendous potential for increasing fish productivity. Some fish species also recruit primarily to algae (Jones 1984, DeMartini *personal communication*). Our data, along with a number of other studies (Miller and Geibel 1973, Coyer 1979, Carr 1983, Larson and DeMartini 1983, DeMartini 1987), indicate the importance of *Macrocystis* for water-column fish. Yet one of the most conspicuous differences between artificial and natural reefs is the relative lack of algae on artificial reefs.

The scarcity of algae on artificial reefs may significantly reduce their potential for enhancing fish production. However, the actual relationships between fish and algae need to be explored in more detail. For example, prey availability on artificial reefs with and without algae should be quantified, and the influence of algal abundance on fish recruitment should be determined. Without studies such as these, the true importance of algae cannot be demonstrated. Nonetheless, the current evidence, based primarily on studies on natural reefs, suggests that artificial reefs with abundant algal assemblages may be better producers of fish than those without algae.

Perhaps as conspicuous as the difference between artificial and natural reefs was the difference between breakwaters and traditional artificial reefs. Breakwaters differed from traditional artificial reefs in a suite of physical characteristics, being shallower, larger, steeper, higher, emergent, and constructed from somewhat larger rocks; in addition, some of the breakwater sites were more protected. Presumably as a consequence of these differences, breakwaters had more algae than traditional artificial reefs, including more *Macrocystis*. The consequences of these differences are most noticeable with the water-column fish, which are far more abundant on breakwaters, but there may be differences among the benthic fish as well. Some of the attributes of breakwaters may be worth duplicating in traditional artificial reefs. For example, the shallowness of the breakwaters may be responsible for their high algal and fish abundances. The Department of Fish and Game is already exploring the influence of depth in their Experimental Reef Program; however, their shallowest planned reefs are 15 m deep, which is considerably deeper than most breakwaters.

Artificial reefs supported higher numerical densities of fish than natural reefs, at least near the benthos, but biomass densities were comparable. Fish richness and diversity on artificial reefs were equal to or higher than natural reefs. Estimates of fish recruitment to the two reef types was also comparable, with generally higher recruitment on artificial reefs in Fall 1986.

There were some differences in the species composition of fish communities on artificial and natural reefs. In general, the same species were found on both reefs but the relative abundances of some of the common species were different on the two reef types. Rock wrasse, senorita, sheephead and garibaldi comprised a higher proportion of the fish seen on natural reefs than artificial reefs. In contrast, blacksmith made up a much higher proportion of the fish on artificial reefs. The proportion of fish in the water column that were young-of-year was about the same on artificial and natural reefs. However, a much greater proportion of fish near the benthos were young-of-year on artificial reefs than on natural reefs. The size distributions of a few species also seemed to differ between artificial and natural reefs. In particular, for sheephead and kelp bass, larger individuals tended to occur on natural reefs.

CHAPTER 2

ARTIFICIAL REEFS AND MITIGATION

2.1 Fish production

The fact that the density of fish is frequently higher on artificial reefs than on natural reefs has been established by many previous studies (see Bohnsack & Sutherland 1985 for review), and confirmed in this study. However, the extent of increased production of fish on artificial reefs remains one of the critical questions regarding their use in mitigation. To date, no study has demonstrated increased fish production on an artificial reef in the ocean. However, the data collected during this project provide some new information on this question.

Fish production can be increased by higher recruitment, faster growth or greater survival. We measured the density of young-of-year fish on natural and artificial reefs as an indication of the recruitment rates to the reefs. Our data demonstrate unequivocally that a variety of fish species recruit to artificial reefs. Furthermore, the richness of young-of-year was greater, and the density higher, on artificial reefs. Thus, our data indicate that artificial reefs do lead to increased fish recruitment. (Note that, because our study did not extend over an entire year, and because recruitment patterns differ from year to year, we do not know if our estimates of higher recruitment to artificial reefs are generally true.)

We have no new data on growth or survival of fish on artificial reefs. Information about growth of fish on artificial reefs, based on inferences from gut-content data rather than direct measurements of growth, indicates that some fish species, including rockfish, do feed on the reefs (Pearce and Chess 1968, Prince and Gotshall 1976, Hueckel 1980, Hueckel & Stayton 1982, Davis *et al.* 1982, Buckley and Hueckel 1985). However, too little is known about the natural history of most species, especially their movements and feeding ecology, to be able to conclude that they obtain a substantial portion of their diet from the reefs. There are also data showing that some fish on artificial reefs do *not* feed on the reefs (Randall 1963, Kakimoto 1982, Russell 1975, Mottet 1981, Davis *et al.* 1982, Hueckel and Stayton 1982, Steimle and Ogren 1982).

Mottet (1981) has suggested that artificial reefs will attract fish as long as there is adequate food nearby, with the food resources on the reef not being essential. An artificial reef could be located near food resources that otherwise would not be exploited. If the reef allowed fish to consume these resources, and the fish grew faster or more fish survived as a result, fish production would increase. But if the fish attracted to the reef were consuming the resources anyway, or their feeding efficiency was not higher as a result of living on the reef, fish production would not be enhanced.

There are very few data regarding the survival of fish on artificial reefs. Increased survival due to the presence of refuges on the reefs has frequently been postulated. However, one of the few studies of tagged fish on and around artificial reefs suggests that adult fish may actually have lower survival on artificial reefs due to increased fishing pressure (Matthews 1985, Solonsky 1985). This conclusion seems sensible, since many studies have reported greater fishing success on artificial reefs (Turner *et al.* 1969, Buchanan 1973, 1974, Dewees and Gotshall 1974, Fast 1974, Tolley 1981, Matthews 1983, Solonsky 1983), which must translate to greater mortality for fish populations. Huntsman (1981) has argued that reef fish are easily overexploited because of their low mobility, low natural mortality, and slow growth rates.

The sum of the information regarding fish production on artificial reefs still is not sufficient to establish whether fish production is increased by these types of reefs or, if it is increased, by how much. The fact that recruitment rates are at least as high on artificial reefs as natural reefs suggests increased production. Inferences Inferences bout growth and arguments (but no data) about survival also suggest that production is increased. On the other hand, data on mortality and arguments about the concentration of fish on artificial reefs and mortality due to fishing suggest that production may not be increased.

Because the available data regarding production on artificial reefs are ambiguous, any determination of the relative importance of production vs. attraction on artificial reefs must be subjective. Researchers might be tempted to rely on "common sense" based on their personal observations for evaluating the question of fish production on artificial reefs. Below, I relate a few observations that suggest that production need not be increased on artificial reefs in spite of appearances to the contrary. These observations are meant as a caution against relying on common sense, rather than rigorous scientific data, to evaluate this question.

Fish aggregation on artificial reefs, as opposed to fish production, is well known. For instance, many studies have reported significant abundances of adult fish shortly after a reef has been constructed (Turner *et al.* 1969, Fein &

Morganstein 1974, Russell *et al.* 1974, Russell 1975, Molles 1978, Bohnsack & Talbot 1980, Ranasinghe 1981, Tubb *et al.* 1981, Wilson *et al.* 1981, Walsh 1985). The adult fish certainly could not have been produced on such a young artificial reef, nor could they be obtaining food from it. Similarly, Fish Attracting Devices (FADs) are so structurally simply that they could not be increasing recruitment, growth or survival, yet large numbers of fish aggregate around them (Klima & Wickham 1971, Brock 1985). It is generally acknowledged that the high density of fish on new artificial reefs is due primarily to aggregation; the implication is that older reefs, with more mature biota, have produced the high densities of fish.

However, high densities of fish on older reefs could still be due primarily to aggregation. Some older artificial reefs, such as the Newport Beach Artificial Reef, have virtually no algal or invertebrate populations that could provide food for fish, yet still have high densities of fish. Other reefs, such as the Hermosa Beach Artificial Reefs, have few food resources and in addition have an open structure that provides little shelter, yet a high density of fish occurs there. A focus for fish aggregations does not even have to be a large structure: I have observed a high density of fish aggregating around a single boulder (approx. 2m in diameter) surrounded by sand 100 m offshore from Pendleton Artificial Reef, even though the boulder was mostly covered with the cnidarian *Corynactis californica* (which few fish eat) and had no crevices for shelter.

As suggested above, fish behavior can result in high densities of fish around structures that appear to provide few resources; for example, midwater FADs rely on behavioral responses to attract large densities of fish. Fish behavior (rather than high fish production) may also be responsible for high densities on reefs that have abundant resources. For example, if fish are using a reef for orientation, they might not be utilizing food or shelter on the reef, even if it is available. It is important to recognize that, even on reefs that have abundant resources for fish, the presence of high densities of fish does not guarantee that the reef has increased net productivity of fish.

With the strong caveat that important aspects of fish production have not been adequately evaluated, the available data suggest that fish production might be increased by an artificial reef. If this is true, then artificial reefs would be appropriate for mitigating some resource losses; the remaining question is how to design an artificial reef to replace a certain level of resources.

2.2 Reef design

The best design for a reef, including its configuration and construction material, will depend on its purpose. For mitigation, the purpose will generally be to maximize the production of fish, although it is possible that particular fish taxa might be targeted. Unfortunately, fish production on artificial reefs has not been quantified, and there certainly are too few data to establish how particular aspects of reef design could influence *production* of fish. However, an indication of the factors important for production can be obtained by examining factors that influence density or standing stock. (Use of standing stock or density as a proxy for production in this case must be evaluated cautiously, as always.) The advantage of this approach is that we *do* have data concerning the factors influencing fish density.

Aspects of reef design discussed in this section include: reef placement (depth and distance to nearest natural reef), spatial distribution of material, height, construction material, and size.

The site chosen for an artificial reef may be more important than the design of the reef (Ogawa 1982). The depth of a reef may have a substantial influence on the community that develops on it. In some locations, navigational safety considerations may constrain how shallow a reef can be constructed; otherwise, a wide range of depths is available. In the past, most of DFG's artificial reefs were constructed in water that was at least 20 m deep; we sampled some of these reefs, but could not sample others because of their extreme depths. More recently, DFG has constructed more reefs in shallow water, including PAR (15 m) and PPAR (11 m). In addition, we sampled a number of breakwaters that were relatively shallow.

The most obvious difference between deep and shallow artificial reefs is the high abundance of algae on shallow reefs. Shallow artificial reefs tend to have higher densities of algae, especially the kinds of algae that are likely to enhance fish populations. *Macrocystis*, which also may enhance fish populations, grew only on shallow artificial reefs. In addition, the density of some benthic fish, including young-of-year, were higher on shallow reefs.

Perhaps as a consequence of their shallowness, breakwaters had some of the highest abundances of algae seen on artificial reefs. Three of the four artificial reefs with kelp were breakwaters. Breakwaters also had some of the highest densities and diversities of fish of all artificial and natural reefs. The highest densities of sport fish young-of-year occurred on breakwaters. In addition, the highest biomass of fish in the water column on artificial reefs occurred on breakwaters . It appears that a breakwater-type configuration might be an effective way to generate a rich and abundant fish fauna. However, there is not enough information to evaluate which aspects of breakwaters contribute most to their biological communities.

A second aspect of reef placement concerns the distance to the nearest natural reef. Fish are attracted to an artificial reef from a considerable distance; for example, Shimizu (1981) reports an effective range of 300 m. Locating an artificial reef in isolation from natural reefs creates reef habitat in an area that is otherwise unsuitable for reef fish, and this may be desirable for many artificial reefs, depending on their objectives. However, an isolated artificial reef may not be appropriate for some purposes. Natural reefs provide a source of recruits for algae, invertebrates and fish. Species with limited dispersal may find it difficult to reach an isolated artificial reef. In particular, reefs that are designed to support kelp beds may be more likely to achieve that goal if they are close to existing kelp beds, since under most circumstances kelp only disperses over short distances. Placing an artificial reef near a natural reef might also reduce the fishing pressure on the artificial reef because of adjacent fishing sites.

Traditional artificial reefs have been constructed using two different spatial arrangements. The most common configuration in the United States is to deposit all of the reef material in one place. Alternatively, the material may be placed in discrete piles, or modules, separated from each other by expanses of sandy substrate. Recently, DFG has constructed an experimental artificial reef with two sets of modules that are separated at different distances, so information on the importance of distance between modules will be available in the future. Most of

DFG's reefs are still constructed with a number of different modules, although no studies have determined what benefits (if any) accrue from having several separate units within one reef complex. Too few reefs of each type were sampled during our survey for a detailed analysis of modular vs. non-modular reefs, but there were no obvious differences in either total fish densities or the densities of young-of-year fish on the two types.

Reef height may be important for attracting or supporting certain fish species (such as blacksmith), and has been suggested to be influential in other studies (see Mottet 1981). However, Patton *et al.* (1985) suggest that tall artificial reefs may be "over-engineered" and not provide a cost-effective way of producing fish. Our data suggest that reef height might influence the density of some fish, but there is no evidence that taller artificial reefs produce more fish. It seems that a variety of heights in an artificial reef might be more important that the maximum height of the reef, since the increased diversity of microhabitats might have a greater affect of fish production.

Most of the artificial reefs that currently exist in Southern California have been constructed from quarry rock. Two of the reefs in our survey (NBAR and HBAR), however, were made of concrete. Concrete reefs frequently have a distinctly different configuration; in the case of HBAR especially, the concrete pilings created a large, lattice-like effect with relatively low density of hard substrate. The density of fish on these reefs was not noticeably lower than on quarry rock reefs. However, algae and invertebrates did tend to occur at lower densities, even when only hard surfaces are considered. (The reefs were also relatively deep, which confounds any analysis of the influence of the concrete alone.) These reefs might provide somewhat fewer resources for fish, which might affect production, but fish density did not seem to suffer as a result.

Reef size is obviously very important to the standing stock of fish associated with a reef since, for a given density, standing stock is directly related to area. The relationship between the density of fish and reef size is less clear. Based on our data, more species and a higher density of fish might be expected as reef area increases, at least with reefs within the size range of the artificial reefs we sampled. However, species richness and density were only rarely related to the size of the natural reefs we sampled, which were all larger than the artificial reefs.

The difference in the richness and density of fish on artificial compared to natural reefs could be due to the difference in attractiveness between the two reef types. Rocky reefs are typically large or are in close proximity to neighboring reefs that have abundant suitable habitats for fish. In contrast, artificial reefs are usually placed on sand plains, isolated from rocky reef areas; they are also usually fairly small, with a high perimeter-to-area ratio. Both of these factors might influence the size of the area surrounding a reef from which fish are attracted to the reef.

Shimizu (1981) reports that fish are attracted to a reef from up to 300 m away. Assuming fish are attracted to a reef from a set distance (such as 300 m), small reefs will attract fish from a larger area, relative to reef size, than large reefs. For example, if the radius of an artificial reef is 10 m and it effectively attracts fish from 300 m away, then the ratio of area of attraction to reef area is 960:1. If the radius of the reef is increased to 100 m, the absolute area of attraction increases, but the ratio of attraction area to reef area decreases to 15:1. If the radius of the reef is increased to 1000 m, the ratio decreases to 0.69:1. Small reefs attract fish from a *proportionately* larger area than large reefs, so the fish attracted to the reef will occur at a higher density on the reef. Because artificial reefs are usually small, they probably attract fish from a large area relative to their size.

Note that this argument may explain why artificial reefs (which are small) have higher fish densities than natural reefs (which are large), but it does not imply that large artificial reefs are inferior to small ones. Although the density of fish on a large artificial reef might not be as high, a large artificial reef could support higher standing stocks. Furthermore, this argument only applies to fish occurring on a reef because they were attracted to it; fish production might be higher on a large reef because of the increased habitat complexity or greater buffering from adverse environmental conditions.

2.3 Conclusions

The biological communities on artificial reefs did not seem to be qualitatively different from those on natural reefs. Some artificial reefs seemed relatively depauperate in algae and invertebrates, but this condition may be due more to reef design or location than simply because the reef was man-made. However, these reefs demonstrate that care must be taken to utilize an appropriate design if a reef is to be used to replace resources from a natural reef.

One of the most conspicuous differences between artificial and natural reefs was the relative scarcity of algae on artificial reefs. Low algal abundance on artificial reefs was not inevitable, however, since some shallow artificial reefs had substantial algal assemblages. Because algae provide food and shelter for many fish species, placing an artificial reef in shallow water might result in higher fish production.

The most fundamental question about the use of artificial reefs in mitigation, how much fish production can be increased through the construction of an artificial reef, remains unanswered. It is clear that artificial reefs contribute to one important aspect of production, since the densities of young-of-year were generally higher on artificial reefs than natural reefs during our survey. But there are data concerning survivorship and growth, so the overall contribution of artificial reefs to fish production cannot yet be determined.

If an artificial reef is to be used in mitigation, one of the most critical decisions about the reef is the size that will be required. The size of reef needed to mitigate a particular impact depends on (1) the resources lost by the impact, and (2) the resources provided by the reef. The resources lost by the impact can usually be estimated, but because of the uncertainty about fish production on an artificial reef, it is very difficult to estimate the resources provided by the reef.

An initial estimate of the resources provided by an artificial reef can be made under the assumption that the standing stock of an artificial reef (i.e. the biomass of fish on the reef) is produced entirely on the reef. As discussed above and in Ambrose (1986a), there are no good data to indicate that this assumption is true (in fact, it is likely to overestimate true fish production considerably), but it can serve as a starting point for calculating necessary reef size.

Several estimates of standing stock (DeMartini 1987; this report) indicate that, in spite of higher biomass densities, the standing stock of fish on artificial reefs is considerably lower than on natural reefs. Therefore, even under the liberal assumption that all fish on an artificial reef (i.e. the standing stock) are produced by the reef, the size of a reef needed to compensate for the impacts may be substantial. For example, if SONGS were to cause the loss of half of the fish resources at SOK (the equivalent of 52 ha), the biomass of the lost resources would be approximately 9.9 MT, assuming the biomass density of 0.191 MT/ha we measured at SOK Main 4-1. (Because this station may have been impacted by SONGS, the actual biomass could be higher.) An artificial reef with a biomass density similar to PAR's (0.359 MT/ha) would need to be approximately 27.5 ha to replace these lost resources. For comparison, PAR is only 1.4 ha in size.

However, this large size may provide the solution to questions about the relative contribution of attraction versus production of fish on artificial reefs. Existing artificial reefs are usually relatively small; in California, artificial reefs are on the order of hundreds of meters on a side (see Table 1-10, DFG 1987). The debate about the attraction versus production of fish on artificial reefs stems in part from the small size of artificial reefs. Small artificial reefs can attract fish from an area that is large relative to their size. The contributions of attraction and production are hard to estimate because we know that high densities of fish congregate around structures that do nothing to increase production, and we generally do not know the exact nature or quantity of resources that an artificial reef provides for fish.

It seems likely that a large reef (on the order of 1 km^2) constructed from a natural substrate, such as quarry rock, would support a natural community of invertebrates and algae and would supply the same resources for fish as a natural reef. A large, complex artificial reef would furnish many different habitat and microhabitat types. Placed in an appropriate location, it could support a rich assemblage of algae and associated invertebrates, thereby providing food for a number of fish species. An artificial reef on such a scale has never been built, but by supplying an abundance of appropriate features, it would, in my judgment, increase fish production.

Because very large scale reefs have not been built in California, it is difficult to predict the nature of the fish community that would develop on one. Fish densities might not be as high as on existing artificial reefs because the area of attraction might be proportionately smaller than it would be for a small reef. Many of the fish on existing artificial reefs occur along the ecotone between rock and sand, and this area might also be proportionally smaller on a large reef. On the other hand, a large artificial reef could be designed to contain a large proportion of sand/rock ecotone and increased habitat complexity. These features might lead to high densities of fish. The many unknowns make it impossible to accurately predict the eventual number of fish that a large artificial reef could support, but it seems likely that eventually it would be at least as productive as a similar natural reef.

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TABLES

Table 1-1

Artificial Reef Project Site List

No.*	Reef Name	Reef Code	Loran X	Loran Y	Latitude	Longitude	Date Sampling Began
Artificial Reefs							
A1.	Torrey Pines #2 (Bureaucrat Reef)	TPAR	28272.3	40629.8	32°53'15"	117°27'44"	18SEP86
A2.	Pendleton Artificial Reef	PAR	28266.0	40741.8	33°19'10"	117°31'39"	12NOV86
A3.	Newport Beach Art. Reef	NBAR	28225.0	40906.3	33°35'09"	117°58'20"	10NOV86
A4.	L.A. Harbor Breakwater -outside	LOAR	28188.3	41011.5	33°42'12"	118°16'03"	06NOV86
A5.	L.A. Harbor Breakwater -inside	LIAR	28189.4	41010.5	33°42'17"	118°16'03"	07NOV86
A6	King Harbor Breakwater	KHAR	28177.4	41077.7	33°50'33"	118°23'46"	27OCT86
A7	Hermosa Beach Art. Reef	HBAR	28175.6	41082.3	33°51'16"	118°24'34"	23OCT86
A8.	Marina Del Rey Art. Reef	MDAR	28171.1	41127.2	33°58'05"	118°29'09"	03NOV86
A9.	Pitas Point Artificial Reef	PPAR	28046.0	41462.2	34°18'07"	119°22'06"	11DEC86
A10.	Rincon Oil Island	RIAR	28035.5	41491.3	34°20'51"	119°26'41"	10DEC86
Natural Reefs							
N1.	Marine Street Reef	MSR	28266.5	40631.6	32°50'18"	117°17'18"	22SEP86
N2.	La Jolla Cove Reef	LJCR	28270.5	40627.2	32°51'10"	117°15'58"	29SEP86
N3.	Del Mar Reef	DMR	28276.0	40644.4	32°58'11"	117°17'36"	26SEP86
N4.	Barn Kelp	BK	28268.1	40727.3	33°17'01"	117°29'30"	14NOV86
N5.	Las Pulgas Reef	LPR	28270.8	40723.6	33°17'30"	117°28'22"	17DEC86
N6.	Box Canyon	BC	28265.4	40742.7	33°19'03"	117°31'54"	13NOV86
N7.	San Onofre Kelp Main (4-1)	SOKM	28262.1	40756.2	33°20'38"	117°34'08"	24NOV86
N8.	San Onofre Kelp North (002)	SOKN	28262.3	40757.8	33°21'06"	117°34'17"	20NOV86
N9.	San Mateo Kelp	SMK	28259.3	40771.4	33°22'50"	117°36'27"	16OCT86
N10.	Two Man Rock	TMR	28258.8	40773.8	33°22'50"	117°36'44"	21NOV86
N11.	Laguna Beach North (Victor Hugo)	LBN	28244.6	40846.8	33°32'28"	117°47'35"	15OCT86
N12.	Pelican Point	PP	28238.4	40870.8	33°33'55"	117°51'59"	21OCT86
N13.	Point Vicente	PV	28169.0	41060.3	33°44'20"	118°24'46"	29OCT86
N14.	Don't Dive There	DDT	28168.7	41069.6	33°46'09"	118°25'49"	24OCT86
N15.	Flat Rock	FR	28182.7	41070.7	33°47'47"	118°24'32"	21OCT86
N16.	Rincon Kelp	RK	28040.4	41462.7	34°20'26"	119°25'38"	12DEC86

*Numbering of reefs within the two groups is in order of occurrence from south to north (see Figure 1).

Table 1-2

Classification of Substrate Types.
Size is the length of the longest dimension.

TYPE	SIZE
Sand	< 2 mm
Cobble	2 - 49 mm
Small Rock	5 - 10 cm
Medium Rock	11 - 50 cm
Large Rock	51 - 150 cm
Boulders	> 150 cm
Bedrock	---

Table 1-3

Sampling techniques used to estimate the density or percent cover of species or groups of algae and invertebrates.

Band Transects (2 m x 10 m)

Algae:
- *Laminaria farlowii*
- *Eisenia arborea*
- *Egregia menziesii*
- *Macrocystis pyrifera*
- *Cystoseira osmundacea*
- *Sargassum spp.*

Invertebrates:
- *Tethya aurantia*
- *Pachycerianthus interruptis*
- *Panulirus interruptis*
- *Haliotis* spp.
- *Megathura crenulata*
- *Octopus* spp.
- *Pisaster ochraceus*
- *Linckia columbiae*
- *Patiria miniata*
- sea cucumbers

Quadrats ($1\ m^2$)

Invertebrates:
- cup corals
- Diopatra ornata
- barnacles
- hermit crabs
- snails
- *Kelletia kelleti*
- bivalves
- *Hinnites giganteus*
- brittle stars
- *Lytechinus anamesus*
- solitary tunicates
- *Styela montereyensis*

Quadrats or band transects[a]

Invertebrates:
- *Muricea fruticosa*
- *Muricea californica*
- *Lophogorgia chilensis*
- anemones
- shrimp & crabs
- opisthobranchs
- *Strongylocentrotus franciscanus*
- *Strongylocentrotus purpuratus*

Random Point Contacts (10 pts within a $1\ m^2$ quadrat)

Algae:
- encrusting red algae
- filamentous red algae
- foliose red algae
- encrusting coralline algae
- erect coralline algae
- encrusting brown algae
- filamentous brown algae
- foliose brown algae
- turf

Invertebrates:
- sponges
- hydroids
- *Corynactis californica*
- tube worms
- vermetid snails
- bryozoans
- colonial tunicates

[a] These invertebrates were usually counted in quadrats; however, at some sites, they were sampled in band transects instead.

Table 1-4

Fish Length Classes

nd = no data available

Species	YOY	Juvenile	Adult
	Length Classes (cm)		
Scorpionfish	< 10	10 - 30	> 30
Kelp rockfish	< 10	10 - 20	> 20
Treefish	< 8	8 - 18	> 18
Olive rockfish	< 13	13 - 30	> 30
Gopher rockfish	< 8	8 - 18	> 18
Vermillion rockfish	< 8	8 - 18	> 18
Grass rockfish	< 8	8 - 18	> 18
Painted greenling	< 10	10 - 18	> 18
Cabezon	< 13	13 - 38	> 38
Kelp bass	< 8	8 - 30	> 30
Barred sand bass	< 8	8 - 30	> 30
Jack mackerel	nd	nd	> 25
Sargo	< 10	10 - 23	> 23
Black croaker	< 10	10 - 25	> 25
Opaleye	< 10	10 - 25	> 25
Halfmoon	< 13	13 - 20	> 20
Black surfperch	< 13	13 - 18	> 18
White surfperch	< 13	13 - 18	> 18
Pile perch	< 13	13 - 23	> 23
Rainbow surfperch	< 10	10 - 18	> 18
Rubberlip surfperch	< 15	15 - 25	> 25
Kelp surfperch	< 8	8 - 10	> 10
Garibaldi	< 5	5 - 25	> 25
Blacksmith	< 8	8 - 15	> 15
California sheephead	< 8	8 - 36	> 36
Senorita	< 8	8 - 13	> 13
Rock wrasse	< 10	10 - 15	> 15
Bluebanded goby	≤ 5	nd	nd
Blackeye goby	< 3	3 - 5	> 5
Turbot	< 10	10 - 20	> 20
Dover sole	nd	nd	> 45
California halibut	< 23	23 - 46	> 46
Giant kelpfish	< 13	13 - 25	> 25
Kelpfish spp.	< 3	3 - 15	> 15
Island kelpfish	< 3	3 - 15	> 15
Smelts	< 8	8 - 13	> 13
Zebraperch	< 10	10 - 25	> 25
Ronquil	< 5	5 - 10	> 10
Leopard shark	nd	nd	> 90
Pacific bonito	< 15	15 - 51	> 51

Table 1-5

Results of regression analysis of sample date versus density of young-of-year fish.

SPECIES	SLOPE	R^2	N	P
Kelp bass	0.000	0.0191	26	0.5008
Black surfperch	0.000	0.0036	26	0.7704
Pile surfperch	-0.000	0.0000	26	0.9830
Rainbow surfperch	-0.000	0.0391	26	0.3327
Blacksmith	-0.000	0.0013	26	0.8619
California sheephead	-0.000	0.0016	26	0.8459
Senorita	-0.000	0.0405	26	0.3244
Bluebanded goby	-0.000	0.0050	26	0.7306
Blackeye goby	0.000	0.0003	26	0.9338

Table 1-6

Characteristics of water-column fish transects on artificial and natural reefs.
nd = no data available.

Site	Distance from bottom (m)	Mean swim time (sec)	Mean visibility (m)
ARTIFICIAL REEFS			
Torrey Pines AR	nd	nd	nd
Pendleton AR	9.4	72	4.6
Newport Beach AR	19.8	71	4.6
LA Harbor Breakwater - outside	6.1	101	2.4
LA Harbor Breakwater - inside	3.7	85	2.0
King Harbor Breakwater	1.8	73	4.4
Hermosa Beach AR	16.5	100	0.9
Marina Del Rey AR	16.8	58	3.2
Pitas Point AR	4.6	122	3.3
Rincon Oil Island	5.8	97	0.8
NATURAL REEFS			
Marine Street	7.0	136	1.9
La Jolla Cove Reef	nd	nd	nd
Del Mar Reef	12.2	63	1.9
Barn Kelp	11.6	91	2.9
Las Pulgas	nd	nd	nd
Box Canyon	12.8	111	3.2
San Onofre Kelp - Main (4-1)	12.2	62	2.2
San Onofre Kelp - North (002)	11.3	80	3.0
San Mateo Kelp	12.2	101	2.0
Two Man Rock	13.4	67	1.8
Laguna Beach North	11.3	67	3.0
Pelican Point	9.8	97	2.3
Point Vicente	14.9	67	4.4
Don't Dive There	6.1	67	4.0
Flat Rock	7.0	102	3.0
Rincon Kelp	6.1	75	3.3

Table 1-7

Comparison of Characteristics of Water Column Fish Transects on Artificial and Natural Reefs.

VARIABLE	ARTIFICIAL REEFS MEAN	SE	N	NATURAL REEFS MEAN	SE	N	DF	T	P
Distance from Bottom (m)	9.38	2.2048	9	10.56	0.7706	14	10.0	-0.504	0.62[a]
Swim Time (sec)	86.48	6.6987	9	84.68	5.9649	14	21	0.196	0.85
Visibility (m)	2.91	0.4965	9	2.78	0.2149	14	11.0	0.2450	0.81[a]

[a]Variances are not equal, T statistic and d. f. are approximated (SAS User's Guide: Statistics, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were not significantly different at the P = 0.05 level.

Table 1-8

Results of regression analyses of fish density and species richness versus visibility.

Fish density is no./1,000 m^3; data were $\log_{10}(x + 1)$ transformed for analyses. Species richness and density of benthic fish were regressed against visibility near the benthos. Species richness and density of water column fish were regressed against visibility in the water column. * indicates $p \leq 0.05$.

HABITAT	LIFESTAGE	SLOPE	R^2	N	P
A. DENSITY					
Benthic	Young of Year	0.123	0.183	26	0.0295*
	Juveniles & Adults	0.044	0.120	26	0.0834
	All Life Stages Combined	0.063	0.192	26	0.0250*
Water Column	Young of Year	-0.078	0.010	20	0.65
	Juveniles & Adults	-0.413	0.183	20	0.0415*
	All Life Stages Combined	-0.353	0.126	20	0.0963
B. SPECIES RICHNESS					
Benthic	Young of Year	0.376	0.239	26	0.0113*
	Juveniles & Adults	0.688	0.223	26	0.0149*
	All Life Stages Combined	0.791	0.276	26	0.0059*
Water Column	Young of Year	-0.348	0.060	23	0.26
	Juveniles & Adults	-0.979	0.120	23	0.11
	All Life Stages Combined	-1.023	0.107	23	0.13

Table 1-9

Results of regression analyses of fish density and species richness versus surge.

Fish density is no./1,000 m^3; data were $\log_{10}(x + 1)$ transformed for analyses. Surge was measured near the benthos.

Habitat	Lifestage	Slope	R^2	N	P
A. Density					
Benthic	Young of Year	-0.007	0.030	26	0.40
	Juveniles & Adults	0.001	0.003	26	0.80
	All Life Stages Combined	-0.001	0.001	26	0.89
Water Column	Young of Year	-0.008	0.022	20	0.47
	Juveniles & Adults	0.016	0.049	20	0.28
	All Life Stages Combined	0.011	0.023	20	0.46
B. Species Richness					
Benthic	Young of Year	-0.022	0.037	26	0.34
	Juveniles & Adults	-0.030	0.019	26	0.50
	All Life Stages Combined	-0.033	0.021	26	0.48
Water Column	Young of Year	-0.003	0.001	26	0.87
	Juveniles & Adults	0.050	0.058	26	0.24
	All Life Stages Combined	0.049	0.045	26	0.30

Table 1-10

Physical Characteristics of Reefs
Sampled September - December 1986

Reef		Area (km²)	Depth[a] (m)	Height[b] (m)	Slope[c]	Substrate[d]
Artificial Reefs						
Torrey Pines AR	TPAR	0.0018	16	5	21.3°	large rock, boulders
Pendleton AR	PAR	0.0140	15	4	27.5°	medium & large rock, boulders
Newport Beach AR	NBAR	0.0250	24	3	21.3°	concrete pilings, sand
L.A. Harbor Breakwater - outside	LOAR	0.0581	11	11*	33.8°	boulders
L.A. Harbor Breakwater - inside	LIAR	0.0475	9	9*	38.1°	large rock, boulders
King Harbor Breakwater	KHAR	0.0386	9	9*	39.8°	large rock, boulders
Hermosa Beach AR	HBAR	0.0024	21	2	1.3°	concrete pilings, sand
Marina Del Rey AR	MDAR	0.0032	21	4	41.7°	large rock, boulders
Pitas Point AR	PPAR	0.0045	11	3	11.3°	medium & large rock, sand
Rincon Oil Island	RIAR	0.0281	16	16*	47.5°	large rock, boulders
Natural Reefs						
Marine Street Reef	MSR	2.2000[1]	22	13	0.3°	bedrock
La Jolla Cove Reef	LJCR	2.2000[1]	18	3	0°	large rock, boulders, sand
Del Mar Reef	DMR	2.1400	16	1	0°	bedrock
Barn Kelp	BK	0.8000	15	1	1.8°	small & med. rock, bedrock
Las Pulgas Reef	LPR	0.5300	12	5	18.8°	large rock, bedrock
Box Canyon	BC	0.1600	17	1	0°	sand, cobble, med. rock
San Onofre Kelp - Main (4-1)	SOKM	1.0400[2]	16	1	0°	small & med. rock, sand
San Onofre Kelp - North (002)	SOKN	1.0400[2]	15	1	1.3°	cobble, small & med. rock
San Mateo Kelp	SMK	1.1400[3]	16	2	0°	medium rock, sand
Two Man Rock	TMR	1.1400[3]	18	5	17.5°	med. & large rock, bedrock, sand, boulder
Laguna Beach North	LBN	0.2300	18	5	0°	sand, cobble, rocks, bedrock
Pelican Point	PP	0.3100	15	4	35.0°	small rock, bedrock
Point Vicente	PV	5.5100[4]	24	13	33.8°	boulders, bedrock
Don't Dive There	DDT	5.5100[4]	15	8	39.6°	boulders, bedrock
Flat Rock	FR	5.5100[4]	16	5	18.8°	medium & large rock, bedrock, boulders
Rincon Kelp	RK	0.0680	11	2	10.9°	medium & large rock, sand

a Depth to the base of the reef.
b Height from the base of the reef to the reef crest.
c Average slope of the substrate under the transect lines.
d Sizes of substrate types are given in Table 1-2
1 Both reefs are part of the La Jolla reef complex.
2 Both reefs are part of the San Onofre Kelp Bed
3 Both reefs are part of the San Mateo Kelp Bed
4 All three reefs are part of the Palos Verdes Peninsula reef complex
* These sites are breakwaters or man-made islands and therefore reach the water surface

Table 1-11

Results of t-tests comparing physical characteristics of artificial and natural reefs.

Mean reef area is shown as km^2; for analysis, reef area was measured in m^2 and data were transformed using the $\log_{10}(x + 1)$ transformation. * indicates $p \leq 0.05$

	VARIABLE	ARTIFICIAL REEFS Mean	SE	N	NATURAL REEFS Mean	SE	N	df	T	P
Breakwaters Included	Reef Area	0.0223	0.00649	10	1.8455	0.48609	16	24	-8.349	0.0001*
	Depth (m)	15.3	1.69	10	16.5	0.80	16	24	-0.718	0.48
	Height (m)	6.6	1.42	10	4.4	0.99	16	24	1.326	0.20
	Slope	28.3°	4.63	10	11.1°	3.59	16	24	2.955	0.0069*
Breakwaters Excluded	Reef Area	0.0085	0.00378	6	1.8455	0.48609	16	20	-8.833	0.0001*
	Depth (m)	18.0	1.97	6	16.5	0.80	16	20	0.853	0.40
	Height (m)	3.5	0.43	6	4.4	0.99	16	19.1[a]	-0.813	0.43
	Slope	20.7°	5.64	6	11.1°	3.59	16	20	1.409	0.17

a Variances are not equal, T-statistic and d.f. are approximations (SAS User's Guide: Statistics, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and was not significantly different at the $p = 0.05$ level.

Table 1-12

Substrate characteristics on artificial and natural reefs.

Shown are (a) the percentages of different substrate types sampled on each reef, (b) richness, Shannon-Wiener and Simpson's indices describing the diversity of substrate types and c) mean particle size and the standard deviation of particle size. Note that particle size is an inverse scale; the smallest number indicates the largest particle size. Substrate types are shown as percentages. "--" indicates that particle size was not calculated for concrete reefs.

	Substrate Type								Substrate Type Diversity Indices			Particle Size	
ARTIFICIAL REEFS	SAND	COBBLE	SMALL ROCK	MEDIUM ROCK	LARGE ROCK	BOULDER	BEDROCK	CONCRETE	RICH-NESS	SHANNON-WIENER	SIMPSON	MEAN PARTICLE SIZE	STD. DEV. PARTICLE SIZE
Torrey Pines AR	11	0	0	5	61	23	0	0	4	0.4497	2.269	-4.66	-2.31682
Pendleton AR	13	0	1	24	29	33	0	0	5	0.599	3.747	-4.28	-2.65924
Newport Beach	38	0	0	2	1	0	0	60	4	0.343	2.004	--	--
LA Harbor BW outside	0	0	0	0	8	92	0	0	2	0.121	1.173	-6.10	-0.32727
LA Harbor BW inside	0	0	0	9	29	63	0	0	3	0.377	2.082	-5.40	-0.98129
King Harbor BW	0	1	1	18	34	46	0	0	5	0.496	2.807	-4.93	-1.25765
Hermosa Beach AR	62	2	0	4	0	1	0	31	5	0.397	2.085	--	--
Marina Del Rey	4	6	0	5	56	30	0	0	5	0.485	2.447	-4.78	-2.08333
Pitas Point AR	22	0	4	19	45	10	0	0	5	0.597	3.379	-1.38	-4.29402
Rincon Oil Island	2	5	1	9	12	71	0	0	6	0.424	1.869	-5.16	-2.01333
NATURAL REEFS													
Marine Street Reef	2	0	2	0	0	0	96	0	3	0.078	1.075	-7.56	-0.18394
La Jolla Cove Reef	21	4	6	5	38	16	11	0	7	0.727	4.383	-2.03	-4.86470
Del Mar Reef	4	0	1	3	1	0	92	0	5	0.164	1.179	-7.50	-0.93485
Barn Kelp	4	4	11	27	7	2	46	0	7	0.628	3.260	-4.58	-3.14985
Las Pulgas	5	1	3	8	25	5	52	0	8	0.601	2.909	-6.03	-2.87621
Box Canyon	38	31	11	21	0	0	0	0	4	0.563	3.425	-1.98	-3.34689
San Onofre Kelp 4-1	15	0	14	71	0	0	0	0	3	0.352	1.849	-1.48	-2.16439
San Onofre Kelp N002	3	21	25	46	5	0	0	0	5	0.557	3.088	-1.18	-2.28485
San Mateo Kelp	23	1	6	46	13	0	11	0	6	0.612	3.327	-0.89	-4.41189
Two Man Rock	11	7	4	23	12	22	21	0	7	0.782	5.536	-3.27	-4.21591
Laguna Beach North	15	27	15	5	4	1	33	0	7	0.699	4.326	-1.31	-4.89750
Pelican Point	1	4	11	4	2	0	79	0	6	0.348	1.581	-1.58	-2.64818
Point Vicente	7	0	0	1	12	21	60	0	5	0.483	2.388	-6.63	-2.51136
Don't Dive There	0	0	0	7	6	14	72	0	4	0.380	1.810	-7.07	-1.01917
Flat Rock	10	4	0	19	21	12	35	0	6	0.705	4.470	-5.06	-3.17235
Rincon Kelp	20	2	2	32	44	1	0	0	6	0.535	2.994	-0.93	-3.90598

Table 1-13

Results of t-tests comparing substrate characteristics on artificial and natural reefs.

Means for substrate types are percentages; data were converted to proportions and transformed (arcsine-$\sqrt{p_i}$) for analyses. Concrete reefs were excluded from the analyses. Part size = particle size. * indicates $p \leq 0.05$

	VARIABLE	ARTIFICIAL REEFS MEAN	SE	N	NATURAL REEFS MEAN	SE	N	DF	T	P
SUBSTRATE TYPE	Sand	6.5	2.91	8	11.1	2.57	16	22	-1.43	0.17
	Cobble	1.6	0.91	8	6.6	2.54	16	22	-1.519	0.14
	Small Rock	0.9	0.54	8	6.9	1.77	16	22	-2.630	0.0153*
	Medium Rock	11.1	2.92	8	19.9	5.09	16	22	-0.964	0.34
	Large Rock	34.1	6.78	8	11.7	3.38	16	22	3.326	0.0031*
	Boulder	45.8	9.75	8	5.9	2.04	16	22	5.637	0.0001*
	Bedrock	0	0	8	38.0	8.53	16	22	-3.616	0.0016*
SUBSTRATE TYPE DIVERSITY	Richness	4.4	0.460	8	5.5	0.35	16	22	-1.8832	0.0730
	Shannon-Wiener	0.444	0.0536	8	0.513	0.0504	16	22	-0.850	0.40
	Simpson	2.472	0.2929	8	2.971	0.3210	16	22	-0.995	0.33
PART SIZE	Mean	-4.587	0.4963	8	-3.708	0.7346	16	22	-0.795	0.44
	Std. Dev	-1.992	0.4266	8	-2.912	0.3484	16	22	1.590	0.13

Table 1-14

Abundance of algal groups on artificial and natural reefs.

Abundance of large brown algal groups is shown as number of plants/100 m^2 (1 S.E.). All other algal groups are shown as percent cover (1S.E.). Encrusting reds and browns includes encrusting corallines. Juvenile laminariales includes <u>Macrocystis</u> and other unidentified juvenile laminariales. Understory kelp includes <u>Laminaria</u> <u>farlowii</u>, <u>Eisenia</u> <u>arborea</u>, <u>Egregia</u> <u>menziesii</u>, <u>Pterygophora</u> <u>californica</u> and <u>Cystoseira</u> <u>osmundacea</u>. N = 10 for mean percent cover of various algal groups and N = 8 for mean density of laminariales, understory kelp and <u>Macrocystis</u>.

	Algal Group							
	Percent Cover					No. of Plants/100m^2		
Reefs	Encrusting Reds & Browns	Filamentous Reds	Turf	Foliose Reds & Browns	Erect Corallines	Juvenile Laminariales	Understory Kelp	Macrocystis pyrifera
Artificial Reefs								
Torrey Pines AR	1 (1.0)	0	7 (3.3)	24 (8.2)	12 (5.1)	0	2.5 (1.64)	0
Pendleton AR	0	0	7 (5.0)	17 (7.5)	0	0	0	0
Newport Beach AR	0	0	1 (1.0)	0	0	0	0	0
LA Harbor Breakwater - outside	41 (7.1)	0	0	36 (13.2)	6 (3.4)	13.8 (6.25)	22.5 (11.30)	122.5 (31.04)
LA Harbor Breakwater - inside	0	7 (7.0)	0	4 (2.2)	0	0	0	76.3 (22.03)
King Harbor Breakwater	55 (11.4)	0	0	20 (7.0)	59 (8.4)	0	0	0
Hermosa Beach AR	0	1 (1.0)	0	10 (3.0)	0	0	0	0
Marina Del Rey AR	1 (1.0)	4 (4.0)	0	0	4.0 (2.2)	0	0	0
Pitas Point AR	1.0 (1.0)	0	1.0 (1.0)	42.0 (8.7)	1.0 (1.0)	28.8 (20.65)	1.3 (1.25)	17.5 (8.18)
Rincon Oil Island	20 (5.8)	3 (1.5)	0	11 (5.5)	2 (1.3)	0	83.8 (28.28)	21.3 (11.09)
Natural Reefs								
Marine Street Reef	35 (7.9)	0	0	49 (12.4)	54 (7.6)	15.0 (10.00)	76.3 (18.70)	80.0 (24.20)
La Jolla Cove Reef	25 (8.3)	0	7 (4.0)	60 (11.5)	14 (5.2)	0	150 (58.16)	35.0 (13.23)
Del Mar Reef	1 (1.0)	0	8 (3.9)	5 (2.7)	0	0	1.3 (1.25)	36.3 (9.62)
Barn Kelp	5 (1.7)	0	4 (3.1)	39 (8.9)	5 (2.2)	0	43.8 (12.38)	0
Las Pulgas Reef	4 (2.2)	4 (3.1)	0	22 (7.6)	6 (3.4)	3.8 (2.63)	5.0 (5.00)	0
Box Canyon	39 (6.6)	0	0	40 (13.9)	2 (1.3)	0	297.5 (82.89)	0
San Onofre Kelp - Main 4-1	43 (8.0)	2 (1.3)	0	10 (3.3)	0	0	17.5 (17.50)	7.5 (2.50)
San Onofre Kelp - North 002	38 (5.5)	0	2 (1.3)	44 (10.0)	0	127.5 (86.99)	402.5 (54.76)	20.0 (5.00)
San Mateo Kelp	31 (9.4)	0	12 (4.4)	36 (10.0)	1 (1.0)	138.8 (67.39)	7.5 (4.91)	62.5 (26.58)
Two Man Rock	24 (4.3)	0	0	60 (10.2)	1 (1.0)	316.2 (248.81)	11.3 (7.43)	78.8 (17.47)
Laguna Beach North	37 (9.8)	0	7 (3.7)	26 (7.8)	9 (5.9)	0	243.8 (116.42)	20.0 (4.23)
Pelican Point	24 (7.8)	0	1 (1.0)	54 (8.3)	13 (5.8)	0	40.0 (14.76)	0
Point Vicente	44 (9.5)	0	7 (3.3)	11 (4.8)	2 (1.3)	0	0	0
Don't Dive There	44 (11.8)	0	1 (1.0)	54 (12.1)	6 (2.7)	0	25.0 (19.46)	181.3 (36.42)
Flat Rock	43 (5.8)	0	5 (3.1)	19 (12.9)	8 (3.3)	0	1660.0 (453.43)	287.5 (26.71)
Rincon Kelp	17 (5.0)	0	0	8 (3.6)	0	20.0 (14.27)	0	5 (1.89)

Table 1-15

Results of t-tests comparing either percent cover or density (no./100m^2) of algal types on artificial and natural reefs.

Percent cover data were converted to proportions and transformed (arcsine $\sqrt{p_i}$) for analysis. Density data were transformed [$\log_{10}(x + 1)$] for analysis. * indicates $p \leq 0.05$.

VARIABLE	ARTIFICIAL REEFS MEAN	SE	N	NATURAL REEFS MEAN	SE	N	DF	T	P
Encrusting Red & Brown Algae	11.9	6.41	10	28.4	3.72	16	24	-3.045	0.0056*
Turf	1.6	0.51	10	3.4	0.96	16	24	-1.316	0.20
Bushy Red & Brown Algae	16.4	4.56	10	33.6	4.83	16	24	-2.555	0.0174*
Erect Coralline Algae	7.4	5.77	10	7.6	3.30	16	24	-0.199	0.84
Total Percent Cover Algae	36.4	10.43	10	70.2	6.71	16	24	-2.610	0.0153*
Understory Kelp Species	11.0	8.38	10	186.3	102.94	16	24	-3.092	0.0050*
Macrocystis	23.8	13.31	10	50.9	19.80	16	24	-1.275	0.21
Total Density Large Brown Algae	34.8	17.04	10	237.2	118.13	16	24	-2.961	0.0068*

Table 1-16

Characteristics of the algal assemblage on artificial and natural reefs.

Samples were taken at regular intervals along transects. "nc" indicates that algae were not present and therefore, diversity of algal height was not calculated. For mean % cover algae, % cover on each transect was determined and then the mean was calculated (N = 8). For mean algal height, mean algal height on each transect was calculated and then averaged to determine the mean algal height on the reef (N = 8).

	Mean (1S.E.) % Cover Algae	Mean (1S.E.) Algal Height (cm)	Shannon Diversity of Algal Height	Simpson Diversity of Algal Height
ARTIFICIAL REEFS				
Torrey Pines AR	25.0 (8.43)	1.8 (0.75)	0.387	1.716
Pendleton AR	6.3 (2.50)	0.2 (0.10)	0.118	1.135
Newport Beach AR	0	0	nc	nc
LA Harbor Breakwater outside	39.3 (4.48)	8.6 (1.59)	0.634	2.540
LA Harbor Breakwater inside	4.5 (2.68)	0.3 (0.17)	0.099	1.095
King Harbor Breakwater	64.3 (11.21)	4.1 (0.73)	0.584	3.256
Hermosa Beach AR	0	0	nc	nc
Marina Del Rey AR	0	0	nc	nc
Pitas Point AR	24.1 (7.01)	3.2 (1.01)	0.401	1.695
Rincon Oil Island	21.4 (7.14)	3.3 (1.01)	0.393	1.598
NATURAL REEFS				
Marine Street Reef	65.2 (3.68)	9.8 (1.13)	0.779	4.691
La Jolla Cove Reef	28.6 (5.40)	3.2 (1.19)	0.461	1.890
Del Mar Reef	4.5 (2.68)	0.5 (0.29)	0.100	1.095
Barn Kelp	41.1 (5.01)	4.3 (0.72)	0.597	2.570
Las Pulgas Reef	38.4 (7.01)	4.6 (0.99)	0.534	2.366
Box Canyon	60.7 (6.88)	15.6 (3.21)	0.890	5.006
San Onofre Kelp Main (4-1)	8.9 (3.51)	0.4 (0.15)	0.156	1.200
San Onofre Kelp North (002)	45.5 (7.86)	10.9 (2.94)	0.759	3.116
San Mateo Kelp	18.8 (5.22)	2.0 (0.63)	0.341	1.496
Two Man Rock	39.3 (6.88)	5.9 (0.93)	0.586	2.496
Laguna Beach North	14.3 (5.23)	3.8 (1.82)	0.305	1.356
Pelican Point	52.7 (3.80)	7.6 (1.33)	0.734	3.619
Point Vicente	8.9 (3.99)	0.6 (0.27)	0.176	1.201
Don't Dive There	47.3 (9.91)	7.4 (2.24)	0.719	3.225
Flat Rock	25.0 (3.57)	5.6 (1.45)	0.455	1.747
Rincon Kelp	45.5 (7.86)	10.9 (2.94)	0.759	3.116

TABLE 1-17

Results of t-tests comparing characteristics of the algal assemblage on artifical and natural reefs.

Percent cover data were converted to proportions and transformed (arcsine $\sqrt{p_i}$) for analysis. Algal height data were transformed [$\log_{10}(x + 0.1)$] for analysis. * indicates $p \leq 0.05$.

VARIABLE	ARTIFICIAL REEFS MEAN	ARTIFICIAL REEFS SE	ARTIFICIAL REEFS N	NATURAL REEFS MEAN	NATURAL REEFS SE	NATURAL REEFS N	DF	T	P
Percent cover Algae	18.4	6.65	10	32.1	4.83	16	24	-2.112	0.0453*
Algal Height (cm)	2.1	0.88	10	5.2	1.06	16	24	-2.686	0.0129*
Shannon diversity Algal Height	0.374	0.0778	7[a]	0.490	0.0622	16	21	-1.084	0.29
Simpson Diversity Algal Height	1.862	0.2944	7[a]	2.403	0.3095	16	21	-1.059	0.30

[a]The three sites with algal height = 0 were excluded from the analysis.

Table 1-18

Characteristics of Macrocystis pyrifera on artificial and natural reefs

Reefs	Number of stipes/plant: Mean (1S.E.)	N	Mean (1S.E.) no. of stipes/10m^2 (N = 8)
ARTIFICIAL REEFS			
Torrey Pines AR	0	0	0
Pendleton AR	0	0	0
Newport Beach AR	0	0	0
LA Harbor Breakwater outside	9.7 (1.51)	98	118.9 (35.20)
LA Harbor Breakwater inside	7.4 (0.64)	61	56.1 (16.50)
King Harbor Breakwater	0	0	0
Hermosa Beach AR	0	0	0
Marina Del Rey AR	0	0	0
Pitas Point AR	2.3 (0.21)	15	4.4 (2.22)
Rincon Oil Island	6.5 (1.43)	16	13.0 (7.33)
NATURAL REEFS			
Marine Street Reef	6.8 (0.58)	64	54.8 (16.04)
La Jolla Cove Reef	3.0 (0.41)	28	10.5 (4.22)
Del Mar Reef	21.0 (2.22)	29	76.0 (21.32)
Barn Kelp	0	0	0
Las Pulgas Reef	0	0	0
Box Canyon	0	0	0
San Onofre Kelp Main (4-1)	47.3 (5.93)	6	35.5 (11.99)
San Onofre Kelp North (002)	40.5 (6.31)	16	81.0 (21.38)
San Mateo Kelp	9.9 (2.25)	51	62.9 (17.90)
Two Man Rock	2.2 (0.17)	63	17.5 (4.00)
Laguna Beach North	28.4 (4.56)	16	56.9 (16.05)
Pelican Point	0	0	0
Point Vicente	0	0	0
Don't Dive There	6.9 (0.47)	145	125.5 (23.78)
Flat Rock	5.3 (0.18)	230	153.1 (16.31)
Rincon Kelp	53.3 (34.56)	4	26.6 (18.90)

Table 1-19

Results of t-tests comparing characteristics of Macrocystis pyrifera on artificial and natural reefs.

Data were transformed [$\log_{10}(x+1)$] for analyses.

VARIABLE		ARTIFICIAL REEFS			NATURAL REEFS					
		MEAN	SE	N	MEAN	SE	N	DF	T	P
Includes sites with no Macrocystis present	Mean Number of Stipes/ plant	2.6	1.20	10	14.0	4.58	16	24	-1.907	0.0685
	Mean Number of Stipes/ 10 m^2	19.2	12.37	10	43.8	11.81	16	24	-1.760	0.0911
Includes only sites with Macrocystis present	Mean Number of Stipes/ plant	6.5	1.54	4	20.4	5.73	11	13	-1.307	0.21
	Mean Number of Stipes/ 10 m^2	48.1	26.17	4	63.7	13.32	11	13	-1.126	0.28

Table 1-20

Mean percent cover (1SE) of sessile invertebrates on artificial and natural reefs.

Total percent cover includes all species sampled with point contact method. nc = standard error was not calculated. N = 10 for all groups on all reefs.

	TOTAL PERCENT COVER	ENCRUSTING SPONGES	HYDROIDS	BRYOZOANS	COLONIAL TUNICATES
ARTIFICIAL REEFS					
Torrey Pines AR	60 nc	15 (5.2)	0	26 (8.1)	9 (1.8)
Pendleton AR	84 nc	5 (1.7)	4 (3.1)	64 (6.4)	1 (1.0)
Newport Beach	12 nc	11 (4.1)	0	1 (1.0)	0
LA Harbor BW - outside	78 nc	4 (2.2)	2 (1.3)	33 (10.2)	3 (3.0)
LA Harbor BW - inside	75	1 (1.0)	3 (1.5)	62 (8.4)	2 (2.0)
King Harbor BW	16 nc	0	1 (1.0)	2 (2.0)	1 (1.0)
Hermosa Beach AR	73 nc	6 (3.1)	13 (8.8)	32 (8.3)	0
Marina Del Rey	26 nc	0	17 (6.7)	9 (4.6)	0
Pitas Point AR	83 nc	10 (3.0)	5 (2.2)	58 (8.4)	9 (3.1)
Rincon Oil Island	50 nc	2 (1.3)	4 (2.2)	28 (7.0)	3 (2.1)
NATURAL REEFS					
Marine Street Reef	19 nc	3 (1.5)	0	7 (3.4)	9 (3.1)
La Jolla Cove Reef	22 nc	2 (1.3)	0	19 (5.5)	1 (1.0)
Del Mar Reef	48 nc	12 (4.9)	1 (1.0)	6 (2.2)	28 (6.5)
Barn Kelp	35 nc	10 (2.6)	3 (2.1)	18 (5.1)	4 (2.2)
Las Pulgas	51 nc	4 (2.2)	3 (1.5)	35 (5.0)	9 (4.8)
Box Canyon	7 nc	0	4 (1.6)	2 (1.3)	0
San Onofre Kelp 4-1	20 nc	0	1 (1.0)	12 (6.3)	0
San Onofre Kelp N002	22 nc	1 (1.0)	10 (5.4)	11 (3.5)	0
San Mateo Kelp	29 nc	7 (4.0)	1 (1.0)	5 (2.2)	7 (2.6)
Two Man Rock	50 nc	9 (3.1)	5 (2.2)	34 (3.7)	1 (1.0)
Laguna Beach North	48 nc	8 (3.6)	6 (4.0)	25 (8.2)	3 (1.5)
Pelican Point	69 nc	9 (2.3)	2 (1.3)	49 (18.0)	8 (2.0)
Point Vicente	27 nc	7 (2.6)	0	12 (3.9)	3 (2.1)
Don't Dive There	74 nc	13 (6.0)	2 (1.3)	36 (8.5)	1 (1.0)
Flat Rock	13 nc	3 (2.1)	1 (1.0)	3 (1.5)	2 (1.3)
Rincon Kelp	51 nc	5 (2.2)	4 (1.6)	24 (4.3)	5 (2.7)

TABLE 1-21

Results of T-tests comparing percent cover of invertebrates on artificial and natural reefs.

Means are percent cover; data were converted to proportions and transformed (arcsine $\sqrt{p_i}$) for analysis.

VARIABLE	ARTIFICIAL REEFS MEAN	SE	N	NATURAL REEFS MEAN	SE	N	DF	T	P
Total Percent Cover of Invertebrates	55.7	8.90	10	36.6	4.96	16	24	2.000	0.0569
Encrusting Sponges	4.9	1.62	10	5.8	1.04	16	24	-.0421	0.68
Hydroids	4.9	1.79	10	2.7	0.67	16	24	0.989	0.33
Bryozoans	31.5	7.48	10	18.6	3.50	16	24	1.436	0.16
Colonial Tunicates	2.8	1.09	10	5.1	1.73	16	24	-0.995	0.33

Table 1-22

Mean (1SE) density (no./m^2) of invertebrates on artificial and natural reefs.

"nc" indicates standard errors were not calculated because means are the sum of means for species counted in quadrats and species counted in band transects. "Q" indicates invertebrates counted in quadrats, "B" indicates those counted in band transects and "BQ" indicates those counted in band transects on some reefs and in quadrats on other reefs. N = 10 for invertebrates counted in quadrats; N = 8 for those counted in band transects. Snails do not include limpets or abalone.

	TOTAL DENSITY	TETHYA[B]	ANEMONES[BQ]	CUP CORALS[Q]	GORGONIANS[BQ]	MURICEA FRUTICOSA[BQ]	MURICEA CALIFORNICA[BQ]	LOPHOGORGIA[BQ]
					ARTIFICAL REEFS			
Torrey Pines AR	40.9	0	0.30	20.10	14.01	13.20	0.80	0.01
	nc		(0.21)	(6.28)	nc	(3.03)	(0.80)	(0.01)
Pendleton AR	49.16	0	0.20	0	42.60	37.10	5.40	0.10
	nc		(0.20)		nc	(4.88)	(5.40)	(0.10)
Newport Beach	0.59	0	0.01	0	0.13	0.01	0.01	0.10
	nc		(0.01)		nc	(0.01)	(0.01)	(0.10)
LA Harbor BW outside	44.08	0	0.50	16.90	4.41	4.20	0.20	0.01
	nc		(0.50)	(7.84)	nc	(2.64)	(0.20)	(0.01)
LA Harbor BW inside	21.11	0	0	10.00	6.10	5.70	0.20	0.20
	nc			(8.72)	nc	(1.07)	(0.20)	(0.13)
King Harbor BW	53.36	0	0.05	14.60	0.74	0.30	0.40	0.04
	nc		(0.03)	(11.19)	nc	(0.15)	(0.40)	(0.04)
Hermosa Beach AR	13.24	0	0	0.10	7.60	6.30	0	1.30
	nc			(0.10)	nc	(1.90)		(0.50)
Marina Del Rey	16.38	0	0	0	0	0	0	0
	nc							
Pitas Point AR	68.20	0	0	0	0.20	0.20	0	0
	nc				nc	(0.2)		
Rincon Oil Island	26.51	0	0.08	0.20	20.40	18.90	0.20	1.30
	nc		(0.06)	(0.13)	nc	(8.28)	(0.20)	(0.65)
					NATURAL REEFS			
Marine Street Reef	4.58	0	0.10	1.00	0.10	0.10	0	0
	nc		(0.10)	(0.68)	nc	(0.10)		
La Jolla Cove Reef	4.15	0	0	0	2.60	2.40	0.20	0
	nc				nc	(1.28)	(0.20)	
Del Mar Reef	2.63	0.01	0.50	0.20	0.50	0.20	0.30	0
	nc	(0.01)	(0.22)	(0.20)	nc	(0.20)	(0.30)	
Barn Kelp	23.61	0	0.20	3.40	10.80	9.40	1.40	0
	nc		(0.13)	(2.63)	nc	(2.97)	(1.40)	
Las Pulgas	22.40	0	0.50	0	17.00	11.50	5.50	0
	nc		(0.40)		nc	(1.19)	(5.50)	
Box Canyon	9.86	0.01	0	3.00	0.60	0.60	0	0
	nc	(0.01)		(3.00)	nc	(0.27)		
San Onofre Kelp 4-1	28.14	0	0	0.30	9.51	7.80	1.70	0.01
	nc			(0.15)	nc	(1.51)	(1.70)	(0.01)
San Onofre Kelp N002	27.06	0	0.60	4.50	5.03	4.40	0.60	0.03
	nc		(0.27)	(4.50)	nc	(1.61)	(0.60)	(0.03)
San Mateo Kelp	32.29	0	0.20	23.80	3.20	2.80	0.40	0
	nc		(0.20)	(10.65)	nc	(0.79)	(0.40)	
Two Man Rock	21.85	0	0.10	7.10	3.60	3.30	3.30	0
	nc		(0.10)	(4.95)	nc	(0.87)	(0.30)	
Laguna Beach North	11.93	0	0.10	2.90	4.20	4.00	0.20	0
	nc		(0.10)	(2.36)	nc	(1.69)	(0.20)	
Pelican Point	29.99	0	1.14	18.60	5.51	4.80	0.70	0.01
	nc		(1.14)	(12.22)	nc	(1.60)	(0.70)	(0.01)
Point Vicente	37.64	0.04	0.20	14.40	0.14	0.10	0	0.04
	nc	(0.04)	(0.13)	(12.42)	nc	(0.10)		(0.03)
Don't Dive There	69.99	0	3.00	1.50	0	0	0	0
	nc		(1.26)	(1.50)				
Flat Rock	32.03	0	12.10	0	0.05	0.05	0	0
	nc		(11.99)		nc	(0.02)		
Rincon Kelp	34.20	0	0.40	3.40	1.81	1.50	0.01	0.30
	nc		(0.22)	(3.40)	nc	(1.00)	(0.01)	(0.30)

Table 1-22

	HERMIT CRABS[Q]	MEGA-THURA[B]	SNAILS[Q]	KEL-LETIA[Q]	BI-VALVES[Q]	HIN-NITES[Q]	SOLI-TARY TUNICATES[Q]	STYELA MONTEREY-ENSIS[Q]
ARTIFICIAL REEFS								
Torrey Pines AR	0.10 (0.10)	0.71 (0.08)	0.40 (0.16)	0	0	0	0	0
Pendleton AR	0	0	0.10 (0.10)	0.10 (0.10)	1.90 (0.84)	0.70 (0.26)	0.30 (0.15)	0.20 (0.13)
Newport Beach	0	0	0	0	0	0	0	0
LA Harbor BW outside	6.50 (2.13)	0.09 (0.04)	1.20 (0.57)	0.50 (0.34)	0.40 (0.31)	0.10 (0.10)	0.20 (0.13)	0.10 (0.10)
LA Harbor BW inside	0	0.06 (0.03)	3.20 (0.87)	0	0.20 (0.13)	0.20 (0.13)	0.10 (0.10)	0.10 (0.10)
King Harbor BW	2.20 (0.80)	0	34.40 (4.37)	0.10 (0.10)	0.40 (0.31)	0.30 (0.21)	0.10 (0.10)	0
Hermosa Beach AR	2.70 (1.10)	0	1.00 (0.33)	0	0.20 (0.20)	0	0	0
Marina Del Rey	0	0	0	0	0.80 (0.47)	0.40 (0.31)	0	0
Pitas Point AR	0	0	0	0	0.40 (0.31)	0	33.20 (12.93)	33.10 (12.95)
Rincon Oil Island	0.30 (0.15)	0.03 (0.02)	0	0	1.10 (0.55)	0.20 (0.13)	1.30 (0.40)	0.90 (0.38)
NATURAL REEFS								
Marine Street Reef	0	0.05 (0.03)	1.10 (0.31)	0.20 (0.13)	0	0	0	0
La Jolla Cove Reef	0.30 (0.21)	0.03 (0.02)	0.20 (0.20)	0.10 (0.10)	0	0	0	0
Del Mar Reef	0	0.03 (0.02)	0.80 (0.47)	0.30 (0.21)	0	0	0	0
Barn Kelp	1.40 (0.64)	0	1.20 (0.36)	0.50 (0.22)	0	0	0.30 (0.21)	0.30 (0.21)
Las Pulgas	0.10 (0.10)	0.44 (0.18)	0.50 (0.31)	0	0	0	0	0
Box Canyon	0	0	0.30 (0.21)	0.10 (0.10)	0	0	0.80 (0.33)	0.80 (0.33)
San Onofre Kelp 4-1	3.70 (1.86)	0	2.30 (0.60)	0.80 (0.39)	0	0	0.10 (0.10)	0
San Onofre Kelp N002	0.20 (0.20)	0	1.70 (0.50)	1.70 (0.50)	0	0	1.70 (0.45)	1.70 (0.45)
San Mateo Kelp	0.70 (0.50)	0	0.80 (0.39)	0.50 (0.27)	0.10 (0.10)	0.10 (0.10)	0.30 (0.21)	0.30 (0.21)
Two Man Rock	1.80 (0.68)	0.04 (0.03)	2.20 (0.66)	2.00 (0.58)	0	0	0.30 (0.21)	0.30 (0.21)
Laguna Beach North	0.50 (0.31)	0	1.70 (0.52)	0.20 (0.20)	0.20 (0.20)	0.10 (0.10)	0	0
Pelican Point	0.30 (0.21)	0	1.80 (0.53)	0.80 (0.29)	0.10 (0.10)	0.10 (0.10)	0.10 (0.10)	0
Point Vicente	0.70 (0.33)	0.23 (0.06)	3.60 (0.62)	2.20 (0.33)	0	0	0	0
Don't Dive There	0.10 (0.10)	0.16 (0.05)	4.40 (0.98)	2.90 (0.80)	13.10 (10.35)	0.40 (0.22)	0.10 (0.10)	0
Flat Rock	0.80 (0.33)	0	10.50 (3.36)	0.80 (0.29)	0	0	0.10 (0.10)	0
Rincon Kelp	0.60 (0.50)	0.19 (0.07)	1.30 (1.19)	0	0.20 (0.20)	0.20 (0.20)	7.10 (2.35)	3.70 (1.04)

Table 1-22
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	S. FRANS[BQ]	S. PURP[BQ]	LYTECH[Q]	BRIT-STAR[Q]	SEA-STAR[Q]	PIS-ASTER[B]	P. GIG[B]	PATIRIA[B]
				ARTIFICIAL REEF				
Torrey Pines AR	1.30 (0.37)	0	0	0	1.18 (0.32)	1.18 (0.32)	0.98 (0.27)	0
Pendleton AR	0	0	0	0	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0
Newport Beach	0	0	0	0	0.08 (0.03)	0.08 (0.03)	0	0
LA Harbor BW outside	0.20 (0.20)	6.10 (3.31)	0	0	0.16 (0.04)	0.15 (0.03)	0.13 (0.03)	0.01 (0.01)
LA Harbor BW inside	0.20 (0.20)	0.30 (0.30)	0	0	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0
King Harbor BW	0.20 (0.13)	0.01 (0.01)	0	0.20 (0.20)	0	0	0	0
Hermosa Beach AR	0.04 (0.04)	0.05 (0.03)	0	1.20 (1.20)	0.05 (0.03)	0.05 (0.03)	0.05 (0.03)	0
Marina Del Rey	0	0	0	0	0	0	0	0
Pitas Point AR	0	0.20 (0.13)	0	0	0.03 (0.03)	0.03 (0.03)	0.01 (0.01)	0
Rincon Oil Island	0.50 (0.31)	0.20 (0.13)	0	0.10 (0.10)	0.34 (0.09)	0.34 (0.09)	0.33 (0.09)	0
				NATURAL REEFS				
Marine Street Reef	1.00 (0.56)	0.60 (0.40)	0	0.10 (0.10)	0.05 (0.03)	0.05 (0.03)	0.05 (0.03)	0
La Jolla Cove Reef	0.50 (0.34)	0.10 (0.10)	0	0	0	0	0	0
Del Mar Reef	0.10 (0.10)	0.01 (0.01)	0	0	0.04 (0.02)	0.03 (0.02)	0.03 (0.02)	0
Barn Kelp	0.50 (0.40)	0	0.30 (0.30)	2.50 (2.07)	0.03 (0.02)	0	0	0.03 (0.02)
Las Pulgas	2.50 (0.65)	0.80 (0.29)	0	0.10 (0.10)	0.09 (0.07)	0.06 (0.06)	0.06 (0.06)	0
Box Canyon	0	0	2.80 (2.80)	0	0.03 (0.02)	0	0	0.03 (0.02)
San Onofre Kelp 4-1	0.43 (0.22)	0.10 (0.10)	4.40 (1.67)	0	0.11 (0.05)	0.01 (0.01)	0.01 (0.01)	0.10 (0.04)
San Onofre Kelp N002	0.20 (0.13)	0.10 (0.10)	7.60 (7.49)	0	0.10 (0.03)	0	0	0.10 (0.03)
San Mateo Kelp	0.20 (0.13)	0	1.00 (0.73)	0	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0
Two Man Rock	0.20 (0.20)	0	0	0.20 (0.13)	0.13 (0.06)	0.13 (0.06)	0.13 (0.06)	0
Laguna Beach North	0.10 (0.10)	0.10 (0.10)	0.10 (0.10)	0	0.03 (0.02)	0	0	0
Pelican Point	0.50 (0.50)	0.20 (0.13)	0	0	0.26 (0.17)	0.24 (0.17)	0.24 (0.17)	0
Point Vicente	3.10 (0.66)	9.90 (4.77)	2.30 (0.72)	0	0.36 (0.04)	0	0	0.04 (0.02)
Don't Dive There	4.20 (2.52)	24.00 (9.44)	0	0	0.34 (0.10)	0.34 (0.10)	0.34 (0.10)	0
Flat Rock	2.10 (1.49)	3.00 (1.44)	0	0	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0
Rincon Kelp	4.60 (2.79)	9.30 (3.39)	0	0	0.44 (0.09)	0.43 (0.09)	0.43 (0.09)	0.01 (0.01)

Key to invertebrates:

S. FRANS	*Strongylocentrotus franciscanus*
S. PURP	*Strongylocentrotus purpuratus*
LYTECH	*Lytechinus anamesus*
BRITSTAR	brittle stars
SEASTAR	all seastars combined
PISASTER	*Pisaster* spp.
P. GIG	*Pisater giganteus*

Table 1-23

Results of T-tests comparing density of invertebrates on artificial and natural reefs.

Means are no. of individuals/m^2; data were converted to no./100m^2 and transformed [($\log_{10}(x + 1)$] for analysis. * indicates $p \leq 0.05$.

VARIABLE	ARTIFICIAL REEFS MEAN	ARTIFICIAL REEFS SE	ARTIFICIAL REEFS N	NATURAL REEFS MEAN	NATURAL REEFS SE	NATURAL REEFS N	DF	T	P
Total Density of Invertebrates	33.3	6.66	10	24.5	4.16	16	24	0.339	0.69
Anemones	0.1	0.05	10	1.2	0.75	16	24	-2.142	0.0425*
Cup Corals	6.2	2.62	10	5.3	1.82	16	24	-0.984	0.34
Gorgonians	9.6	4.24	10	4.0	1.19	16	24	0.431	0.67
Muricea fruticosa	8.6	3.74	10	3.3	0.89	16	24	0.256	0.80
Muricea californica	0.7	0.53	10	0.7	0.34	16	24	-0.236	0.82
Lophogorgia	0.3	0.17	10	0.02	0.019	16	12.1[a]	2.584	0.0237*
Hermit Crabs	1.2	0.67	10	0.7	0.24	16	24	-1.013	0.32
Snails	4.0	3.39	10	2.2	0.63	16	10.3[b]	-2.075	0.0640
Megathura crenulata	0.09	0.070	10	0.07	0.031	16	24	-0.327	0.75
Kelletia kelletii	0.07	0.50	10	0.8	0.22	16	24	-4.085	0.0004*

[a]Variances are not equal, T statistic and d.f. are approximated (SAS Users Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were significantly different at the p = 0.05 level.

[b]Variances are not equal, T statistic and d. f. are approximated (SAS Users Guide: STATISTICS, SAS Institute, Cary, N. C.). Equality of means was also tested using Wilcoxon rank-sum test and means were not significantly different at the P = 0.05 level.

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VARIABLE	ARTIFICIAL REEFS MEAN	SE	N	NATURAL REEFS MEAN	SE	N	DF	T	P
Bivalves	0.5	0.19	10	0.9	0.82	16	24	2.618	0.015*
Hinnites giganteus	0.2	0.07	10	0.05	0.027	16	24	1.806	0.0835
Solitary Tunicates	3.5	3.30	10	0.7	0.44	16	24	0.188	0.85
Styela montereyensis	3.4	3.30	10	0.4	0.24	16	24	0.448	0.66
Strongylocentrotus franciscanus	0.2	0.13	10	1.3	0.39	16	24	-2.847	0.0089*
Strongylocentrotus purpuratus	0.7	0.60	10	3.0	1.61	16	24	-1.225	0.23
Seastars	0.2	0.11	10	0.1	0.04	16	24	-0.533	0.60
Pisaster spp.	0.2	0.11	10	0.08	0.033	16	24	0.821	0.42
Pisaster giganteus	0.2	0.10	10	0.08	0.033	16	24	0.304	0.76

Table 1-24

Species list of fish sampled on artificial and natural reefs.

Included are scientific and common names. Species that are fished either commercially or for sport are indicated by ^{S}.

SCORPAENIDAE	
Scorpaena guttata	Spotted scorpionfish^S
Sebastes atrovirens	Kelp rockfish^S
Sebastes serriceps	Treefish^S
Sebastes serranoides	Olive rockfish^S
Sebastes carnatus	Gopher rockfish^S
Sebastes miniatus	Vermilion rockfish^S
Sebastes rastrelliger	Grass rockfish^S
Sebastes caurinus	Copper rockfish^S
HEXAGRAMMIDAE	
Oxylebius pictus	Painted greenling
COTTIDAE	
Scorpaenichthys marmoratus	Cabezon^S
SERRANIDAE	
Paralabrax clathratus	Kelp bass^S
Paralabrax nebulifer	Barred sand bass^S
CARANGIDAE	
Trachurus symmetricus	Jack mackerel^S
PRISTIPOMATIDAE	
Anisotremus davidsonii	Sargo^S
SCIAENIDAE	
Cheilotrema saturnum	Black croaker^S
GIRELLIDAE	
Girella nigricans	Opaleye^S
SCORPIDIDAE	
Medialuna californiensis	Halfmoon^S
EMBIOTOCIDAE	
Embiotoca jacksoni	Black surfperch^S
Phanerodon furcatus	White surfperch
Damalichthys vacca	Pile surfperch^S
Hypsurus caryi	Rainbow surfperch^S
Rhacochilus toxotes	Rubberlip surfperch
Brachyistius frenatus	Kelp surfperch
POMACENTRIDAE	
Hypsypops rubicundus	Garibaldi
Chromis punctipinnis	Blacksmith
LABRIDAE	
Semicossyphus pulcher	California sheephead^S
Oxyjulis californica	Senorita
Halichoeres semicinctus	Rock wrasse

Table 1-24

GOBBIIDAE	
Lythrypnus dalli	Blue-banded goby
Coryphopterus nicholsii	Blackeye goby
PLEURONECTIDAE	
Pleuronichthys coenosus	Turbot[S]
Microstomus pacificus	Dover sole[S]
BOTHIDAE	
Paralichthys californicus	California halibut[S]
CLINIDAE	
Heterostichus rostratus	Giant kelpfish
Gibbonsia spp.	Kelpfish spp.
Alloclinus holderi	Island kelpfish
ATHERINIDAE	
Atherinids	Jacksmelt, Topsmelt[S]
KYPHOSIDAE	
Hermosilla azurea	Zebraperch[S]
BATHYMASTERIDAE	
Rathbunella spp.	Ronquil
SCOMBRIDAE	
Sarda chiliensis	Pacific bonito[S]
CARCHARINIDAE	
Triakis semifasciata	Leopard shark[S]

Table 1-25

Occurrence of species of fish on artificial and natural reefs.

Shown is the proportion of artificial or natural reefs on which a species was found as a young-of-year only or in any lifestage. Included are fish seen in the benthic and water column transects and fish length samples.

	Young of Year		All Lifestages	
Reef Type	Artificial	Natural	Artificial	Natural
Spotted scorpionfish	0	0	0.40	0.06
Kelp rockfish	0.10	0.06	0.20	0.19
Treefish	0	0	0	0.06
Olive rockfish	0.20	0	0.70	0.19
Gopher rockfish	0	0	0	0.06
Vermilion rockfish	0	0	0.10	0
Grass rockfish	0	0	0.10	0
Copper rockfish	0	0	0.10	0
Painted greenling	0.10	0.06	0.60	0.50
Cabezon	0	0	0.20	0.06
Kelp bass	0.40	0.25	1.00	1.00
Barred sand bass	0	0	0.80	0.88
Jack mackerel	0	0	0.20	0.38
Sargo	0	0.06	0.70	0.38
Black croaker	0	0	0.60	0.06
Opaleye	0.10	0	1.00	0.56
Halfmoon	0	0	0.90	0.81
Black surfperch	0.70	0.50	1.00	1.00
White surfperch	0	0	0.50	0.13
Pile surfperch	0.40	0.13	1.00	0.69
Rainbow surfperch	0.10	0.19	0.80	0.63
Rubberlip surfperch	0	0	0.60	0.25
Kelp surfperch	0.20	0.06	0.50	0.63
Garibaldi	0	0.06	0.70	0.69
Blacksmith	0.90	0.44	1.00	0.75
California sheephead	0.20	0.13	0.80	1.00
Senorita	0.40	0.56	0.90	0.88
Rock wrasse	0.10	0.06	1.00	1.00
Bluebanded goby	0.40	0.25	0.40	0.25
Blackeye goby	0.20	0.13	0.40	0.31
Turbot	0	0	0.10	0.06
Dover sole	0	0	0.10	0
California halibut	0	0	0	0.06
Giant kelpfish	0	0.13	0.30	0.25
Kelpfish spp.	0.10	0	0.20	0
Island kelpfish	0	0	0	0.13
Jacksmelt, topsmelt	0.20	0	0.30	0.13
Zebraperch	0	0	0.20	0.13
Ronquil	0	0	0.10	0
Leopard shark	0	0	0	0.06
Pacific bonito	0	0	0.20	0

Table 1-26

Species richness of fish on artificial and natural reefs.

Included are richness of young-of-year, juveniles and adults, and all lifestages near the benthos and in the water column. Total on reef includes all species sampled in benthic transects, water column transects, and fish length samples.

	BENTHIC			WATER COLUMN			TOTAL
	YOY	Juveniles & Adults	Total	YOY	Juveniles & Adults	Total	ON REEF
ARTIFICIAL REEFS							
Torrey Pines AR	4	12	12	0	0	0	13
Pendleton AR	6	15	16	0	2	2	21
Newport Beach AR	3	19	20	0	0	0	22
LA Harbor Breakwater outside	4	15	15	3	8	8	18
LA Harbor Breakwater inside	7	11	12	6	11	13	20
King Harbor Breakwater	7	15	16	1	3	3	18
Hermosa Beach AR	3	18	19	0	0	0	21
Marina Del Rey AR	3	16	16	0	0	0	17
Pitas Point AR	2	13	13	1	5	5	16
Rincon Oil Island	2	14	14	1	9	9	21
NATURAL REEFS							
Marine Street Reef	3	7	9	3	6	6	14
La Jolla Cove Reef	2	13	13	0	2	2	16
Del Mar Reef	3	11	11	1	5	5	17
Barn Kelp	3	10	11	0	2	2	12
Las Pulgas Reef	2	7	7	0	0	0	11
Box Canyon	2	6	6	0	0	0	10
San Onofre Kelp Main (4-1)	1	10	10	0	5	5	12
San Onofre Kelp North (002)	2	10	10	3	4	5	14
San Mateo Kelp	1	8	9	3	5	6	14
Two Man Rock	3	12	12	0	2	2	13
Laguna Beach North	4	11	12	2	5	5	17
Pelican Point	3	13	14	0	1	1	15
Point Vicente	5	15	16	0	1	1	17
Don't Dive There	3	13	14	2	8	9	19
Flat Rock	1	10	10	1	4	4	13
Rincon Kelp	0	10	10	0	3	3	11

Table 1-27

Results of t-tests comparing species richness of fish on artificial and natural reefs.

Included are richness of young-of-year, juveniles and adults, and all lifestages near the benthos and in the water column, and total number of species sampled on the reef in benthic and water column transects and in fish length samples. * indicates $p \leq 0.05$.

	VARIABLE	ARTIFICIAL REEFS Mean	SE	N	NATURAL REEFS Mean	SE	N	df	T	P
BENTHIC	Young of Year	4.1	0.60	10	2.4	0.31	16	24	2.785	0.0103*
BENTHIC	Juveniles & Adults	14.8	0.79	10	10.4	0.63	16	24	4.400	0.0002*
BENTHIC	All Lifestages Combined	15.3	0.86	10	10.9	0.65	16	24	4.151	0.0004*
WATER COLUMN	Young of Year	1.2	0.61	10	0.9	0.31	16	24	0.424	0.68
WATER COLUMN	Juveniles & Adults	3.8	1.33	10	3.3	0.57	16	12[a]	0.336	0.74
WATER COLUMN	All Lifestages Combined	4.0	1.46	10	3.5	0.63	16	12[a]	0.314	0.76
TOTAL ON REEF		18.7	0.90	10	14.2	0.62	16	24	4.275	0.0003*

a Variances are not equal, T statistic and d.f. are approximations (SAS Users Guide: Statistics, SAS Institute Inc., Cary, NC). Equality of means was also tested using Wilcoxon rank-sum test and was not significantly different at the p = 0.05 level.

Table 1-28

Diversity of fish on artificial and natural reefs.

Included are Shannon-Wiener and Simpson indices for young-of-year and all lifestages near the benthos and in the water column. "nc" indicates that no fish were found in the transects and, therefore, diversity indices were not calculated. SH = Shannon-Wiener, SI = Simpson.

	BENTHIC				WATER COLUMN			
	Young of Year		All Lifestages		Young of Year		All Lifestages	
	SH	SI	SH	SI	SH	SI	SH	SI
ARTIFICIAL REEFS								
Torrey Pines AR	0.152	1.195	0.479	1.859	nc	nc	nc	nc
Pendleton AR	0.211	1.260	0.488	1.885	nc	nc	0	1.0
Newport Beach AR	0.133	0.156	0.688	2.662	nc	nc	nc	nc
LA Harbor BW outside	0.477	2.372	0.863	5.470	0.346	1.815	0.216	1.317
LA Harbor BW inside	0.609	3.166	0.860	5.857	0.663	3.846	0.627	3.101
King Harbor BW	0.315	1.504	0.651	2.571	0	1.0	0.027	1.023
Hermosa Beach AR	0.360	2.133	1.032	8.139	nc	nc	nc	nc
Marina del Rey AR	0.261	1.458	0.975	7.795	nc	nc	nc	nc
Pitas Point AR	0.196	1.385	0.923	7.042	0	1.0	0.111	1.147
Rincon Oil Island	0.301	2.000	0.865	5.231	0	1.0	0.293	1.482
NATURAL REEFS								
Marine Street Reef	0.452	2.667	0.835	6.160	0.378	2.190	0.401	2.223
La Jolla Cove Reef	0.186	1.352	0.836	4.692	nc	nc	0.298	1.976
Del Mar Reef	0.477	3.000	0.871	6.237	0	1.0	0.046	1.041
Barn Kelp	0.150	1.185	0.795	5.198	nc	nc	0	1.0
Las Pulgas Reef	0.168	1.293	0.690	4.400	nc	nc	nc	nc
Box Canyon	0.151	1.246	0.565	2.898	nc	nc	nc	nc
San Onofre Kelp Main (4-1)	0	1.0	0.628	2.673	nc	nc	0.447	2.432
San Onofre Kelp North (002)	0.244	1.600	0.796	4.832	0.458	2.778	0.641	3.901
San Mateo Kelp	0	1.0	0.616	2.928	0.413	2.273	0.640	3.862
Two Man Rock	0.206	1.350	0.707	3.800	nc	nc	0.301	2.000
Laguna Beach North	0.528	3.000	0.864	6.357	0.217	1.471	0.283	1.555
Pelican Point	0.461	2.793	0.948	7.413	nc	nc	0	1.0
Point Vicente	0.382	1.819	0.777	3.280	nc	nc	0	1.0
Don't Dive There	0.452	2.667	0.917	7.121	0.196	1.385	0.777	5.344
Flat Rock	0	1.0	0.711	3.973	0	1.0	0.421	2.330
Rincon Kelp	nc	nc	0.806	5.478	nc	nc	0.142	1.199

Table 1-29

Results of t-tests comparing the diversity of fish on artificial and natural reefs.

Included are Shannon-Wiener and Simpson indices for young-of-year and all lifestages near the benthos and in the water column.

VARIABLE			ARTIFICIAL REEFS Mean	SE	N	NATURAL REEFS Mean	SE	N	df	T	P
BENTHIC	Young of year	Shannon	0.300	0.0475	10	0.257	0.0483	15	23	0.607	0.55
		Simpson	1.760	0.2057	10	1.798	0.2032	15	23	- 0.127	0.90
	All life-stages	Shannon	0.778	0.0637	10	0.772	0.0276	16	24	0.100	0.92
		Simpson	4.840	0.7763	10	4.840	0.3817	16	24	- 0.0001	0.99
WATER COLUMN	Young of year	Shannon	0.202	0.1334	5	0.237	0.0714	7	10	- 0.254	0.80
		Simpson	1.732	0.5515	5	1.728	0.2608	7	10	0.008	0.99
	All life-stages	Shannon	0.212	0.0946	6	0.314	0.0688	14	18	- 0.831.	0.42
		Simpson	1.512	0.3265	6	2.205	0.3538	14	18	- 1.182	0.25

Table 1-30
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Mean (1S.E.) density (no./1000m^3) of fish of all lifestages near the benthos on artificial and natural reefs.
N = 8 for all species on all reefs.

	All Species	Sport Fish	Kelp Bass	Sand Bass	Opal-Eye	Half-Moon	Black Surfperch	Pile Surf-perch	Gari-baldi	Black-smith	Calif. Sheephead	Seno-rita	Rock Wrasse
	ARTIFICIAL REEFS												
Torrey Pines AR	732.6	116.4	15.5	0	0	5.6	14.8	2.1	36.1	529.4	74.3	19.7	28.0
	(138.1)	(11.9)	(4.7)			(2.7)	(4.7)	(2.1)	(9.1)	(129.1)	(11.5)	(18.6)	(8.7)
Pendleton AR	940.0	118.3	3.5	1.4	5.1	2.4	28.5	0.9	4.6	696.8	74.4	29.2	75.1
	(256.9)	(20.1)	(1.8)	(1.0)	(4.2)	(1.4)	(8.8)	(0.6)	(2.3)	(246.1)	(13.8)	(11.3)	(10.1)
Newport Beach AR	501.6	164.1	31.3	16.7	1.9	0.9	19.4	6.3	0	296.8	16.2	0	0
	(96.6)	(65.2)	(8.3)	(3.6)	(1.9)	(0.9)	(3.8)	(4.4)		(61.4)	(6.4)		
LA Harbor Breakwater	235.0	151.2	24.1	0	7.4	1.9	65.0	24.8	1.9	62.5	2.1	0	0
outside	(34.9)	(31.8)	(6.9)		(2.8)	(1.9)	(15.5)	(9.9)	(1.2)	(18.6)	(2.1)		
LA Harbor Breakwater	319.7	231.5	40.0	10.2	31.5	3.9	82.4	52.1	0	70.8	0	2.1	6.3
inside	(62.8)	(20.0)	(16.9)	(4.0)	(16.8)	(2.2)	(9.4)	(19.0)		(61.6)		(2.1)	(3.0)
King Harbor Breakwater	562.7	148.4	29.2	43.3	4.2	2.1	48.8	8.3	6.3	0	0	47.9	13.4
	(90.5)	(33.3)	(7.7)	(17.1)	(4.2)	(2.1)	(19.0)	(5.5)	(4.4)			(21.9)	(4.0)
Hermosa Beach AR	260.2	94.0	6.9	11.1	0.9	0.9	4.6	1.9	0	44.2	11.3	4.9	1.9
	(91.2)	(40.2)	(2.4)	(2.8)	(0.9)	(0.9)	(2.8)	(1.2)		(32.2)	(6.0)	(3.2)	(1.9)
Marina del Rey AR	269.8	147.8	42.0	24.1	2.5	0	21.3	30.2	0	62.0	2.5	0	3.7
	(46.0)	(17.8)	(14.9)	(7.7)	(2.5)		(9.2)	(7.2)		(22.3)	(2.5)		(1.7)
Pitas Point AR	208.3	189.6	35.4	41.7	37.5	0	33.3	14.6	0	0	0	14.6	4.2
	(57.2)	(56.5)	(11.1)	(7.0)	(26.9)		(11.8)	(8.0)				(8.0)	(2.7)
Rincon Oil Island	222.7	89.1	34.5	3.9	4.6	0.9	11.3	1.9	0.9	79.2	0	31.5	3.9
	(54.3)	(19.6)	(9.1)	(2.2)	(1.9)	(0.9)	(4.7)	(1.2)	(0.9)	(52.0)		(7.2)	(3.0)

Table 1-30

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	All Species	Sport Fish	Kelp Bass	Sand Bass	Opal-Eye	Half-Moon	Black Surfperch	Pile Surf-perch	Gari-baldi	Black-smith	Calif. Sheephead	Seno-rita	Rock Wrasse
	NATURAL REEFS												
Marine Street Reef	51.2	24.5	11.3	0	0	0	6.3	2.1	10.2	4.2	4.9	0	10.2
	(11.3)	(8.6)	(5.1)				(3.0)	(2.1)	(4.4)	(2.7)	(3.0)		(3.4)
La Jolla Cove Reef	191.7	49.3	12.5	2.8	0	0	12.5	2.1	20.1	24.1	17.6	77.1	16.0
	(42.5)	(8.8)	(6.1)	(1.4)			(4.2)	(2.1)	(6.1)	(8.3)	(4.0)	(41.3)	(7.4)
Del Mar Reef	87.5	66.0	16.9	8.1	0	0.9	22.5	6.3	0.9	0.9	11.3	4.2	13.4
	(23.7)	(15.4)	(4.2)	(3.4)		(0.9)	(9.6)	(3.0)	(0.9)	(0.9)	(5.2)	(4.2)	(6.9)
Barn Kelp	198.6	65.7	0	2.8	0	2.1	8.3	0	4.9	56.3	10.9	30.8	38.9
	(79.2)	(42.2)		(1.4)		(2.1)	(4.5)		(2.5)	(35.1)	(3.7)	(26.4)	(9.6)
Las Pulgas Reef	124.8	40.3	0	3.0	0	0	9.3	0	23.1	41.7	28.0	0	19.7
	(44.3)	(16.7)		(2.2)			(6.2)		(11.4)	(41.7)	(10.2)		(5.9)
Box Canyon	86.1	26.2	14.1	0	0	5.1	0	0	0	0	6.9	45.6	14.4
	(44.5)	(6.6)	(4.6)			(3.4)					(4.2)	(41.2)	(5.0)
San Onofre Kelp	316.4	238.7	24.8	4.2	0	2.1	7.2	2.1	0	0	13.4	34.0	33.3
Main (4-1)	(99.6)	(95.5)	(13.8)	(4.2)		(2.1)	(3.6)	(2.1)			(4.9)	(21.1)	(7.4)
San Onofre Kelp	94.7	49.3	24.8	1.9	0	0	4.2	4.6	0	0	7.2	29.9	15.5
North (002)	(35.9)	(12.1)	(10.1)	(1.2)			(2.7)	(4.6)			(3.6)	(24.8)	(6.4)
San Mateo Kelp	176.2	133.8	0	2.1	0	8.3	10.2	8.3	0	0	12.3	0	40.3
	(94.3)	(91.8)		(2.1)		(6.3)	(4.2)	(8.3)			(4.4)		(7.8)
Two Man Rock	303.5	162.3	2.1	1.9	12.0	4.6	36.3	2.1	20.6	108.3	102.3	0	10.2
	(133.1)	(73.1)	(2.1)	(1.2)	(5.8)	(3.1)	(11.7)	(2.1)	(7.3)	(76.6)	(66.1)		(4.1)
Laguna Beach North	153.3	44.4	20.1	0.9	0.9	0	2.1	0	15.5	0	20.4	33.3	35.0
	(39.3)	(12.4)	(6.4)	(0.9)	(0.9)		(2.1)		(12.5)		(8.4)	(19.9)	(6.8)
Pelican Point	165.0	62.3	8.6	2.8	1.9	2.1	14.6	0	24.3	13.4	32.4	19.4	33.1
	(29.5)	(14.2)	(2.8)	(1.4)	(1.9)	(2.1)	(4.9)		(6.3)	(4.4)	(10.1)	(12.0)	(9.7)
Point Vicente	571.3	85.2	31.7	3.0	11.3	2.1	17.1	3.0	17.6	300.5	13.9	7.4	45.6
	(158.7)	(11.1)	(6.5)	(2.2)	(6.3)	(2.1)	(5.0)	(2.2)	(2.4)	(165.5)	(4.1)	(2.8)	(22.0)
Don't Dive There	280.3	135.6	15.5	0	44.9	2.1	55.3	4.2	41.7	0	10.6	32.4	49.1
	(17.7)	(13.8)	(4.7)		(12.5)	(2.1)	(12.9)	(2.7)	(6.1)		(3.0)	(15.7)	(5.9)
Flat Rock	68.8	22.0	8.8	0	0.9	0	8.3	1.9	13.9	0	0	0	28.7
	(15.2)	(6.7)	(4.7)		(0.9)		(3.1)	(1.9)	(5.5)				(7.6)
Rincon Kelp	87.5	79.2	22.9	16.7	12.5	0	18.8	2.1	0	0	0	0	0
	(22.7)	(22.2)	(11.3)	(8.3)	(8.8)		(8.0)	(2.1)					

Table 1-31

Results of t-tests comparing the mean density of fish of all lifestages near the benthos on artificial and natural reefs.

Means are no. of fish/1000 m^3; data were transformed $[\log_{10}(x + 1)]$ for analysis. * indicates $p \leq 0.05$.

VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS					
	MEAN	SE	N	MEAN	SE	N	DF	T	P
All Species Combined	425.3	79.66	10	184.9	33.12	16	24	3.639	0.0013*
Sport Fish	145.0	13.80	10	80.3	14.82	16	22.1[a]	3.946	0.0007*
Kelp bass	26.2	4.27	10	13.4	2.47	16	24	2.072	0.0492*
Barred sand bass	15.2	5.16	10	3.1	1.04	16	24	2.321	0.0291*
Opaleye	9.6	4.2	10	5.3	2.89	16	24	1.765	0.0903
Halfmoon	1.9	0.56	10	1.8	0.60	16	24	0.458	0.65
Black surfperch	33.0	7.93	10	14.6	3.51	16	24	2.397	0.0247*
Pile surfperch	14.3	5.30	10	2.4	0.61	16	24	3.112	0.0048*
Garibaldi	5.0	3.53	10	12.1	3.06	16	24	-1.707	0.10
Blacksmith	184.2	77.15	10	34.3	19.24	16	24	2.653	0.0139*
Sheephead	18.1	9.54	10	18.3	6.02	16	24	-1.386	0.18
Senorita	15.0	5.29	10	19.6	5.58	16	24	-0.126	0.90
Rock wrasse	13.6	7.33	10	25.2	3.64	16	24	-2.619	0.0150*

[a] Variances are not equal, T statistic and d.f. are approximated (SAS User's Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were significantly different at the p = 0.05 level.

Table 1-32

Mean (1S.E.) density (no./1000 m^3) of young-of-year fish near the benthos on artificial and natural reefs.

Sport fish indicated by ^{S}. N = 8 for all species on all reefs.

Reefs	All Species	Black-smith	% Black Smith	All Spp. Excluding Blacksmith	Sport Fish	Kelp Bass^S	Black Surfperch^S	Pile Surf-perch^S	Calif. Sheephead^S	Seno-rita
ARTIFICIAL REEFS										
Torrey Pines AR	260.4 (92.8)	237.5 (90.7)	0.91	22.9 (18.3)	4.2 (2.7)	0	2.1 (2.1)	0	2.1 (2.1)	18.8 (18.8)
Pendleton AR	464.6 (157.7)	417.7 (152.1)	0.90	46.9 (12.8)	16.7 (6.8)	1.0 (1.0)	11.5 (6.4)	0	4.2 (3.2)	24.0 (10.9)
Newport Beach AR	58.3 (47.9)	54.2 (36.0)	0.93	4.1 (2.7)	0	0	0	0	0	0
LA Harbor Breakwater outside	47.9 (11.5)	29.2 (11.7)	0.61	18.7 (5.8)	18.8 (5.8)	6.3 (6.3)	6.3 (3.0)	6.3 (3.0)	0	0
LA Harbor Breakwater inside	85.4 (17.7)	2.1 (2.1)	0.03	83.3 (17.3)	77.1 (17.2)	6.3 (4.4)	33.3 (7.7)	33.3 (12.2)	0	0
King Harbor Breakwater	420.8 (95.5)	0	0	420.8 (95.5)	41.7 (14.4)	4.2 (2.7)	31.3 (13.5)	4.2 (4.2)	0	37.5 (15.0)
Hermosa Beach AR	50.0 (22.7)	20.8 (20.8)	0.42	29.2 (16.0)	0	0	0	0	0	0
Marina del Rey AR	30.6 (15.8)	25.0 (17.1)	0.82	5.6 (3.5)	2.8 (2.8)	0	0	2.8 (2.8)	0	0
Pitas Point AR	12.5 (8.2)	0	0	12.5 (8.2)	12.5 (8.2)	0	10.4 (6.3)	0	0	0
Rincon Oil Island	12.5 (5.2)	6.3 (4.4)	0.50	6.3 (4.4)	6.3 (4.4)	0	6.3 (4.4)	0	0	0
NATURAL REEFS										
Marine Street Reef	8.3 (4.5)	0	0	8.3 (4.5)	6.3 (4.4)	0	4.2 (2.7)	2.1 (2.1)	0	0
La Jolla Cove Reef	27.1 (20.2)	0	0	27.1 (20.2)	4.2 (2.7)	0	4.2 (2.7)	0	0	22.9 (20.6)
Del Mar Reef	6.3 (4.4)	0	0	6.3 (4.4)	4.2 (2.7)	0	2.1 (2.1)	2.1 (2.1)	0	0
Barn Kelp	50.0 (34.8)	45.8 (35.5)	0.92	4.2 (2.7)	2.1 (2.1)	0	2.1 (2.1)	0	0	0
Las Pulgas Reef	47.9 (41.0)	41.7 (41.7)	0.87	6.2 (4.4)	0	0	0	0	0	
Box Canyon	18.8 (16.5)	0	0	18.8 (16.5)	2.1 (2.1)	2.1 (2.1)	0	0	0	16.7 (16.7)
San Onofre Kelp Main (4-1)	2.1 (2.1)	0	0	2.1 (2.1)	2.1 (2.1)	2.1 (2.1)	0	0	0	0
San Onofre Kelp North (002)	16.7 (14.4)	0	0	16.7 (14.4)	4.2 (4.2)	4.2 (4.2)	0	0	0	12.5 (10.3)
San Mateo Kelp	2.1 (2.1)	0	0	2.1 (2.1)	0	0	0	0	0	0
Two Man Rock	125.0 (73.7)	106.3 (74.7)	0.85	18.7 (8.0)	18.8 (8.0)	0	16.7 (8.3)	0	2.1 (2.1)	0
Laguna Beach North	18.8 (10.2)	0	0	18.8 (10.2)	0	0	0	0	0	2.1 (2.1)
Pelican Point	18.8 (5.8)	4.2 (2.7)	0.22	14.6 (5.8)	6.3 (3.0)	0	6.3 (3.0)	0	0	0
Point Vicente	87.5 (28.7)	16.7 (16.7)	0.19	70.8 (26.9)	2.1 (2.1)	0	0	0	2.1 (2.1)	0
Don't Dive There	8.3 (6.3)	0	0	8.3 (6.3)	4.2 (2.7)	0	2.1 (2.1)	0	0	0
Flat Rock	6.3 (3.0)	0	0	6.3 (3.0)	6.3 (3.0)	0	6.3 (3.0)	0	0	0
Rincon Kelp	0	0	0	0	0	0	0	0	0	0

Table 1-33

Results of t-tests comparing the mean density of young-of-year fish near the benthos on artificial and natural reefs.

Means are no. of fish/ 1000 m^3; data were transformed [$\log_{10}$ (x + 1)] for analysis. * indicates p $\leq$ 0.05.

VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS					
	MEAN	SE	N	MEAN	SE	N	DF	T	P
All Species Combined	144.3	54.70	10	27.7	8.68	16	24	3.060	0.0054*
Blacksmith	79.3	43.84	10	13.4	7.23	16	24	2.386	0.0253*
All species excluding blacksmith	65.0	40.27	10	14.3	4.23	16	24	1.985	0.0581
Sport Fish	18.0	7.67	10	3.9	1.14	16	24	1.982	0.0590
Kelp bass	1.8	0.85	10	0.5	0.30	16	24	1.402	0.17
Black surfperch	10.1	3.93	10	2.7	1.09	16	24	1.888	0.0712
Pile surfperch	4.7	3.26	10	0.3	0.18	16	10.1[a]	1.764	0.1080
Senorita	8.0	4.33	10	3.4	1.80	16	24	0.691	0.50

[a]Variances are not equal, T statistic and d.f. are approximated (SAS User's Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were not significantly different at the p = 0.05 level.

Table 1-34

Mean density (no./1000m^3) of fish of all lifestages in the water column on artificial and natural reefs.

N = 8 for all species on all reefs.

Reefs	All Species	Sport Fish	Kelp Bass	Half-Moon	Kelp Surfperch	Black-Smith	Senorita
Artificial Reefs							
Torrey Pines AR	0	0	0	0	0	0	0
Pendleton AR	0.66	0.66	0	0	0	0	0
Newport Beach AR	0	0	0	0	0	0	0
LA Harbor Breakwater outside	296.22	4.25	0.02	0	29.37	256.35	0
LA Harbor Breakwater inside	581.68	296.23	14.62	2.08	202.08	52.08	14.58
King Harbor Breakwater	184.10	2.11	2.11	0	0	181.99	0
Hermosa Beach AR	0	0	0	0	0	0	0
Marina Del Rey AR	0	0	0	0	0	0	0
Pitas Point AR	156.86	146.16	0.01	0	0	0.04	10.66
Rincon Oil Island	399.48	37.74	0	0	0.29	324.56	34.81
Natural Reefs							
Marine Street Reef	362.57	4.19	4.17	0	2.08	145.83	193.80
La Jolla Cove Reef	75.0	75.0	0	0	0	0	0
Del Mar Reef	116.92	0.16	0.06	0.10	2.08	0.10	114.58
Barn Kelp	0.02	0.02	0	0.02	0	0	0
Las Pulgas Reef	0	0	0	0	0	0	0
Box Canyon	0	0	0	0	0	0	0
San Onofre Kelp Main (4-1)	109.13	94.43	59.00	35.12	2.08	0	0.13
San Onofre Kelp North (002)	27.28	10.42	6.25	4.17	4.17	0	10.61
San Mateo Kelp	100.16	52.13	27.14	20.83	12.50	0	35.53
Two Man Rock	4.16	4.16	2.08	2.08	0	0	0
Laguna Beach North	869.09	693.77	10.44	6.25	164.58	0	10.74
Pelican Point	189.58	0	0	0	0	189.58	0
Point Vicente	0.20	0	0	0	0	0.20	0
Don't Dive There	81.46	29.34	0.04	4.17	4.17	20.83	18.76
Flat Rock	25.04	0	0	0	4.17	0	14.58
Rincon Kelp	2.28	2.09	0.01	0	0	0	0.19

Table 1-35

Results of t-tests comparing the mean density of fish of all lifestages in the water column on artificial and natural reefs.

Means are shown as no./1,000 m^3; data were scaled to no./100,000 m^3 and transformed [$\log_{10}(x + 1)$] for analysis.

VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS					
	MEAN	SE	N	MEAN	SE	N	DF	T	P
All Species Combined	162.1	65.23	10	122.7	55.20	16	24	-0.728	0.47
Sport Fish	48.7	31.06	10	60.4	42.88	16	24	-0.154	0.88
Kelp bass	1.7	1.45	10	6.8	3.90	16	24	-1.122	0.27
Halfmoon	0.2	0.21	10	4.6	2.44	16	24	-1.937	0.0646
Kelp surfperch	23.2	20.09	10	12.2	10.19	16	24	-0.734	0.47
Blacksmith	81.5	39.51	10	22.3	14.39	16	24	1.204	0.24
Senorita	6.0	3.62	10	24.9	13.35	16	24	-1.047	0.31

Table 1-36

Mean (1S.E.) density (no./1000m^3) of young-of-year fish in the water column on artificial and natural reefs.

N = 8 for all species on all reefs.

Reefs	All Species	Sport Fish	Kelp Bass	Kelp Surfperch	Black-smith	Senorita
Artificial Reefs						
Torrey Pines AR	0	0	0	0	0	0
Pendleton AR	0	0	0	0	0	0
Newport Beach AR	0	0	0	0	0	0
LA Harbor Breakwater outside	14.8 (14.8)	2.08 (2.08)	0	2.08 (2.08)	10.42 (10.42)	0
LA Harbor Breakwater inside	41.67 (11.79)	29.17 (9.83)	6.25 (4.38)	2.08 (2.08)	0	0
King Harbor Breakwater	181.25 (132.19)	0	0	0	181.25 (132.19)	0
Hermosa Beach AR	0	0	0	0	0	0
Marina Del Rey AR	0	0	0	0	0	0
Pitas Point AR	83.33 (62.99)	83.33 (62.99)	0	0	0	0
Rincon Oil Island	6.25 (6.25)	0	0	0	0	6.25 (6.25)
Natural Reefs						
Marine Street Reef	264.58 (148.95)	0	0	0	145.83 (96.76)	102.08 (52.75)
La Jolla Cove Reef	0	0	0	0	0	0
Del Mar Reef	114.58 (103.19)	0	0	0	0	114.58 (103.19)
Barn Kelp	0	0	0	0	0	0
Las Pulgas Reef	0	0	0	0	0	0
Box Canyon	0	0	0	0	0	0
San Onofre Kelp Main (4-1)	0	0	0	0	0	0
San Onofre Kelp North (002)	10.42 (5.40)	4.17 (4.17)	4.17 (4.17)	0	0	4.17 (4.17)
San Mateo Kelp	10.42 (8.30)	4.17 (2.73)	2.08 (2.08)	0	0	6.25 (6.25)
Two Man Rock	0	0	0	0	0	0
Laguna Beach North	10.42 (5.42)	0	0	8.33 (5.46)	0	2.08 (2.08)
Pelican Point	0	0	0	0	0	0
Point Vicente	0	0	0	0	0	0
Don't Dive There	25.00 (13.36)	0	0	0	20.83 (13.64)	4.17 (4.17)
Flat Rock	8.33 (8.33)	0	0	0	0	8.33 (8.33)
Rincon Kelp	0	0	0	0	0	0

Table 1-37

Results of T-tests comparing the mean density of young-of-year in the water column on artificial and natural reefs.

Means are shown as no./1000 m^3; data were scaled to no./100,000 m^3 and transformed [$\log_{10}(x + 1)$] for analysis.

VARIABLE	ARTIFICIAL REEFS MEAN	SE	N	NATURAL REEFS MEAN	SE	N	DF	T	P
All Species Combined	32.7	18.58	10	27.7	17.30	16	24	0.385	0.70
Sport Fish	11.5	8.49	10	0.5	0.36	16	12.5[a]	1.156	0.27
Senorita	0.6	0.63	10	15.1	9.14	16	24	-1.878	0.0726

[a]Variances are not equal, T statistic and d.f. are approximated (SAS User's Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were not significantly different at the p = 0.05 level.

Table 1-38

Biomass density (kg/1000 m^3) of fish near the benthos on artificial and natural reefs.

	ALL SPECIES COMBINED	SPORT FISH	KELP BASS	BARRED SAND BASS	OPAL-EYE	HALF-MOON	BLACK SURF-PERCH	PILE SURF-PERCH	GARI-BALDI	BLACK-SMITH	SHEEP-HEAD	SENO-RITA	ROCK WRASSE
ARTIFICIAL REEFS													
Torrey Pines AR	44.35	12.01	1.76	0	0	1.56	1.76	0.16	15.88	13.89	6.52	0.06	2.43
Pendleton AR	23.92	17.15	0.19	0.79	1.22	0.51	1.60	0.25	1.14	3.19	12.46	0.05	2.38
Newport Beach	52.16	41.72	13.23	12.72	0.68	0.26	1.74	0.48	0	9.35	7.88	0	0
LA Harbor BW outside	31.82	28.59	3.12	0	3.02	0.52	4.75	1.57	0.40	1.91	0.45	0	0
LA Harbor BW inside	28.14	26.73	1.71	0.94	16.22	0.76	4.67	1.83	0	1.04	0	0.02	0.12
King Harbor BW	16.25	14.52	1.81	9.26	0.46	0.24	1.74	0.37	0.46	0	0	0.12	0.65
Hermosa Beach AR	16.82	11.86	0.56	4.64	0.20	0.26	1.00	0.50	0	0.33	2.43	0.17	0.29
Marina Del Rey AR	32.07	25.24	5.17	4.62	1.29	0	2.55	2.60	0	1.84	4.96	0	0.37
Pitas Point AR	41.33	40.44	8.80	13.11	10.55	0	3.47	1.51	0	0	0	0.64	0.25
Rincon Oil Island	14.71	10.42	2.90	1.20	2.43	0.26	0.58	0.50	0.20	1.21	0	0.76	0.22
NATURAL REEFS													
Marine Street Reef	9.04	5.73	1.45	0	0	0	0.20	0.03	2.96	0.03	4.05	0	0.31
La Jolla Cove Reef	18.47	9.91	1.28	0.45	0	0	0.63	0.16	4.65	1.78	5.43	1.20	0.78
Del Mar Reef	11.57	10.83	1.23	1.08	0	0.26	1.86	0.34	0.27	0.09	6.06	0.04	0.33
Barn Kelp	10.92	7.93	0	2.16	0	0.24	0.46	0	1.06	0.20	4.38	0.63	1.11
Las Pulgas	10.29	5.18	0	0.48	0	0	0.77	0	4.77	0.03	3.93	0	0.32
Box Canyon	8.64	7.87	5.64	0	0	0.75	0	0	0	0	1.49	0.35	0.41
San Onofre Kelp 4-1	12.74	10.90	2.95	0.67	0	0.24	0.63	0.16	0	0	3.42	0.80	1.04
San Onofre Kelp N002	26.93	26.33	10.03	1.44	0	0	0.30	1.24	0	0	1.54	0.26	0.34
San Mateo Kelp	24.24	22.33	0	0.33	0	0.97	0.89	0.64	0	0	5.05	0	1.91
Two Man Rock	52.83	44.75	0.21	0.30	5.15	1.30	1.72	0.16	7.53	0.14	35.75	0	0.35
Laguna Beach North	14.09	6.83	2.05	0.15	0.20	0	0.14	0	4.22	0	4.29	0.52	1.92
Pelican Point	26.64	16.86	0.92	1.02	0.39	0.24	0.66	0	7.77	0.19	13.63	0.20	1.58
Point Vicente	33.00	17.26	5.68	1.05	2.98	0.24	1.85	0.41	6.06	6.39	4.93	0.39	1.87
Don't Dive There	61.44	42.33	6.02	0	19.13	0.24	4.88	0.32	13.16	0	10.59	1.36	3.33
Flat Rock	5.76	1.97	0.90	0	0.20	0	0.23	0.50	2.87	0	0	0	0.75
Rincon Kelp	21.80	21.35	4.49	6.53	6.56	0	2.06	0.16	0	0	0	0	0

Table 1-39

Results of t-tests comparing biomass density of fish near the benthos on artificial and natural reefs.

Means are shown as kg/1000 m^3; data were converted to gm/1000 m^3 and then transformed [$\log_{10}(x + 1)$] for analysis. * indicates $p \leq 0.05$.

VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS					
	MEAN	SE	N	MEAN	SE	N	DF	T	P
All Species Combined	30.16	4.041	10	21.78	3.988	16	24	1.907	0.0685
Sport Fish	22.87	3.672	10	16.15	3.177	16	24	1.790	0.0860
Kelp bass	3.93	1.303	10	2.68	0.725	16	21[a]	1.644	0.12
Barred sand bass	4.73	1.639	10	0.98	0.400	16	24	1.174	0.25
Opaleye	3.61	1.710	10	2.16	1.241	16	24	2.423	0.0233*
Halfmoon	0.44	0.145	10	0.28	0.098	16	24	1.277	0.21
Black surfperch	2.39	0.460	10	1.08	0.305	16	20.1[b]	2.697	0.0138*
Pile surfperch	0.98	0.264	10	0.26	0.082	16	19.9[b]	3.577	0.0019*
Garibaldi	1.81	1.567	10	3.46	0.949	16	24	-1.393	0.18
Blacksmith	3.33	1.452	10	0.55	0.404	16	24	2.763	0.0108*
Sheephead	3.47	1.375	10	6.53	2.136	16	24	-1.748	0.0932
Senorita	0.18	0.089	10	0.36	0.110	16	24	-0.308	0.76
Rock wrasse	0.67	0.294	10	1.02	0.223	16	24	-1.476	0.15

[a] Variances are not equal, T statistic and d.f. are approximated (SAS User's Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were not significantly different at the p = 0.05 level.

[b] Variances are not equal, T statistic and d.f. are approximated (SAS User's Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were significantly different at the p = 0.05 level.

Table 1-40

Biomass density (kg/1000 m^3) of fish in the water column on artifical and natural reefs.

REEFS	ALL SPECIES COMBINED	SPORT FISH	KELP BASS	HALF-MOON	KELP SURF-PERCH	BLACK-SMITH	SENO-RITA
ARTIFICAL REEFS							
Torrey Pines AR	0	0	0	0	0	0	0
Pendleton AR	0.01	0.01	0	0	0	0	0
Newport Beach	0	0	0	0	0	0	0
LA Harbor BW Outside	3.49	0.17	0	0	0.29	2.87	0
LA Harbor BW Inside	6.40	3.01	0.43	0.24	2.11	0.78	0.12
King Harbor BW	0.26	0.15	0.15	0	0	0.10	0
Hermosa Beach AR	0	0	0	0	0	0	0
Marina Del Rey AR	0	0	0	0	0	0	0
Pitas Point AR	0.63	0.52	0	0	0	0	0.11
Rincon Oil Island	6.51	0.58	0	0	0	5.39	0.49
NATURAL REEFS							
Marine Street Reef	1.12	0.29	0.27	0	0.02	0.09	0.63
La Jolla Cove Reef	0.79	0.79	0	0	0	0	0
Del Mar Reef	0.08	0.02	0	0.01	0.02	0	0.04
Barn Kelp	0	0	0	0	0	0	0
Las Pulgas	0	0	0	0	0	0	0
Box Canyon	0	0	0	0	0	0	0
San Onofre Kelp 4 - 1	12.58	11.81	7.67	4.14	0.02	0	0.01
San Onofre Kelp N002	0.93	0.82	0.33	0.49	0.04	0	0.06
San Mateo Kelp	5.85	5.44	2.56	2.43	0.13	0	0.28
Two Man Rock	0.46	0.46	0.21	0.24	0	0	0
Laguna Beach North	8.27	6.54	1.06	0.73	1.65	0	0.08
Pelican Point	2.04	0	0	0	0	2.04	0
Point Vicente	0	0	0	0	0	0	0
Don't Dive There	5.09	4.71	0.01	0.49	0.04	0.01	0.09
Flat Rock	0.23	0	0	0	0.04	0	0.06
Rincon Kelp	0.19	0.18	0.01	0	0	0	0.01

Table 1-41

Results of t-tests comparing biomass density of fish in the water column on artificial and natural reefs.

Means are shown as Kg/1000 m_3; data were converted to gm/1000 m^3 and then transformed [$\log_{10}(x + 1)$] for analysis. * indicates $p \leq 0.05$.

VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS					
	MEAN	SE	N	MEAN	SE	N	DF	T	P
All Species Combined	1.73	0.857	10	2.35	0.925	16	24	-1.029	0.31
Sport Fish	0.44	0.293	10	1.94	0.855	16	24	-0.705	0.49
Kelp bass	0.06	0.044	10	0.76	0.490	16	24	-1.364	0.19
Halfmoon	0.02	0.024	10	0.53	0.285	16	23.5[a]	-2.220	0.0364*
Kelp surfperch	0.24	0.210	10	0.12	0.102	16	24	-0.584	0.56
Blacksmith	0.92	0.573	10	0.13	0.127	16	24	1.650	0.11
Senorita	0.07	0.049	10	0.08	0.041	16	24	-0.777	0.44

[a]Variances are not equal, T statistic and d.f. are approximated (SAS User's Guide: STATISTICS, SAS Institute Inc., Cary, N.C.). Equality of means was also tested using Wilcoxon rank-sum test and means were significantly different at the p = 0.05 level.

Table 1-42

Estimated standing stock of fish near the benthos and in the water column on artificial and natural reefs.

Size of reef is from Table 1-9, with km^2 converted to ha. Benthic biomass density is from Table 1-38, with kg/1000 m^3 converted to MT/ha. Canopy biomass density is from Table 1-40 with kg/1,000 m^3 converted to MT/ha. Standing stock was estimated by multiplying biomass density on a reef by the size of the reef. Some natural reefs were sampled at 2 or 3 sites; to estimate standing stock for these reefs, the mean biomass density for the sites was used.

	Area (ha)	Benthic Biomass Density (MT/ha)	Benthic Biomass Density, mean of sites (MT/ha)	Estimated Benthic Standing Stock (MT)	Water Column Biomass Density (MT/ha)	Water Column Biomass Density, mean of sites (MT/ha)	Estimated Water Column Standing Stock (MT)
ARTIFICIAL REEFS							
Torrey Pines AR	0.18	0.665		0.120	0		0
Pendleton AR	1.40	0.359		0.503	0.0003		0.0004
Newport Beach AR	2.50	0.783		1.958	0		0
LA Harbor Breakwater outside	5.81	0.477		2.771	0.048		0.278
LA Harbor Breakwater inside	4.75	0.422		2.005	0.073		0.347
King Harbor Breakwater	3.86	0.244		0.942	0.007		0.025
Hermosa Beach AR	0.24	0.252		0.061	0		0
Marina Del Rey AR	0.32	0.481		0.154	0		0
Pitas Point AR	0.45	0.620		0.279	0.012		0.005
Rincon Oil Island	2.81	0.221		0.621	0.030		0.84
NATURAL REEFS							
Marine Street Reef	220.00	0.136	0.207	45.540	0.012	0.012	2.64
La Jolla Cove Reef		0.277			0.012		
Del Mar Reef	214.00	0.174		37.236	0.001		0.193
Barn Kelp	80.00	0.164		13.120	0		0
Las Pulgas Reef	53.00	0.154		8.162	0		0
Box Canyon	16.00	0.130		2.080	0		0
San Onofre Kelp Main (4-1)	104.00	0.191	0.298	30.992	0.157	0.087	9.058
San Onofre Kelp North (002)		0.404			0.016		
San Mateo Kelp	114.00	0.363	0.578	65.892	0.067	0.036	4.070
Two Man Rock		0.792			0.005		
Laguna Beach North	23.00	0.211		4.853	0.141		3.252
Pelican Point	31.00	0.399		12.369	0.027		0.828
Point Vicente		0.495			0		
Don't Dive There	551.00	0.921	0.501	276.051	0.116	0.040	22.040
Flat Rock		0.086			0.004		
Rincon Kelp	6.80	0.327		2.224	0.004		0.025

Table 1-43

Summary of rank regressions between fish species richness and physical characteristics of reefs.

Independent variables were reef area, depth, and relief. Included are results of regressions with $p \leq 0.1$. Complete results of regression analyses are given in Table D-1 in Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

Ind. Var.	Habitat	Life-stage	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
REEF AREA	BENTHOS		- No Significant Regressions -					
REEF AREA	WATER COLUMN	Young of Year	+	0.65	0.0048**			ns
REEF AREA	WATER COLUMN	Juveniles and Adults	+	0.59	0.0093**			ns
REEF AREA	WATER COLUMN	All Lifestages	+	0.59	0.0093**			ns
REEF AREA	TOTAL SAMPLED ON REEF				ns	+	0.23	0.0582
REEF HEIGHT	BENTHOS	Young of Year			ns	+	0.20	0.0806[1]
REEF HEIGHT	WATER COLUMN	Young of Year	+	0.42	0.0426*			ns
REEF HEIGHT	WATER COLUMN	Juveniles and Adults	+	0.47	0.0279*			ns
REEF HEIGHT	WATER COLUMN	All Lifestages	+	0.47	0.0279*			ns
REEF HEIGHT	TOTAL SAMPLED ON REEF				ns			ns

Table 1-43

Ind. Var.	Habitat	Life-stage	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
REEF DEPTH	BENTHOS	Young of Year	-	0.33	0.0809	+	0.21	0.0781[1]
		Juveniles and Adults	+	0.43	0.0385*			ns
		All Lifestages	+	0.31	0.0917[1]			ns
	WATER COLUMN	Young of Year	-	0.63	0.0058**			ns
		Juveniles and Adults	-	0.55	0.0136*			ns
		All Lifestages	-	0.55	0.0136*			ns
	TOTAL SAMPLED ON REEF				ns			ns

[1]Regression on raw transformed data was significant ($p < 0.05$).

Table 1-44
page 1 of 3

Summary of rank regressions between species richness of fish and algal characteristics of reefs.

Included are results of regressions with $p \leq 0.1$. Complete results of regression analyses are given in Table D-2 in Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

Ind. Var.	Habitat	Life-stage	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Understory Kelp Density	Benthos	- No Significant Regressions -						
	Water Column	- No Significant Regressions -						
	Total Sampled on Reef				ns			ns
Macrocystis Density	Benthos	All Lifestages	-	0.32	0.0887			ns
	Water Column	Young of Year	+	0.77	0.0008**	+	0.42	0.0070**
		Juveniles and Adults	+	0.76	0.0010	+	0.53	0.0014**
		All Lifestages	+	0.76	0.0010**	+	0.53	0.0013**
	Total Sampled on Reef				ns			ns

Table 1-44
page 2 of 3

IND. VAR.	HABITAT	LIFE-STAGE	ARTIFICIAL REEFS SLOPE	R^2	P	NATURAL REEFS SLOPE	R^2	P
DENSITY OF ALL KELPS	BENTHOS	Juveniles and Adults	-	0.40	0.0486*			ns
		All Lifestages	-	0.51	0.0200*			ns
	WATER COLUMN	Young of Year	+	0.58	0.0104*	+	0.26	0.0428*
		Juveniles and Adults	+	0.60	0.0086*			ns
		All Lifestages	+	0.60	0.0086**			ns
	TOTAL SAMPLED ON REEF				ns			ns
PERCENT COVER OF ALGAE	BENTHOS	- No Significant Regressions -						
	WATER COLUMN	- No Significant Regressions -						
	TOTAL SAMPLED ON REEF				ns			ns

Table 1-44

IND. VAR.	HABITAT	LIFE-STAGE	ARTIFICIAL REEFS SLOPE	ARTIFICIAL REEFS R^2	ARTIFICIAL REEFS P	NATURAL REEFS SLOPE	NATURAL REEFS R^2	NATURAL REEFS P
MEAN ALGAL HEIGHT	BENTHOS	- No Significant Regressions -						
	WATER COLUMN	Young of Year	+	0.50	0.0214*			ns
		Juveniles and Adults	+	0.44	0.0360*			ns
		All Lifestages	+	0.44	0.0360*			ns

Table 1-45

Multiple regression analysis of species richness of fish vs. physical and biological characteristics of reefs.

Both artificial and natural reefs are included. The "algae" variable is based on a principal components analysis that included the density of understory kelps, % cover of foliose red and brown algae, % cover of erect coralline algae, total % cover of algae, and mean algal height. See Methods for details of the other independent variables and the transformations used. The analyses were performed on all lifestages combined (ALL) and young-of-year (YOY). Bold indicates p < 0.15.

HABITAT	LIFE-STAGE		REEF TYPE	REEF AREA	REEF HEIGHT	REEF DEPTH	MACRO-CYSTIS	ALGAE	GORG-ONIANS	MODEL R^2	P
BENTHOS	ALL	SLOPE	**-7.87**	**1.94**	-0.05	**0.25**	-0.73	-0.21	-0.20	0.66	0.003
		P	**0.008**	**0.109**	0.75	**0.089**	0.30	0.55	0.71		
	YOY	SLOPE	**-3.82**	**1.43**	0.08	-0.07	**-0.84**	0.02	0.10	0.50	0.050
		P	**0.031**	**0.059**	0.40	0.44	**0.059**	0.94	0.75		
WATER COLUMN	ALL	SLOPE	-0.40	0.31	**0.27**	**-0.30**	**2.57**	**-0.48**	0.27	0.80	0.001
		P	0.85	0.73	**0.034**	**0.012**	**0.001**	**0.084**	0.51		
	YOY	SLOPE	-0.56	0.13	0.06	-0.09	**0.99**	-0.08	0.07	0.52	0.038
		P	0.69	0.83	0.44	0.26	**0.013**	0.65	0.80		
TOTAL SAMPLED ON REEF		SLOPE	**-6.97**	**1.75**	0.09	0.14	0.46	**-0.57**	0.19	0.67	0.002
		P	**0.016**	**0.140**	0.55	0.33	0.50	**0.107**	0.72		

Summary of rank regressions between density of fish near the benthos and in the water column and reef area.

Included are results of regressions with p ≤ 0.10. Complete results are given in Table D-3 in Appendix D. ** indicates p ≤ 0.05. * indicates 0.01 < p ≤ 0.05.

Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Reef Area	Benthos	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Opaleye	+	0.375	0.0600			ns
			Black Surfperch	+	0.486	0.0251*			ns[2]
			Pile Surfperch			ns	+	0.294	0.0299*
			Sheep-head	-	0.296	0.1000			ns
			Rock Wrasse			ns			ns[1]
		Juven. and Adults	All Species			ns			ns
			Sport Fish			ns			ns
		Young of Year	All Species			ns			ns
			Sport Fish	+	0.506	0.0211*	+	0.249	0.0491*
			Kelp Bass	+	0.667	0.0039**			ns
			Black Surfperch	+	0.335	0.0798			ns
			Pile Surfperch			ns[2]			ns

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Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Reef Area	Water Column	All Life-stages	All Species	+	0.671	0.0037**			ns
			Sport Fish	+	0.431	0.0392*			ns
			Kelp Bass	+	0.495	0.0233*			ns
			Black-smith	+	0.592	0.0093**			ns
			Kelp Surfperch	+	0.545	0.0148*			ns
		Young of Year	All Species	+	0.393	0.0523			ns
			Sport Fish			ns			ns
			Senorita			ns	+	0.215	0.073

1 Regression on raw transformed data was significant ($p < 0.05$).
2 Significance level of regression on raw transformed data was $0.05 < p < 0.10$.

Table 1-47
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Summary of rank regressions between density of fish near the benthos and in the water column and reef height.

Included are results of regression with $p \leq 0.10$. Complete results are given in Table D-4 in Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

IND. VAR.	HABITAT	LIFE-STAGE	DEPENDENT VARIABLE	ARTIFICIAL REEFS SLOPE	ARTIFICIAL REEFS R^2	ARTIFICIAL REEFS P	NATURAL REEFS SLOPE	NATURAL REEFS R^2	NATURAL REEFS P
REEF HEIGHT	BENTHOS	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Opaleye			ns	+	0.283	0.0340*
			Gari-baldi			ns	+	0.484	0.0028**
		Juven. and Adults	All Species			ns			ns
			Sport Fish			ns			ns
		Young of Year	All Species			ns			ns
			Sport Fish	+	0.395	0.0515			ns
			Kelp Bass	+	0.329	0.0831	-	0.299	0.0286*

Table 1-47
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Ind. Var.	Habitat	Life-Stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Reef Height	Water Column	All Life-Stages	All Species	+	0.564	0.0123*			ns
			Sport Fish			ns [2]			ns
			Black-smith	+	0.644	0.0052**	+	O.220	0.0669 [1]
			Kelp Surf-perch	+	0.511	0.0201*			ns
		Young of Year	All Species			ns [2]			ns
			Sport Fish			ns			ns
			Senorita			ns [1]			ns

1 Regression on raw transformed data was significant ($p < 0.05$).
2 Sigificance level of regression on raw transformed data was $0.05 < p < 0.10$.

Table 1-48
page 1 of 2

Summary of rank regressions between density of fish near the benthos and in the water column and reef depth.

Included are results of regressions with p $\leq$ 0.10. Complete results are given in Table D-5 Appendix D. ** indicates p $\leq$ 0.01. * indicates 0.01 < p $\leq$ 0.05.

Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
REEF DEPTH	BENTHOS	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Opaleye	-	0.489	0.0244*			ns
			Black Surf-perch	-	0.656	0.0045**			ns
			Sheep-head	+	0.347	0.0734			ns
		Juven. and Adults	All Species			ns			ns
			Sport Fish			ns			ns
		Young of Year	All Species			ns			ns
			Sport Fish	-	0.928	0.0001**			ns
			Kelp Bass	-	0.570	0.0116*			ns
			Black Surf-perch	-	0.862	0.0001**			ns
			Pile Surf-perch	-	0.308	0.0959			ns

Table 1-48

Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Reef Depth	Water Column	All Life-stages	All Species	-	0.592	0.0093**			ns
			Sport Fish	-	0.611	0.0076**			ns
			Kelp Bass	-	0.783	0.0007**			ns
			Black-smith	-	0.379	0.0583[1]			ns
		Young of Year	All Species	-	0.724	0.0018**			ns
			Sport Fish	-	0.365	0.0645			ns

[1] Regression on raw transformed data was significant ($p<0.05$).

Table 1-49

Summary of rank regressions between density of fish near the benthos and in the water column and foliose algae.

Included are results of regressions with p ≤ 0.10. Complete results are given in Table D-6 Appendix D. * indicates p ≤ 0.05.

Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Foliose Algae	Benthos	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Barred Sand Bass			ns	-	0.321	0.0221*
			Gari-baldi	+	0.396	0.0514	+	0.183	0.0988
			Black-smith			ns [2]			ns
			Senorita	+	0.328	0.0838			ns
		Juven. and Adults	All Species	-	0.299	0.1000			ns
			Sport Fish			ns			ns
		Young of Year	All Species			ns			ns
			Sport Fish			ns	+	0.283	0.0341*
			Black Surf-perch			ns [2]	+	0.298	0.0287*
			Senorita			ns [2]			ns

Table 1-49

IND. VAR.	HABITAT	LIFE-STAGE	DEPENDENT VARIABLE	ARTIFICIAL REEFS SLOPE	ARTIFICIAL REEFS R^2	ARTIFICIAL REEFS P	NATURAL REEFS SLOPE	NATURAL REEFS R^2	NATURAL REEFS P
FOLIOSE ALGAE	WATER COLUMN	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Black-smith			ns			ns [1]
		Young of Year	All Species	+	0.356	0.0687			ns
			Sport Fish			ns			ns

1 Regression on raw transformed was significant ($p<0.05$).
2 Significance level of regression on raw tranformed data was $0.05<p<0.10$.

Table 1-50
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Summary of rank regressions between density of fish near the benthos and in the water column and understory kelp (laminarian algae plus Cystoseira but without Macrocystis).

Included are results of regressions with $p \leq 0.10$. Complete results are given in Table D-7 Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

IND. VAR.	HABITAT	LIFE-STAGE	DEPENDENT VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS		
				SLOPE	R^2	P	SLOPE	R^2	P
UNDERSTORY KELP	BENTHOS	All Life-stages	All Species			ns			ns
			Sport Fish			ns	-	0.420	0.0083**
			Barred Sand Bass			ns	-	0.538	0.0012**
			Black Surf-perch			ns	-	0.457	0.0040**
		Juven. and Adults	All Species			ns	-	0.210	0.0746
			Sport Fish			ns	-	0.383	0.0106*
		Young of Year	All Species			ns			ns
			Sport Fish			ns			ns
			Senorita			ns	+	0.373	0.0119*

Table 1-50
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Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Understory Kelp	Water Column	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Black-smith	+	0.0323	0.0866			ns
		Young of Year	All Species			ns			ns
			Sport Fish			ns			ns
			Senorita	+	0.346	0.0736[1]			ns

[1] Regression on raw transformed data was significant ($p < 0.05$).

Table 1-51
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Summary of rank regressions between density of fish near the benthos and in the water column and *Macrocystis pyrifera.*

Included are the results of regressions with $p \leq 0.10$. Complete results are given in Table D-8 in Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
MACROCYSTIS	BENTHOS	All Life-Stages	All Species	-	0.378	0.0587			ns
			Sport Fish			ns			ns
			Barred Sand Bass			ns	-	0.243	0.0526
			Opaleye	+	0.534	0.0164*			ns
			Pile Surf-perch			ns	+	0.255	0.0462*
			Sheep-head	-	0.380	0.0577			ns
		Juven. and Adults	All Species			ns			ns
			Sport Fish			ns			ns
		Young of Year	All Species			ns			ns
			Sport Fish	+	0.308	0.0960	+	0.249	0.0490*
			Black Surf-perch			ns	+	0.222	0.0655
			Black-smith			ns	-	0.190	0.0917

Table 1-53

Summary of rank regressions between density of fish near the benthos and in the water column and percent cover of algae.

Algal cover was estimated along transects. Included are results of regressions with $p \leq 0.10$. Complete results are given in Table D-10 in Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

Ind. Var.	Habitat	Life-Stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
Percent Cover of Algae	Benthos	All Life-stages	All Species			ns			ns
			Sport Fish			ns			ns
			Barred Sand Bass			ns	-	0.405	0.0080**
			Gari-baldi	+	0.567	0.0120*			ns
		Juven. and Adults	All Species			ns			ns
			Sport Fish			ns			ns[2]
		Young of Year	All Species			ns			ns
			Sport Fish	+	0.386	0.0551	+	0.180	0.1000
			Black Surf-perch			ns			ns
	Water Column	All Life-stages	All Species			ns[1]			ns
			Sport Fish			ns			ns
			Black-smith	+	0.355	0.0693[1]			ns[2]
		Young of Year	All Speces	+	0.403	0.0486*			ns
			Sport Fish			ns			ns

[1]Regression on raw transformed data was siginificant ($p < 0.05$)

[2]Significance level of regression on raw transformed data was $0.04 < p < 0.10$.

Table 1-54
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Summary of rank regressions between density of fish near the benthos and in the water column and mean algal height.

Included are results of regressions with $p \leq 0.10$. Complete results are given in Table D-11 in Appendix D. ** indicates $p \leq 0.01$. * indicates $0.01 < p \leq 0.05$.

IND. VAR.	HABITAT	LIFE-STAGE	DEPENDENT VARIABLE	ARTIFICIAL REEFS			NATURAL REEFS		
				SLOPE	R^2	P	SLOPE	R^2	P
MEAN ALGAL HEIGHT	BENTHOS	All Life-stages	All Species			ns			ns
			Sport Fish			ns	-	0.271	0.0387*
			Barred Sand Bass			ns	-	0.572	0.0007**
			Gari-baldi	+	0.310	0.0949			ns
			Sheep-head	-	0.310	0.0944			ns
		Juven. and Adults	All Species	-	0.384	0.0560	-	0.250	0.0486
			Sport Fish			ns	-	0.261	0.0432
		Young of Year	All Species			ns			ns
			Sport Fish	+	0.450	0.0337*	+	0.205	0.0783
			Black Surfperch	+	0.308	0.0962			ns

Table 1-54
page 2 of 2

IND. VAR.	HABITAT	LIFE-STAGE	DEPENDENT VARIABLE	ARTIFICIAL REEFS SLOPE	ARTIFICIAL REEFS R^2	ARTIFICIAL REEFS P	NATURAL REEFS SLOPE	NATURAL REEFS R^2	NATURAL REEFS P
MEAN ALGAL HEIGHT	WATER COLUMN	All Life-stages	All Species	+	0.476	0.0272*			ns
			Sport Fish	+	0.377	0.0590			ns
			Kelp Bass	+	0.329	0.0829			ns
			Black-smith	+	0.713	0.0021**			ns
		Young of Year	All Species	+	0.547	0.0145*			ns
			Sport Fish			ns			ns

Table 1-55

Summary of rank regressions between density of fish near the benthos and density of gorgonians.

Included are results of regressions with $p \leq 0.10$. Complete results of regression analyses are given in Table D-12 in Appendix D. * indicates $p \leq 0.05$.

Ind. Var.	Habitat	Life-stage	Dependent Variable	Artificial Reefs Slope	Artificial Reefs R^2	Artificial Reefs P	Natural Reefs Slope	Natural Reefs R^2	Natural Reefs P
GORGONIANS	BENTHOS	All Life-stages	All Species			ns			ns
			Sport Fish	-	0.373	0.0608			ns
			Kelp Bass	-	0.361	0.0661			ns
			Barred Sand Bass	-	0.413	0.0452*	+	0.207	0.079[1]
			Opaleye			ns			ns[2]
			Half-moon	+	0.436	0.0379*			ns
			Pile Surfperch	-	0.528	0.0174*			ns
			Sheep-head			ns	+	0.251	0.0483*
		Juven. and Adults	All Species			ns			ns
			Sport Fish	-	0.522	0.0182*			ns
		Young of Year	All Species			ns			ns
			Sport Fish			ns			ns
			Black-smith			ns	+	0.223	0.0646

[1]Regression on raw transformed data was siginificant ($p < 0.05$).
[2]Regression raw transformed data was marginally siginificant, $p = 0.0566$.

Table 1-56

Multiple regression analysis of density of fish near the benthos vs. physical and biological characteristics of reefs.

Fish density (No. fish/1000 m^3) was $\log_{10}(x + 1)$ transformed for the analysis. (See Table 1-45 for additional details.) Bold indicates $p < 0.15$.

Species	Life-stage		Reef Type	Reef Area	Reef Height	Reef Depth	Macro-cystis	Algae	Gorg-onians	Model R^2	Model P
ALL SPECIES	ALL	Slope	**-0.76**	**0.25**	-0.003	0.005	**-0.15**	-0.02	0.06	0.58	0.015
		P	**0.013**	**0.053**	0.84	0.76	**0.046**	0.60	0.29		
	YOY	Slope	**-1.89**	**0.58**	-0.02	0.02	**-0.41**	**0.13**	0.14	0.63	0.005
		P	**0.002**	**0.020**	0.58	0.39	**0.007**	**0.066**	0.18		
SPORT FISH	ALL	Slope	-0.39	0.09	-0.01	-0.02	0.03	**-0.07**	0.01	0.50	0.054
		P	0.18	0.45	0.72	0.24	0.71	**0.071**	0.92		
	YOY	Slope	**-1.24**	0.38	0.00	**-0.04**	0.02	**0.08**	-0.02	0.61	0.008
		P	**0.010**	**0.055**	0.99	**0.080**	0.86	**0.145**	0.86		
KELP BASS	ALL	Slope	0.09	-0.19	0.04	-0.01	0.08	-0.05	**-0.20**	0.39	0.190
		P	0.87	0.41	0.24	0.68	0.55	0.44	**0.063**		
	YOY	Slope	**-0.62**	**0.24**	-0.01	**-0.03**	-0.036	0.02	0.040	0.42	0.138
		P	**0.060**	**0.097**	0.51	**0.074**	0.66	0.62	0.52		
SAND BASS	ALL	Slope	-0.06	-0.01	-0.01	**-0.05**	-0.15	**-0.14**	**-0.16**	0.54	0.029
		P	0.89	0.94	0.82	**0.043**	0.22	**0.029**	**0.104**		
OPALEYE	ALL	Slope	0.22	-0.14	**0.06**	**-0.07**	0.095	**-0.11**	**-0.21**	0.52	0.035
		P	0.67	0.54	**0.052**	**0.018**	0.48	**0.106**	**0.050**		
HALFMOON	ALL	Slope	-0.37	0.16	-0.01	0.00	-0.06	0.01	0.09	0.13	0.903
		P	0.35	0.35	0.71	0.98	0.57	0.79	0.25		
BLACK SURF-PERCH	ALL	Slope	**-0.70**	**0.28**	0.01	**-0.05**	0.02	**-0.08**	-0.09	0.62	0.007
		P	**0.063**	**0.085**	0.49	**0.009**	0.82	**0.100**	0.23		
	YOY	Slope	**-1.136**	**0.325**	0.001	**-0.038**	0.054	**0.094**	0.032	0.60	0.009
		P	**0.017**	**0.101**	0.95	**0.111**	0.64	**0.108**	0.72		

Table 1-56
page 2 of 2

Species	Life-stage		Reef Type	Reef Area	Reef Height	Reef Depth	Macro-cystis	Algae	Gorg-onians	Model R^2	Model P
Pile Surf-perch	All	Slope	**-0.69**	0.13	-0.01	**-0.03**	**0.20**	**-0.09**	**-0.17**	0.74	0.0003
		P	**0.045**	0.36	0.74	**0.065**	**0.028**	**0.043**	**0.014**		
	YOY	Slope	-0.35	0.11	0.02	**-0.04**	0.05	-0.06	-0.06	0.48	0.070
		P	0.35	0.50	0.31	**0.044**	0.59	0.24	0.42		
Gari-baldi	All	Slope	0.01	0.15	0.04	0.02	-0.18	0.15	0.02	0.41	0.151
		P	0.99	0.58	0.27	0.64	0.28	**0.088**	0.89		
Black-smith	All	Slope	**-1.46**	0.42	0.05	**0.10**	-0.31	-0.07	**0.44**	0.64	0.005
		P	**0.096**	0.26	0.29	**0.030**	0.16	0352	**0.015**		
	YOY	Slope	-1.08	0.23	0.003	0.07	-0.31	-0.01	**0.34**	0.50	0.051
		P	0.21	0.53	0.95	0.13	0.16	0.96	**0.051**		
Sheep-head	All	Slope	-0.26	0.19	**-0.05**	**0.09**	-0.12	0.07	**0.30**	0.54	0.026
		P	0.65	0.44	**0.145**	**0.007**	0.40	0.34	**0.014**		
Senorita	All	Slope	-0.85	0.32	-0.04	0.002	**-0.31**	**0.19**	0.14	0.28	0.45
		P	0.30	0.37	0.39	0.97	**0.146**	**0.081**	0.41		
	YOY	Slope	**-1.06**	0.26	**-0.06**	0.01	**-0.25**	**0.21**	0.08	0.41	0.149
		P	**0.090**	0.32	**0.100**	0.76	**0.122**	**0.013**	0.46		
Rock Wrasse	All	Slope	-0.31	**0.40**	-0.02	0.003	-0.21	0.07	0.09	0.38	0.198
		P	0.59	**0.122**	0.59	0.91	0.16	0.34	0.44		

Table 1-57

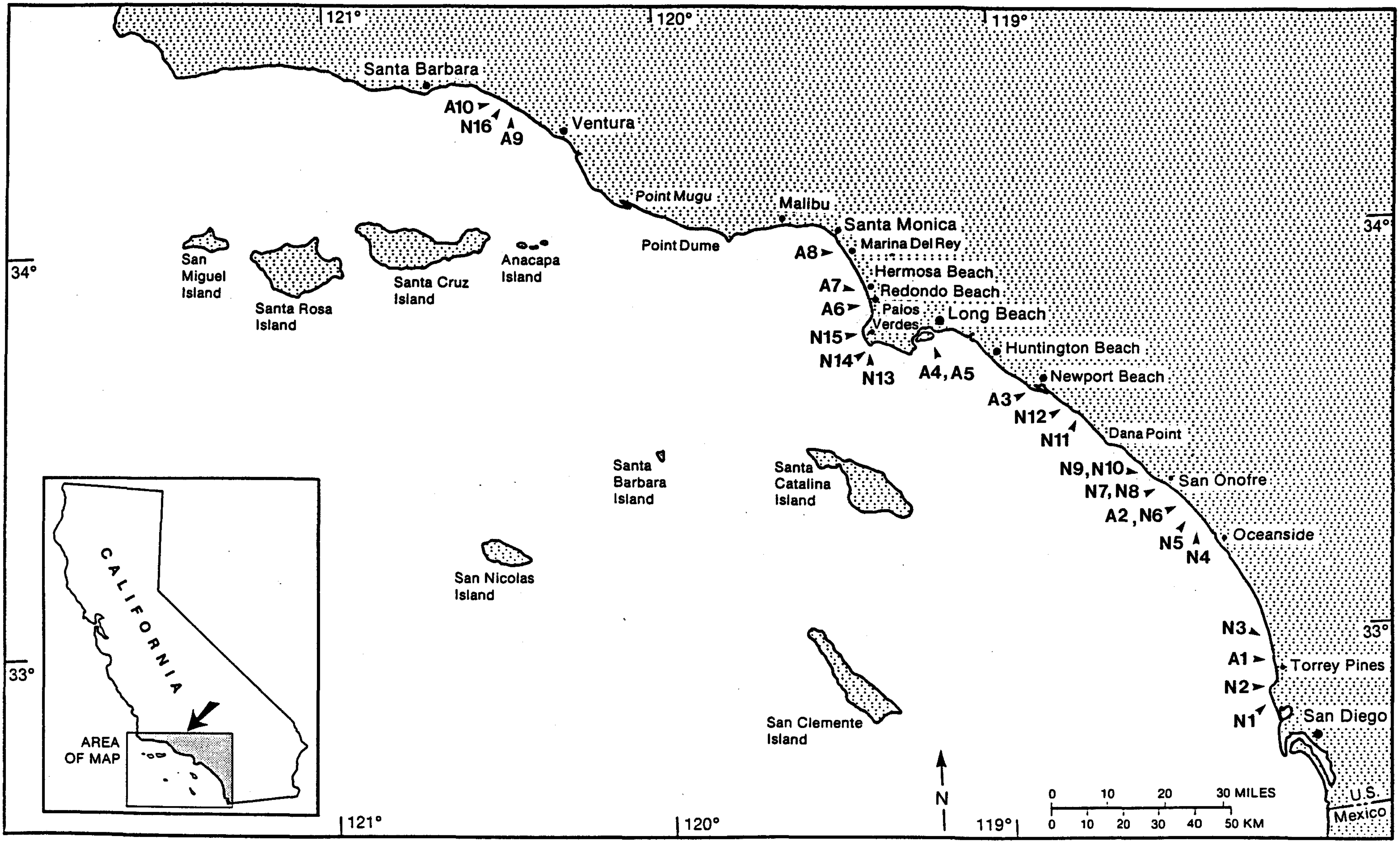
Multiple regression analysis of density of fish in the water column vs. physical and biological characteristics of reefs.

Fish density (No. fish/100,000 m^3) was $log_{10}(x + 1)$ transformed for the analysis. (See Table 1-45 for additional details.) Bold indicates $p < 0.15$.

SPECIES	LIFE-STAGE	TYPE	REEF AREA	REEF HEIGHT	REEF DEPTH	REEF CYSTIS	MACRO- ALGAE	GORG-ONIANS	MODEL R^2	MODEL P
ALL SPECIES	ALL	SLOPE	-0.11	0.21	0.09	-0.16	**1.20**	0.05	0.17	0.64	0.005
		P	0.94	0.75	0.33	0.16	**0.006**	0.81	0.57		
	YOY	SLOPE	-1.35	0.29	0.05	**-0.13**	**0.97**	0.14	**-0.44**	0.62	0.006
		P	0.37	0.65	0.57	**0.121**	**0.020**	0.47	**0.145**		
SPORT FISH	ALL	SLOPE	0.64	-0.42	0.04	-0.07	**1.40**	-0.07	0.38	0.52	0.037
		P	0.70	0.55	0.66	0.41	**0.003**	0.75	0.24		
	YOY	SLOPE	-1.02	0.03	-0.06	-0.09	**0.64**	-0.01	0.01	0.43	0.121
		P	0.42	0.95	0.36	0.17	**0.056**	0.96	0.96		
KELP BASS	ALL	SLOPE	0.39	0.07	-0.01	-0.02	**0.67**	-0.09	0.32	0.26	0.53
		P	0.80	0.91	0.95	0.83	**0.111**	0.65	0.32		
HALFMOON	ALL	SLOPE	0.55	0.17	-0.06	-0.01	**0.75**	-0.19	0.30	0.44	0.112
		P	0.67	0.76	0.39	0.89	**0.035**	0.25	0.25		
KELP SURFPERCH	ALL	SLOPE	0.27	0.07	0.04	-0.03	**1.29**	-0.19	0.23	0.59	0.012
		P	0.84	0.90	0.57	0.64	**0.001**	0.26	0.40		
BLACK-SMITH	ALL	SLOPE	-1.11	0.37	**0.28**	**-0.13**	-0.14	0.19	-0.19	0.70	0.001
		P	0.41	0.53	**0.002**	**0.076**	0.69	0.28	0.49		
SENORITA	ALL	SLOPE	1.81	-0.64	0.08	-0.04	**1.42**	-0.19	-0.18	0.55	0.022
		P	0.24	0.33	0.37	0.65	**0.002**	0.33	0.56		
	YOY	SLOPE	0.77	-0.10	0.04	0.08	**0.94**	0.02	-0.07	0.48	0.068
		P	0.59	0.87	0.63	0.31	**0.018**	0.92	0.81		

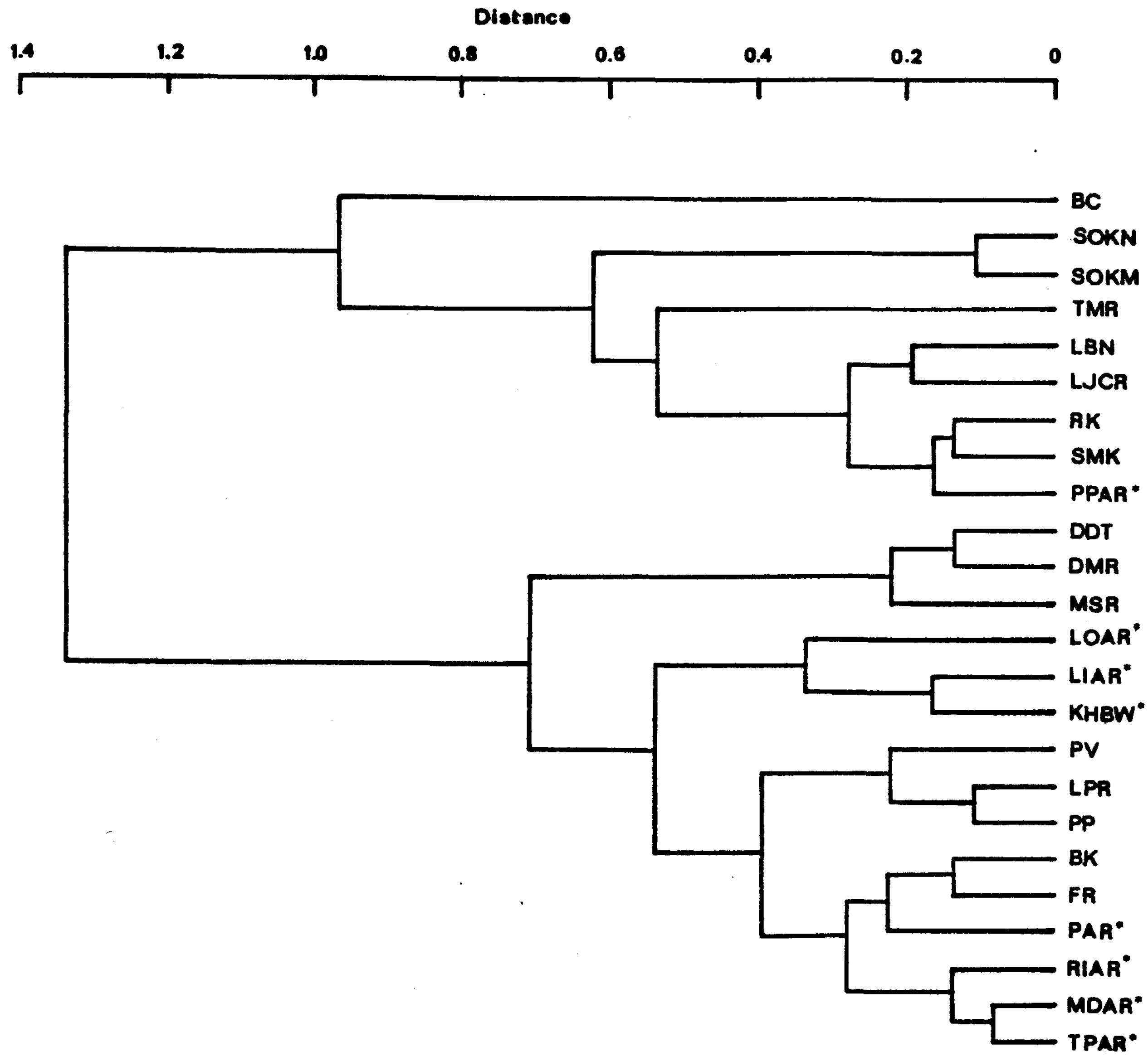
FIGURES

Figure 1-1 Map of survey sites. "A" indicates artificial reef, "N" indicates natural reef. See Table 1-1 for the names of reefs corresponding to numbers.



121°
120°
119°
34°
33°
Santa Barbara
A10
N16
A9
Ventura
Point Mugu
Point Dume
Malibu
Santa Monica
Marina Del Rey
Hermosa Beach
Redondo Beach
Palos
Verdes
Long Beach
Huntington Beach
Newport Beach
Dana Point
San Onofre
Oceanside
Torrey Pines
San Diego
U.S.
Mexico
A8
A7
A6
N15
N14
N13
A4, A5
A3
N12
N11
N9, N10
N7, N8
A2, N6
N5
N4
N3
A1
N2
N1
San
Miguel
Island
Santa Rosa
Island
Santa Cruz
Island
Anacapa
Island
Santa
Barbara
Island
Santa
Catalina
Island
San Nicolas
Island
San Clemente
Island
N
0 10 20 30 MILES
0 10 20 30 40 50 KM
CALIFORNIA
AREA
OF MAP

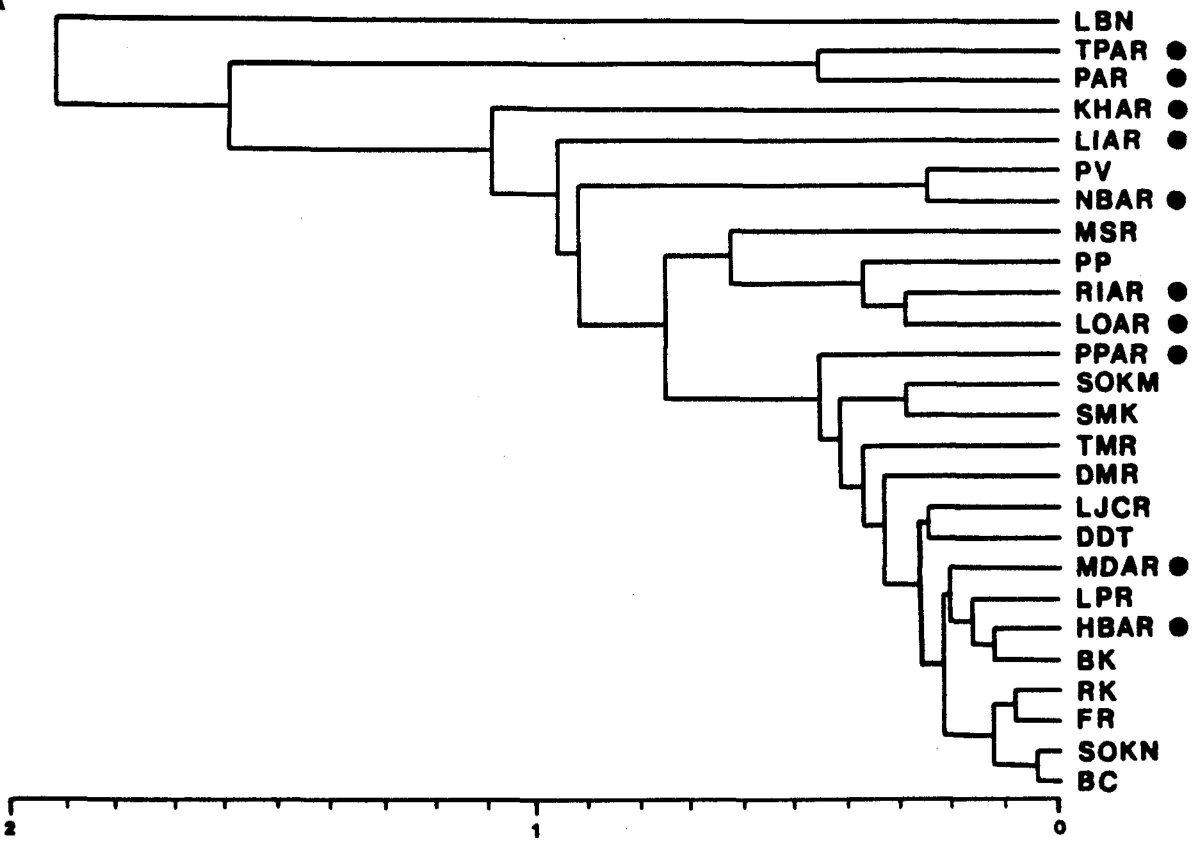
Figure 1-2 Cluster analysis of reefs by substrate characteristics. Mean and standard deviation of particle size on reefs was used in an average linkage cluster analysis. Substrate characteristics on reefs are shown in Table 1-11. Codes for reef names are shown in Table 1-1. * indicates artificial reef.



Distance
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
BC
SOKN
SOKM
TMR
LBN
LJCR
RK
SMK
PPAR*
DDT
DMR
MSR
LOAR*
LIAR*
KHBW*
PV
LPR
PP
BK
FR
PAR*
RIAR*
MDAR*
TPAR*

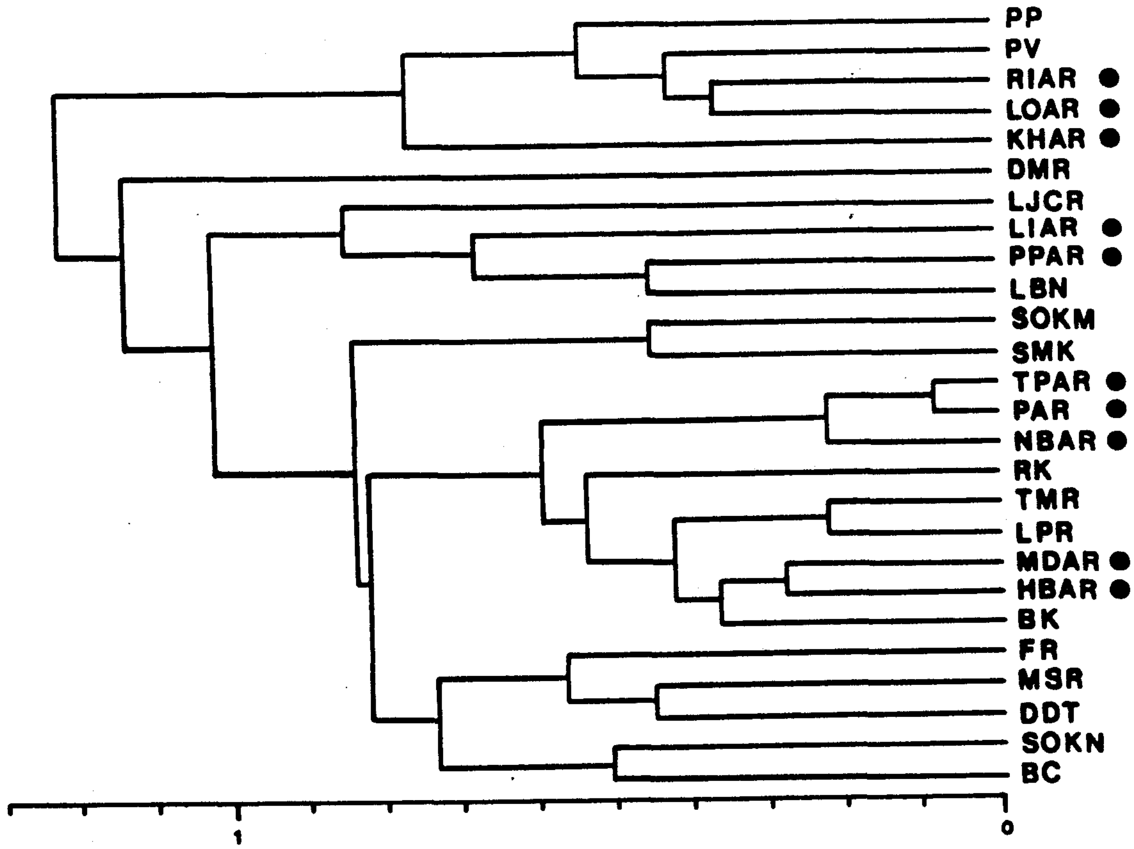
Figure 1-3 Cluster analysis of fish assemblages on sampled reefs. Codes for reef names are given in Table 1-1; artificial reefs are indicated by bullets. (A) Analysis based on absolute densities of fish. (B) Analysis based on relative densities of fish (i.e. density of individual species/total density of fish on a reef).

A



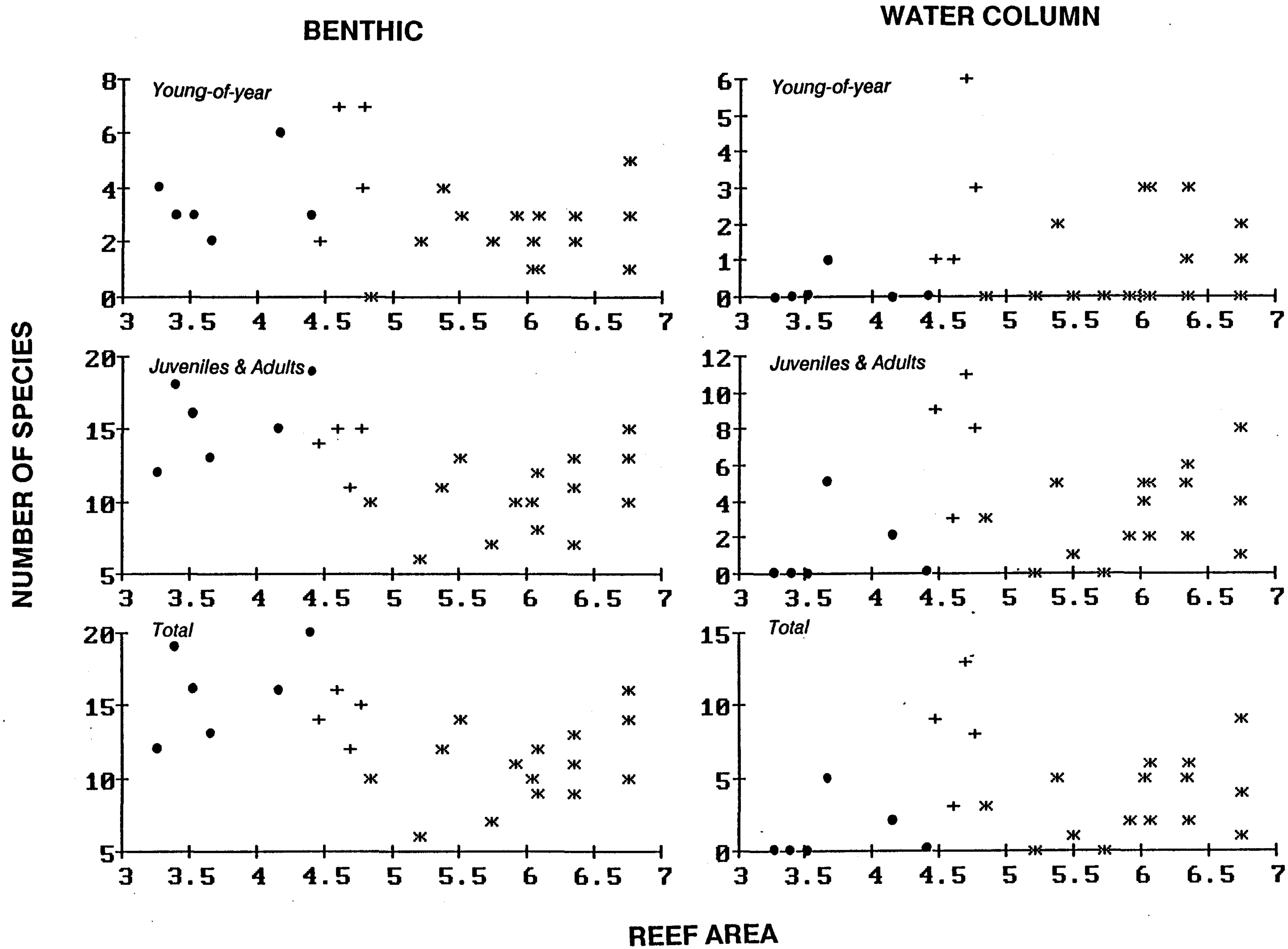
LBN
TPAR
PAR
KHAR
LIAR
PV
NBAR
MSR
PP
RIAR
LOAR
PPAR
SOKM
SMK
TMR
DMR
LJCR
DDT
MDAR
LPR
HBAR
BK
RK
FR
SOKN
BC
2
1
0

B



PP
PV
RIAR
LOAR
KHAR
DMR
LJCR
LIAR
PPAR
LBN
SOKM
SMK
TPAR
PAR
NBAR
RK
TMR
LPR
MDAR
HBAR
BK
FR
MSR
DDT
SOKN
BC
1
0

Figure 1-4 Relationship between fish species richness and reef area. Reef area was measured in m^2; data were transformed ($Log_{10}(x+1)$). Key to symbols: • - traditional artificial reef; + - breakwater; * - natural reef.



BENTHIC
WATER COLUMN
Young-of-year
Juveniles & Adults
Total
NUMBER OF SPECIES
REEF AREA

Figure 1-5 Relationship between fish density and reef area. Fish density was measured as No./1000 m^3 near the benthos and No./100,000 m^3 in the water column; data were transformed ($Log_{10}(x+1)$). Reef area was measured in m^2; data were transformed ($Log_{10}(x+1)$). Key to symbols: • - traditional artificial reef; + - breakwater; * - natural reef.

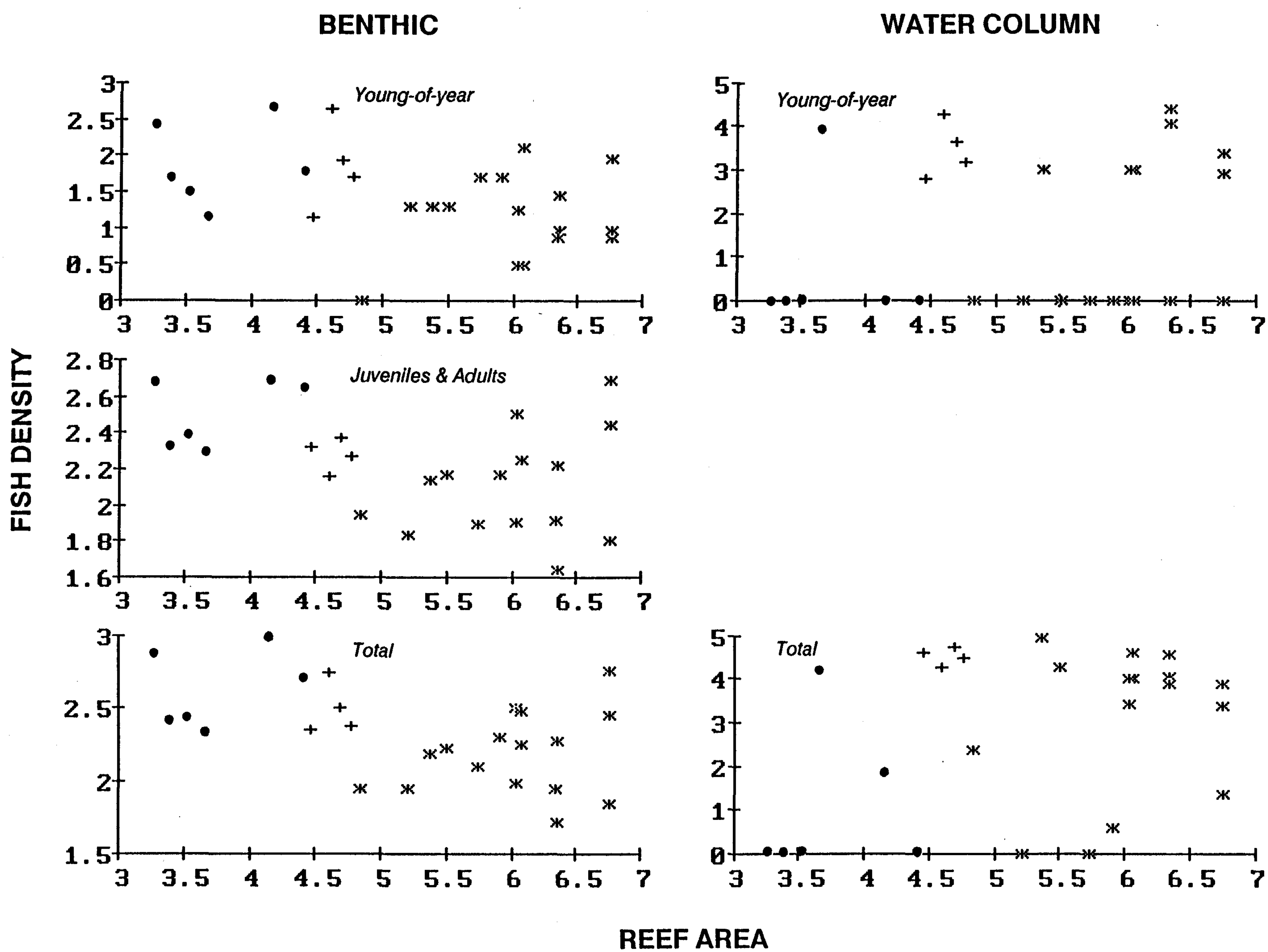

BENTHIC
WATER COLUMN
Young-of-year
Juveniles & Adults
Total
Young-of-year
Total
FISH DENSITY
REEF AREA

Figure 1-6 Relationship between fish species richness and reef height (m). Key to symbols: • - traditional artificial reef; + - breakwater; * - natural reef.

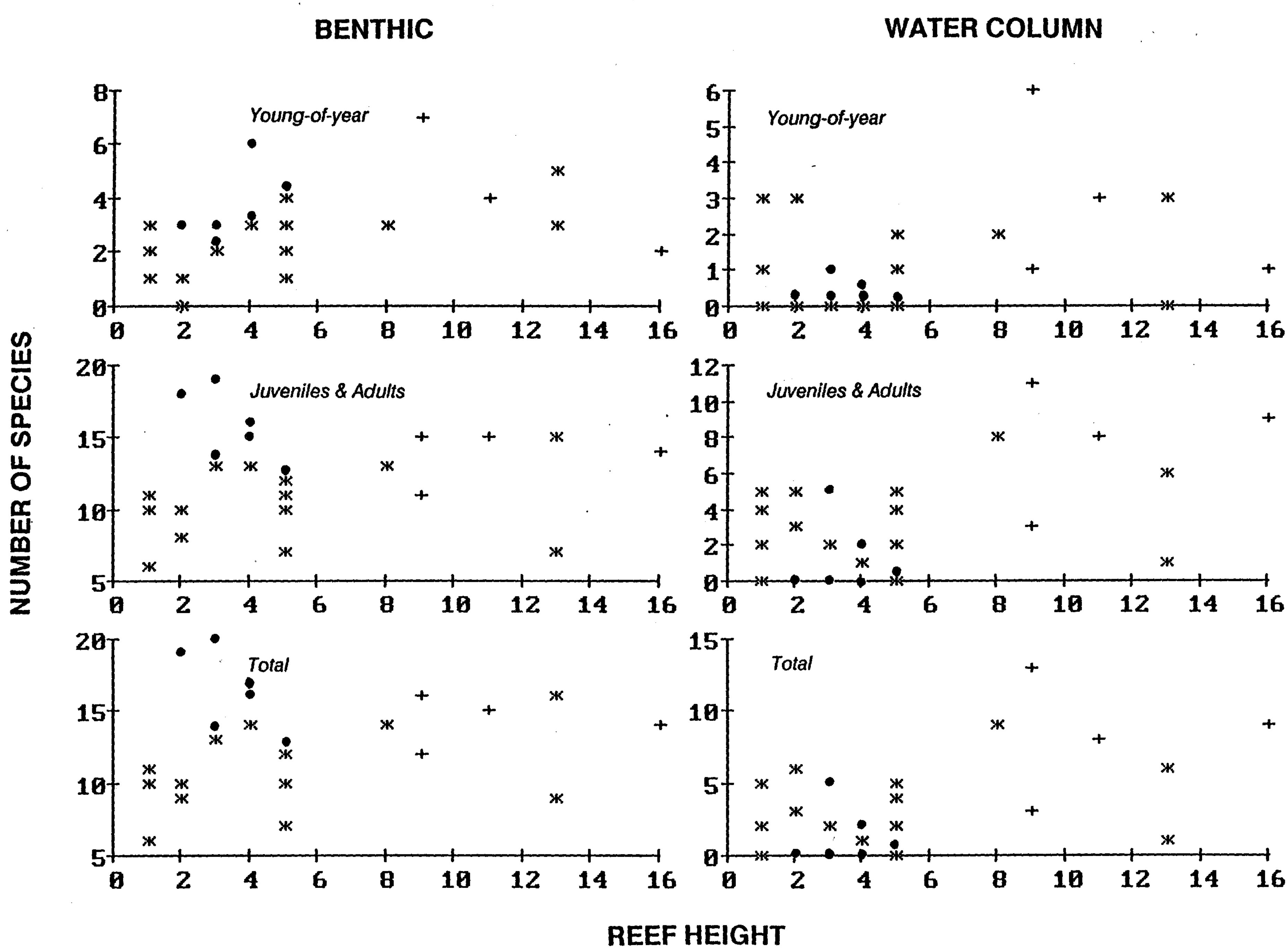
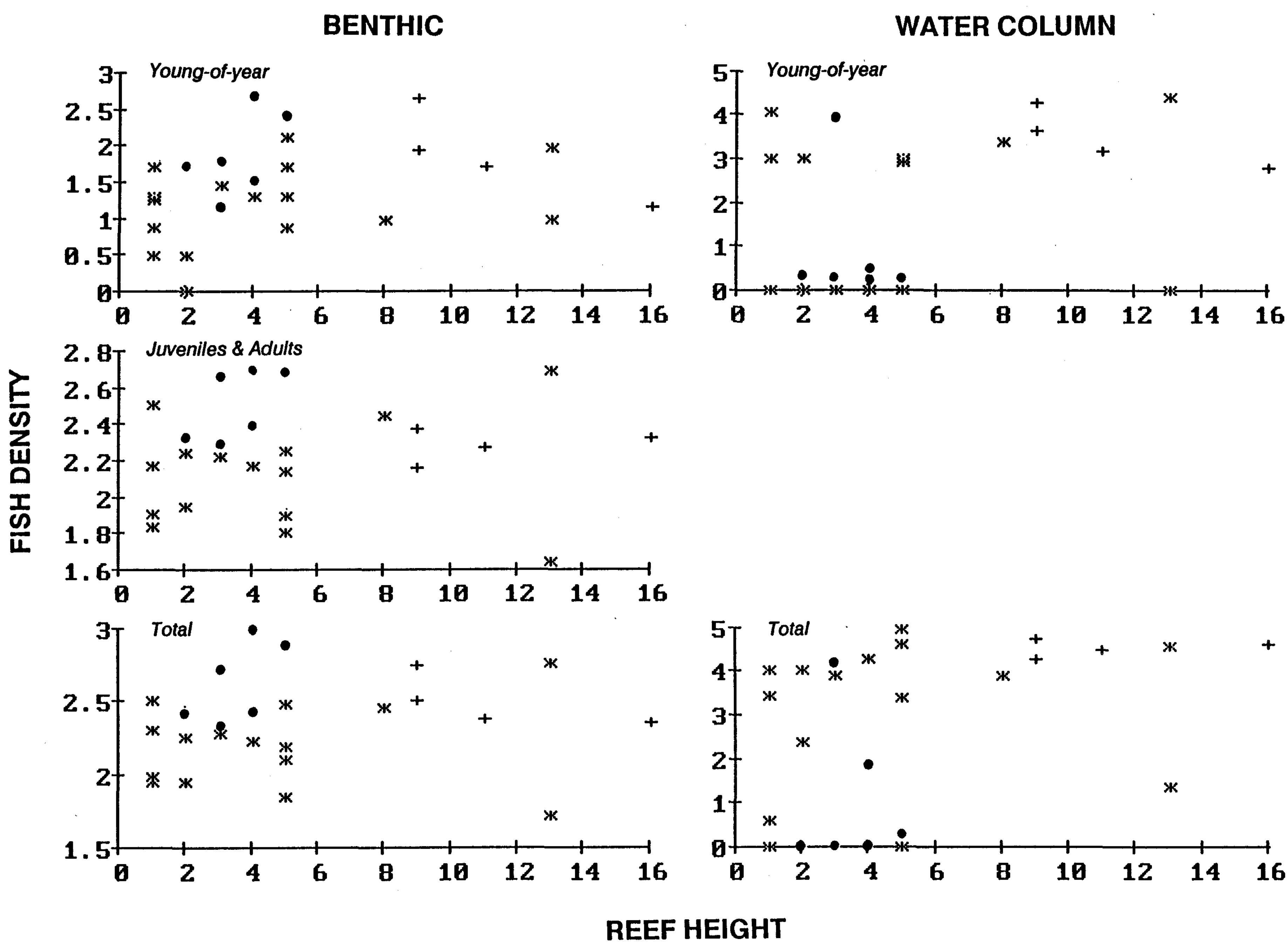

BENTHIC
WATER COLUMN
Young-of-year
Juveniles & Adults
Total
NUMBER OF SPECIES
REEF HEIGHT

Figure 1-7 Relationship between fish density and reef height (m). Fish density was measured as No./1000 m^3 near the benthos and No./100,000 m^3 in the water column; data were transformed ($Log_{10}(x+1)$). Key to symbols: • - traditional artificial reef; + - breakwater; * - natural reef.



BENTHIC
WATER COLUMN
Young-of-year
Juveniles & Adults
Total
FISH DENSITY
REEF HEIGHT

Figure 1-8 Relationship between fish species richness and density of Macrocystis pyrifera. Macrocystis density was measured as No. plants/100 m^2; data were transformed ($Log_{10}(x+1)$). Key to symbols: • - traditional artificial reef; + - breakwater; * - natural reef.

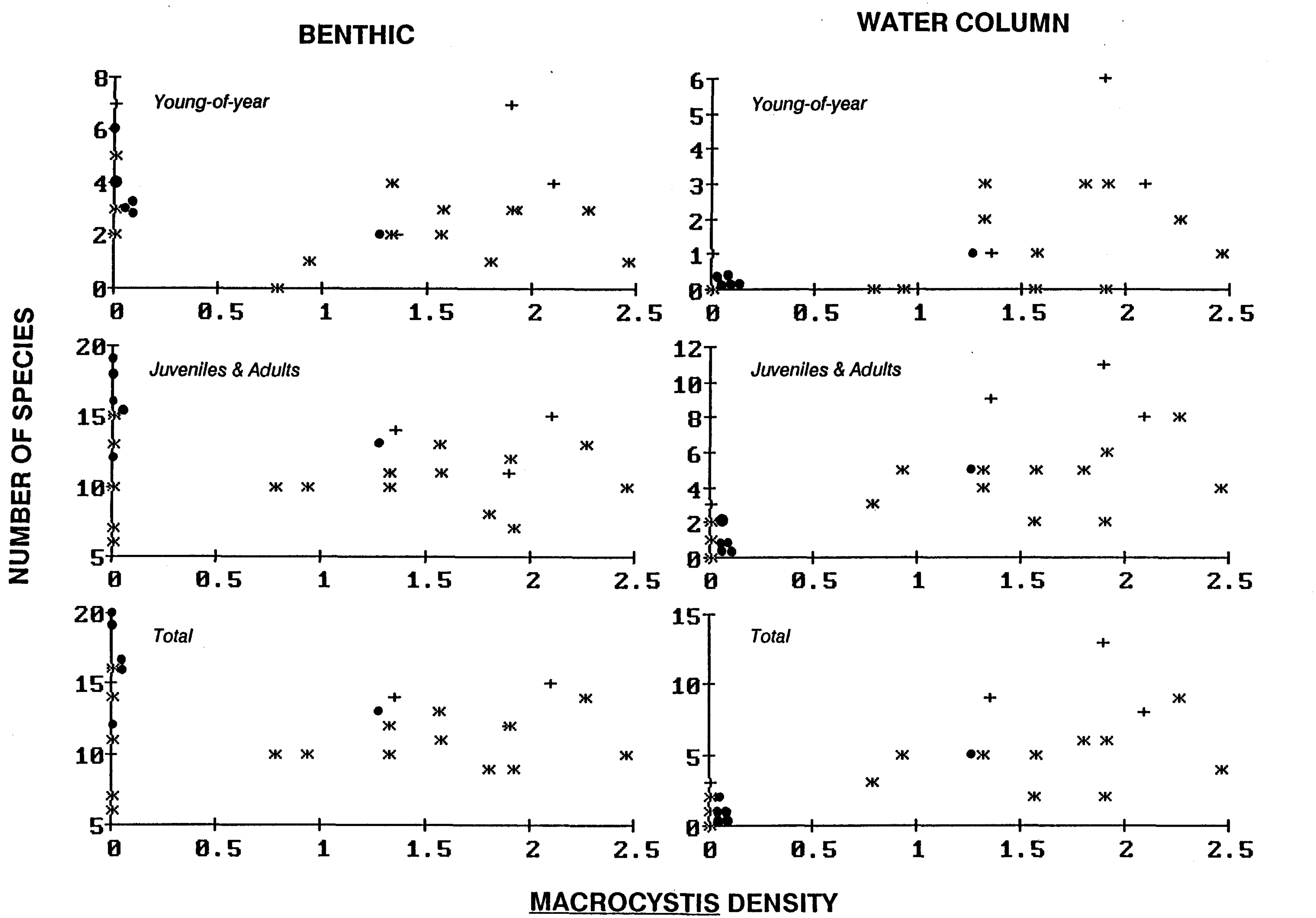
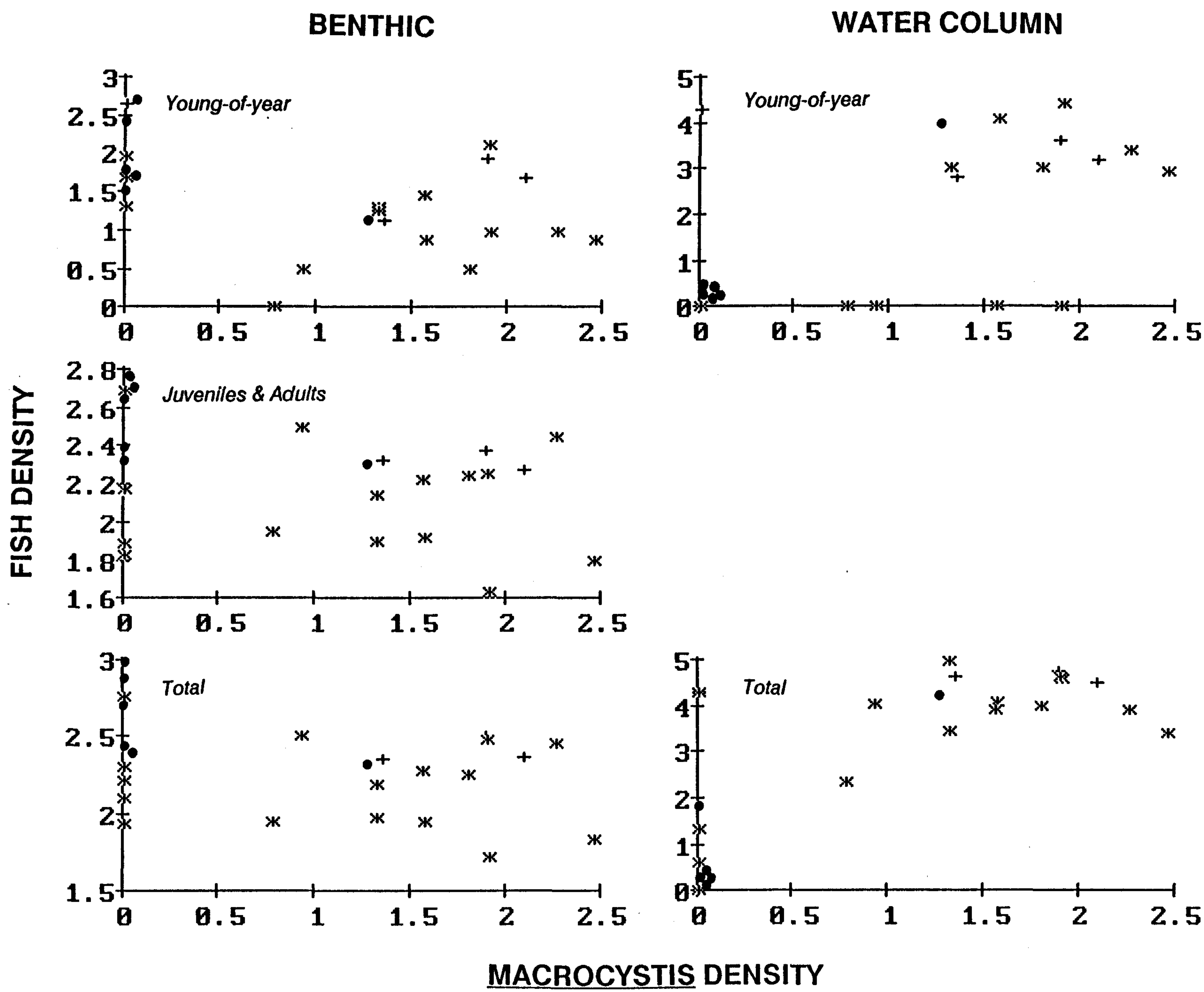

BENTHIC
WATER COLUMN
Young-of-year
Juveniles & Adults
Total
NUMBER OF SPECIES
MACROCYSTIS DENSITY
0
0.5
1
1.5
2
2.5

Figure 1-9 Relationship between fish density and density of Macrocystis pyrifera. Fish density was measured as No./1000 m^3 near the benthos and No./100,000 m^3 in the water column; data were transformed ($Log_{10}(x+1)$). Macrocystis density was measured as No. plants/100 m^2; data were transformed ($Log_{10}(x+1)$). Key to symbols: • - traditional artificial reef; + - breakwater; * - natural reef.



BENTHIC
WATER COLUMN
Young-of-year
Juveniles & Adults
Total
FISH DENSITY
MACROCYSTIS DENSITY

ADDENDUM TO VOLUME II

Errata to Appendices C and D

and

Appendix E

ERRATA FOR APPENDICES C AND D

APPENDIX C

Table C-1

Page 1, Part B : Density of *Eisenia farlowii* is missing. Density is 20.8 (11.65) on LOAR and is 0 on all other artificial reefs.

Table C-4

Page 2 is missing. The entire table is included at the end of the errata.

APPENDIX D

Table D-1

Reef Relief should be Reef Height.

Table D-2

Page 1, bottom : Independent variable is *Macrocystis* and dependent variable should be BENTHIC not WATER COLUMN.

Table D-3

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Page 2: Juveniles & Adults, Sport fish, ranked, Artificial Reefs: P=0.08 should be P=0.80.

Table D-4

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Page 2: Young-of-year, Blacksmith, raw, Natural Reefs: R^2=0.26 should be R^2=0.026.

Page 3: All Lifestages, Blacksmith, raw, Natural Reefs: SLOPE=0.023 should be SLOPE=0.232.

Table D-5

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column; raw data were transformed (Log_{10} (X + 1)) for analyses.

Table D-6

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Page 3: All Lifestages, Halfmoon, ranked - should read Artificial Reefs, SLOPE=-0.248, R^2=0.221, P=0.17, Natural Reefs, SLOPE=-0.030, R^2=-0.001, P=0.91.

Table D-7

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Page 1: All Lifestages, Kelp Bass, raw, Natural Reefs should read: SLOPE=0.047, R^2=0.007, P=0.76.

Table D-8

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Page 3: All stages, Kelp surfperch, raw, Natural Reefs: SLOPE = 10.76 should be SLOPE = 1.076.

Table D-9

Table legend should read: fish density was measured as no./1,000 m^3.

Page 1: All lifestages, Halfmoon, raw, Natural Reefs: SLOPE = 10159 should be SLOPE = 1.159.

Table D-10

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Page 2: Young-of-year, Black surfperch, raw, Natural Reefs: $R^2 = 0.001$ should be $R^2 = 0.110$.

Table D-11

Table legend should read: fish density was measured as no./1,000 m^3 near the benthos and no./100,000 m^3 in the water column.

Table D-12

Table legend should read: Fish density was measured as no./1,000 m^3; raw data were transformed (Log_{10} (X + 1)) for analyses.

Figure Legends

All figure legends for density of fish in the water column should read : fish density was measured as no./100,000 m^3.

Figures D-56 through D-71

Reef Relief should be Reef Height.

Table C-4
page 1 of 2

Mean (1 S.E.) density (number/1000 m^3) of young-of-year fish near the benthos on artificial and natural reefs. (-) indicates that no fish were found.
Reef codes are listed in Table 1 - 1.

NAME	ARTIFICIAL REEFS									
	TPAR	PAR	NBAR	LOAR	LIAR	KHAR	HBAR	MDAR	PPAR	RIAR
olive rock fish	-	-	-	-	4.2 (4.2)	-	-	-	2.1 (2.1)	-
painted greenling	-	-	-	-	-	-	-	2.8 (2.8)	-	-
kelp bass	-	1.0 (1.0)	-	6.3 (6.3)	6.3 (4.4)	4.2 (2.7)	-	-	-	-
sargo	-	-	-	-	-	-	-	-	-	-
opaleye	-	-	-	-	-	2.1 (2.1)	-	-	-	-
black surfperch	2.1 (2.1)	11.5 (6.4)	-	6.3 (3.0)	33.3 (7.7)	31.3 (13.5)	-	-	10.4 (6.3)	6.3 (4.4)
pile surfperch	-	-	-	(6.3) (3.0)	33.3 (12.2)	4.2 (4.2)	-	2.8 (2.8)	-	-
rainbow surfperch	-	-	-	-	4.2 (2.7)	-	-	-	-	-
kelp surfperch	-	-	-	-	2.1 (2.1)	-	-	-	-	-
garibaldi	-	-	-	-	-	-	-	-	-	-
blacksmith	237.5 (90.7)	417.7 (152.1)	54.2 (36.0)	29.2 (11.7)	2.1 (2.1)	-	20.8 (20.8)	25.0 (17.1)	-	6.3 (4.4)
California sheephead	2.1 (2.1)	4.2 (3.2)	-	-	-	-	-	-	-	-
senorita	18.8 (18.8)	24.0 (10.9)	-	-	-	37.5 (15.0)	-	-	-	-
rock wrasse	-	-	-	-	-	2.1 (2.1)	-	-	-	-
bluebanded goby	-	6.3 (3.7)	2.1 (2.1)	-	-	339.6 (103.1)	27.1 (16.0)	-	-	-
blackeye goby	-	-	2.1 (2.1)	-	-	-	2.1 (2.1)	-	-	-
giant kelpfish	-	-	-	-	-	-	-	-	-	-

Table C-4
page 2 of 2

NAME	MSR	LJCR	DMR	BK	LPR	BC	SOKM	SOKN	SMK	TMR	LBN	PP	PV	DDT	FR	RK
	NATURAL REEFS															
olive rockfish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
painted greenling	-	-	-	-	-	-	-	-	-	-	-	-	4.2 (2.7)	-	-	-
kelp bass	-	-	-	-	-	2.1 (2.1)	2.1 (2.1)	4.2 (4.2)	-	-	-	-	-	-	-	-
sargo	-	-	-	-	-	-	-	-	-	-	-	-	-	2.1 (2.1)	-	-
opaleye	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
black surfperch	4.2 (2.7)	4.2 (2.7)	2.1 (2.1)	2.1 (2.1)	-	-	-	-	-	16.7 (8.3)	-	6.3 (3.0)	-	2.1 (2.1)	6.3 (3.0)	-
pile surfperch	2.1 (2.1)	-	2.1 (2.1)	-	-	-	-	-	-	-	-	-	-	-	-	-
rainbow surfperch	-	-	2.1 (2.1)	-	-	-	-	-	-	-	8.3 (4.5)	-	-	4.2 (4.2)	-	-
kelp surfperch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
garibaldi	-	-	-	-	-	-	-	-	-	-	2.1 (2.1)	-	-	-	-	-
blacksmith	-	-	-	45.8 (35.5)	41.7 (41.7)	-	-	-	-	106.3 (74.7)	-	4.2 (2.7)	16.7 (16.7)	-	-	-
California sheephead	-	-	-	-	-	-	-	-	-	2.1 (2.1)	-	-	2.1 (2.1)	-	-	-
senorita	-	22.9 (20.6)	-	-	-	16.7 (16.7)	-	12.5 (10.3)	-	-	2.1 (2.1)	-	-	-	-	-
rock wrasse	-	-	-	-	6.3 (4.4)	-	-	-	-	-	-	-	-	-	-	-
bluebanded goby	-	-	-	-	-	-	-	-	2.1 (2.1)	-	6.3 (6.3)	8.3 (4.5)	62.5 (26.9)	-	-	-
blackeye goby	-	-	-	2.1 (2.1)	-	-	-	-	-	-	-	-	2.1 (2.1)	-	-	-
giant kelpfish	2.1 (2.1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E

LIST OF DATA BASES AND SAS PROGRAMS USED IN ANALYSES

Statistical analyses were done on an IBM 4341 mainframe computer located at the Marine Review Committee (MRC) offices in Encinitas, California. All analyses were done using the SAS software system (SAS Users Guide, Version 5 Edition, SAS Institute Inc., Cary, N.C.). All primary and secondary data bases and SAS programs used in the analyses are listed in this appendix.

PRIMARY (MRC) DATA BASES

This is a list of the data bases created from the raw data collected for this study in the fall, 1986. These data bases were constructed with the help of the MRC contractor, TITAN Systems Inc., and are stored on the Reef Project disk (RE).

Data Base	Contents
DBRPFAB.SUR01	Adult fish densities near the benthos
DBRPFABP.SUR01	Adult fish densities near the benthos on Pendleton Artificial Reef
DBRPFAC.SUR01	Adult fish densities in the water column
DBRPFACT.SUR01	Characteristics of adult fish water column transects
DBRPFJB.SUR01	Juvenile fish densities near the benthos
DBRPRJBP.SUR01	Juvenile fish densities near the benthos on Pendleton Artificial Reef
DBRPFJC.SUR01	Juvenile fish densities in the water column
DBRPFLN.SUR01	Fish lengths
DBRPFLNP.SUR01	Fish lengths on Pendleton Artificial Reef
DBRPKELP.SUR01	Sizes of *Macrocystis* plants
DBRPBAND.SUR01	Invertebrate and algae densities in band transects
DBRPQUAD.SUR01	Invertebrate and algae densities in quadrat samples
DBRPRPC.SUR01	Invertebrate and algae percent cover in random point contact samples
DBRPSUBS.SUR01	Substrate characterization
DBRP.SPECIE	Species list
DBRPSITE.SUR01	Locations of reefs and sample dates.

SECONDARY DATA BASES

This is a list of the secondary data bases used in the analyses for the final report, Comparison of Communities on Artificial and Natural reefs, with Emphasis on Fish Assemblages. These data bases were constructed by the contractor from the primary data bases. Data bases are listed under the SAS data base name. Included are a list of the programs used to create the data base and list of primary data bases (MRC data bases) and/or other secondary data bases that were used in constructing the data base. These secondary data bases are stored on tape. Any raw data files listed are also stored on tape. All SAS programs are stored on the Reef Project report disk (E).

SECONDARY DATA BASE	SOURCE PROGRAM	SOURCE DATA BASES
SUBSTR.DBRPSUBS substrate transect data - incl. algal height, substrate type on pts. along transects	SUBSTR SAS	DBRPSUBS.SUR01
TRANCHAR.DBRPSUBS physical data from substrate transects	TRANSUBS SAS	DBRPSUBS.SUR01
SITEPHYS.DBRPSUBS physical characteristics of reefs	SITEPHYS SAS	DBRPSITE.SUR01 TRANCHAR.DBRPSUBS SITECHAR DATA (raw data set)
TYPEDVRS.DBRPSUBS substrate characteristics on reefs	SUBSDVRS SAS	SUBSTR.DBRPSUBS
GRAINSZE.DBRPSUBS particle size analysis for substrate types	PHISUBS SAS	PHISUBS DATA (raw data set)
RICHNESS.DBRPFISH species richness of fish	FISHRICH SAS	DBRPFAB.SUR01 DBRPFABP.SUR01 DBRPFJB.SUR01 DBRPFJBP.SUR01 DBRPFAC.SUR01 DBRPFJC.SUR01 DBRPFLN.SUR01 DBRPFLNP.SUR01
FLNALL.DBRPFISH · fish lengths	FLNALL SAS	DBRPFLN.SUR01 DBRPFLNP.SUR01

BENTHIC.DBRPFISH benthic fish densities - each lifestage, each species, each transect - all reefs except PAR.	BENTHFSH SAS	DBRPFAB.SUR01 DBRPFJB.SUR01
BENTHPAR.DBRPFISH benthic fish densities each lifestage, each species, each transect - PAR only.	PARBFISH SAS	DBRPFJBP.SUR01 DBRPFABP.SUR01
BNTHMEAN.DBRPFISH benthic fish mean density on each reef for each life- stage of each species.	BNTHMEAN SAS	BENTHIC.DBRPFISH BENTHPAR.DBRPFISH
BNTHBIOM.DBRPFISH benthic fish biomass on each reef for each life- stage of each species.	BNTHBIOM SAS	BNTHMEAN.DBRPFISH FLNALL.DBRPFISH
CNPYMEAN.DBRPFISH water column fish mean density on each reef for each lifestage of each species.	CNPYMEAN SAS	DBRPFJC.SUR01 DBRPFAC.SUR01
CNPYBIOM.DBRPFISH water column fish biomass on each reef for each life- stage of each species.	CNPYBIOM SAS	CNPYMEAN.DBRPFISH FLNALL.DBRPFISH
FISHMEAN.DBRPFISH mean density & mean biomass for each lifestage of each species near the benthos and in the water column.	FISHMEAN SAS	BNTHMEAN.DBRPFISH BNTHBIOM.DBRPFISH CNPYMEAN.DBRPFISH CNPYBIOM.DBRPFISH
DIVERSTY.DBRPFISH Shannon-Wiener & Simpson indices for lifestages of fish near the benthos & in the water column.	FISHDVRS SAS	BNTHMEAN.DBRPFISH CNPYMEAN.DBRPFISH
FISHSP.DBRPFISH species list, scientific & common names.	SITELIST SAS	FISHSP RAWDATA (raw data set)
FACT.DBRPFISH physical measurements & *Macrocystis* density in the water column transects.	CNPYCHAR SAS	DBRPFACT.SUR01

CNPYCHAR.DBRPFISH means for physical characteristics & *Macrocystis* in the water column.		
ALGAMEAN.DBRPALGA mean density or percent cover of algal groups on reefs. ALGABAND.DBRPALGA algal data from band transects ALGAQUAD.DBRPALGA algal data from quadrat samples ALGARPC.DBRPALGA algal data from random point contact samples	ALGAMEAN SAS	DBRPBAND.SUR01 DBRPQUAD.SUR01 DBRPRPC.SUR01
ALGADVRS.DBRPALGA species richness & Shannon-Wiener and Simpson diversity indices for algal assemblage	ALGADVRS SAS	ALGABAND.DBRPALGA ALGARPC.DBRPALGA
ALGASUBS.DBRPALGA algal data from substrate transects (total % cover & mean algal height).	ALGASUBS SAS	DBRPSUBS.SUR01
KELPSIZE.DBRPKELP size of *Macrocystis* plants & mean no. stipes/10m^2	KELPSIZE SAS	DBRPKELP.SUR01 TRANCHAR.DBRPSUBS

PCOVMEAN.DBRPINVT mean percent cover of invertebrates on reefs. DENSMEAN.DBRPINVT mean density of invertebrates on reefs RPC.DBRPINVT invertebrate data from random point contact samples BAND.DBRPINVT invertebrate data from band transects QUAD.DBRPINVT invertebrate data from quadrat samples	INVTDATA SAS	DBRPRPC.SUR01 DBRPBAND.SUR01 DBRPQUAD.SUR01
INVTMEAN.DBRPINVT mean density or % cover of invertebrates on reefs.	INVTMEAN SAS	PCOVMEAN.DBRPINVT DENSMEAN.DBRPINVT SITEPHYS.DBRPSUBS
SITELIST.DBRP list of sites	SITELIST SAS	DBRPSITE.SUR01
PLOTCODE.DBRPSITE site code for plotting regression results.	PLOTCODE SAS	

TABLES IN THE FINAL REPORT

This is a list of the tables found in the final report, Comparison of Communities on Artificial and Natural Reefs in Southern California, with Emphasis on Fish Assemblages. Included in the list are the source programs used to create each table and the data bases that were needed to run the program. The SAS programs are stored on the Reef Project Report disk (E). The data bases are stored on tape.

Table 1-1

Artificial Reef Project Site List

Source data base: DBRPSITE.SUR01

Table 1-2

Classification of Substrate Type

NO DATA

Table 1-3

Sampling techniques used to estimate the density or percent cover of species or groups of algae and invertebrates.

NO DATA

Table 1-4

Fish Length Classes.

From the literature - see list of references.

Table 1-5

Results of regression analysis of sample date versus density of young-of-year fish.

Source program: REGYDATE SAS
Source data bases: BNTHMEAN.DBRPFISH
SITEPHYS.DBRPSUBS

Table 1-6

Characteristics of water column fish transects on artificial and natural reefs.

Source data base: CNPYCHAR.DBRPFISH (variables DFB,
TIMEM, VISM)

Table 1-7

Comparision of characteristics of water column fish transects of artificial and natural reefs.

Source program: TTSTCPCH SAS
Source data bases: CNPYCHAR.DBRPFISH
SITEPHYS.DBRPSUBS

Table 1-8

Regression analyses of fish density and species richness vs visibility.

Source programs: REGFRVS SAS
REGFDBVS SAS
REGFDCVS SAS
Source data bases: RICHNESS.DBRPFISH
BNTHMEAN.DBRPFISH
CNPYMEAN.DBRPFISH
SITEPHYS.DBRPSUBS (benthic vis & surge)
CNPYCHAR.DBRPFISH (water column vis)

Table 1-9

Regression analyses of fish density and species richness vs surge.

SAME AS TABLE 1-8

Table 1-10

Physical characteristics of reefs sampled.

Source data bases: SITEPHYS.DBRPSUBS
TYPEDVRS.DBRPSUBS

Table 1-11

Results of t-tests comparing physical characteristics of artificial and natural reefs.

Source programs: PHYSTTST SAS
WILCXPHY SAS
Source data base: SITEPHYS.DBRPSUBS

Table 1-12

Substrate characteristics on artificial and natural reefs (substrate types, diversity indices, particle sizes).

Source program: SUBSTRAT SAS
Source data bases: TYPEDVRS.DBRPSUBS
GRAINSZE.DBRPSUBS
SITELIST.DBRP

Table 1-13

Results of t-tests comparing substrate characteristics of artificial and natural reefs.

Source program: TTSTSUBT SAS
Source data bases: TYPEDVRS.DBRPSUBS
GRIANSZE.DBRPSUBS

Table 1-14

Abundance of algal groups on artificial and natural reefs (percent cover and density).

Source program: ALGAMTAB SAS
Source data base: ALGAMEAN.DBRPALGA

Table 1-15

Results of t-tests comaparing either percent cover or density of algal groups on artificial and natural reefs.

Source program: TTSTALGA SAS
Source data base: ALGAMEAN.DBRPALGA

Source program: WILCXALG SAS
Source data base: ALGAMEAN.DBRPALGA

Table 1-16

Characteristics of the algal assemblage on artificial and natural reefs (data from substrate transects).

Source data base: ALGASUBS.DBRPALGA

Table 1-17

Results of t-tests comapring characteristics of the algal assemblage on artificial and natural reefs.

Source program: TTSTKELP SAS
Source data bases: ALGASUBS.DBRKPALGA
KELPSIZE.DBRPKELP
SITEPHYS.DBRPSUBS

Table 1-18

Characteristics of *Macrocystis pyrifera* on artificial and natural reefs (no. stipes/plant, no. stipes/10m2).

Source data base: KELPLSIZE.DBRPKELP

Table 1-19

Results of t-tests comparing characteristics of *Macrocystis pyrifera* on artificial and natural reefs.

Source program: TTSTKELP SAS
Source data bases: KELPSIZE.DBRPKELP
SITEPHYS.DBRPSUBS
ALGASUBS.DBRPALGA

Table 1-20

Percent cover of sessile invertebrates on artificial and natural reefs.

Source program: INVTTABM SAS
Source data bases: PCOVMEAN.DBRPINVT
DENSMEAN.DBRPINVT
SITELIST.DBRP

Table 1-21

Results of t-tests comparing percent cover of invertebrates on artificial and natural reefs.

Source programs: TTSTINVT SAS
WILCXINV SAS
Source data base: INVTMEAN.DBRPINVT

Table 1-22

Density of invertebrates on artificial and natural reefs.

Source program: INVTTABM SAS
Source data bases: PCOVMEAN.DBRPINVT
DENSMEAN.DBRPINVT
SITELIST.DBRP

Table 1-23

Results of t-tests comparing density of invertebrates on artificial and natural reefs.

Source programs: TTSTINVT SAS
WILCXINV SAS
Source data base: INVTMEAN.DBRPINVT

Table 1-24

Species list of fish sampled on artificial and natural reefs.

Source data base: DBRP.SPECIE

Table 1-25

Occurrence of species of fish on artificial and natural reefs.

Results were calculated by hand and based on presence or absence of fish species as determined from the from the BNTHMEAN.DBRPFISH and CNPYMEAN.DBRPFISH data bases.

Table 1-26

Species richness of fish on artificial and natural reefs.

Source data base: RICHNESS.DBRPFISH

Table 1-27

Results of t-tests comparing species richness of fish on artificial and natural reefs.

Source programs: TTSTFRCH SAS
WILCXRCH SAS
Source data base: RICHNESS.DBRPFISH

Table 1-28

Diversity of fish on artificial and natural reefs (Shannon-Wiener and Simpson).

Source data base: DIVERSTY.DBRPFISH

Table 1-29

Results of t-tests comparing the diversity of fish on artificial and natural reefs.

Source program: TTSTFDVR SAS
Source data base: DIVERSTY.DBRPFISH

Table 1-30

Density of fish of all lifestages near the benthos on artificial and natural reefs.

Source programs: SPTTOTBM SAS
FSHBMTAB SAS
Source data bases: BENTHIC.DBRFISH
BENTHPAR.DBRPFISH
SITELIST.DBRP

Table 1-31

Results of t-tests comparing density of fish of all lifestages near the benthos on artificial and natural reefs.

Source programs: TTSTFISH SAS
WILCXFSH SAS
Source data base: FISHMEAN.DBRPFISH

Table 1-32

Density of young-of-year fish near the benthos on artificial and natural reefs.

Source programs: SPTTOTBM SAS
FSHBMTAB SAS
Source data bases: BENTHIC.DBRFISH
BENTHPAR.DBRPFISH
SITELIST.DBRP

Table 1-33

Results of t-tests comparing density of young-of-year fish on artificial and natural reefs.

Source programs: TTSTFISH SAS
WILCXFSH SAS
Source data base: FISHMEAN.DBRPFISH

Source program: TTSTYNBB SAS
Source data base: BNTHMEAN.DBRPFISH

Table 1-34

Density of fish of all lifestages in the water column on artificial and natural reefs.

Source programs: SPTTOTCM SAS
FSHMCTAB SAS
Source data bases: CNPYMEAN.DBRPFISH
DBRPFJC.SUR01 (table 1-36)
SITELIST.DBRP
FISHSP.DBRPFISH

Table 1-35

Results of t-tests comparing density of fish of all lifestages in the water column on artificial and natural reefs.

Source programs: TTSTFISH SAS
WILCXFSH SAS
Source data base: FISHMEAN.DBRPFISH

Table 1-36

Density of young-of-year fish in the water column on artificial and natural reefs.

Source programs: SPTTOTCM SAS
FSHMCTAB SAS
Source data bases: CNPYMEAN.DBRPFISH
DBRPFJC.SUR01
SITELIST.DBRP
FISHSP.DBRPFISH

Table 1-37

Results of t-tests comparing density of young-of-year fish in the water column on artificial and natural reefs.

Source programs: TTSTFISH SAS
WILCXFSH SAS
Source data base: FISHMEAN.DBRPFISH

Table 1-38

Biomass density of fish near the benthos on artificial and natural reefs.

Source program: FISHBMTB SAS
Source data base: FISHMEAN.DBRPFISH
SITELIST.DBRP

Table 1-39

Results of t-tests comparing biomass density of fish near the benthos on artificial and natural reefs.

Source programs: TTSTFISH SAS
WILCXFSH SAS
Source data base: FISHMEAN.DBRPFISH

Table 1-40

Biomass density of fish in the water column on artificial and natural reefs.

Source program: FISHBMTB SAS
Source data base: FISHMEAN.DBRPFISH
SITELIST.DBRP

Table 1-41

Results of t-tests comparing biomass density of fish on artificial and natural reefs.

Source programs: TTSTFISH SAS
WILCXFSH SAS
Source data base: FISHMEAN.DBRPFISH

Table 1-42

Summary of rank regressions between fish species richness and physical characteristics of reefs.

Results are taken from APPENDIX TABLE D-1.

Table 1-43

Summary of rank regressions between species richness of fish and algal characteristics of reefs.

Results are taken from APPENDIX TABLE D-2.

Table 1-44

Summary of rank regressions between density of fish near the benthos and in the water column and reef area.

Results are taken from APPENDIX TABLE D-3.

Table 1-45

Summary of rank regressions between density of fish near the benthos and in the water column and reef height.

Results are taken from APPENDIX TABLE D-4.

Table 1-46

Summary of rank regressions between density of fish near the benthos and in the water column and reef depth.

Results are taken from APPENDIX TABLE D-5.

Table 1-47

Summary of rank regressions between density of fish near the benthos and in the water column and foliose algae.

Results are taken from APPENDIX TABLE D-6.

Table 1-48

Summary of rank regressions between density of fish near the benthos and in the water column and understory kelp.

Results are taken from APPENDIX TABLE D-7.

Table 1-49

Summary of rank regressions between density of fish near the benthos and in the water column and *Macrocystis*.

Results are taken from APPENDIX TABLE D-8.

Table 1-50

Summary of rank regressions between density of fish in the water column and density of *Macrocystis* in the water column.

Results are taken from APPENDIX TABLE D-9.

Table 1-51

Summary of rank regressions between density of fish near the benthos and in the water column and percent cover of algae.

Results are taken from APPENDIX TABLE D-10.

Table 1-52

Summary of rank regressions between density of fish near the benthos and in the water column and mean algal height.

Results are taken from APPENDIX TABLE D-11.

Table 1-53

Summary of rank regressions between density of fish near the benthos and density of gorgonians.

Results are taken from APPENDIX TABLE D-12.

Table 1-54

Estimated standing stock of fish near the benthos and in the water column on artificial and natural reefs.

Calculations were done by hand. Biomass estimates were from Tables 1-38 (benthic) and 1-40 (water column).

TABLES IN APPENDIX C

This is a list of the tables found in Appendix C of the final report, Comparison of Communities on Artificial and Natural Reefs in Southern California, with Emphasis in Fish Assemblages. Included in the list are the source program used to created the table and the data bases that were used in the program. The SAS programs are stored on the Reef Project report disk (E). The data bases are stored on tape.

Table C-1

Algae present on reefs sampled, means (SE) (includes both percent cover and density data).

Source program: ALLALGAM SAS
Data bases: DBRPBAND.SUR01
DBRPQUAD.SUR01
DBRPRPC.SUR01
DBRP.SPECIE

Table C-2

Invertebrates found in samples on artificial and natural reefs (presence / absence only).

Source program: INVTALL SAS
Data bases: DBRPBAND.SUR01
DBRPQUAD.SUR01
DBRPRPC.SUR01
DBRP.SPECIE

Table C-3

Fish of all lifestages near the benthos on artificial and natural reefs, mean density (SE).

Source program: FSHBMTAB SAS
Data bases: BENTHIC.DBRPFISH
BENTHPAR.DBRPFISH
FISHSP.DBRPFISH

Table C-4

Young-of-year fish near the benthos on artificial and natural reefs, mean density (SE).

Source program: FSHBMTAB SAS
Data bases: BENTHIC.DBRPFISH
BENTHPAR.DBRPFISH
FISHSP.DBRPFISH

TABLE C-5

Fish of all lifestages in the water column on artificial and natural reefs, mean density (SE).

Source program: FSHMCTAB SAS
Data bases: CNPYMEAN.DBRPFISH
SITELIST.DBRP
FISHSP.DBRPFISH
DBRPFJC.SUR01

Table C-6

Young-of-year fish in the water column on artificial and natural reefs, mean density (SE).

Source program: FSHMCTAB SAS
Data bases: CNPYMEAN.DBRPFISH
FISHSP.DBRPFISH
SITELIST.DBRP
DBRPFJC.SUR01

Table C-7

Biomass density of fish of all lifestages near the benthos on artificial and natural reefs.

Source program: FSHBMAPP SAS
Data bases: BNTHBIOM.DBRPFISH
FISHSP.DBRPFISH

Table C-8

Biomass of young-of-year fish near the benthos on artificial and natural reefs.

Source program: FSHBMAPP SAS
Data bases: BNTHBIOM.DBRPFISH
FISHSP.DBRPFISH

Table C-9

Biomass of fish of all lifestages in the water column on artificial and natural reefs.

Source program: FSHCMAPP SAS
Data bases: CNPYBIOM.DBRPFISH
FISHSP.DBRPFISH

Table C-10

Biomass of young-of-year fish in the water column on artificial and natural reefs.

Source program: FSHCMAPP SAS
Data bases: CNPYBIOM.DBRPFISH
FISHSP.DBRPFISH

TABLES IN APPENDIX D

This is a list of the tables and figures found in Appendix D of the final report, Comparison of Communities on Artificial and Natural Reefs in Southern California, with Emphasis on Fish Assemblages. Included in the following list are the source programs used to calculate the regressions for each table or to plot each figure and the data bases that were used in the programs. The SAS programs are stored on the Reef Project report disk (E). The data bases are stored on tape.

For all regression programs listed below, the SAS program LISTREG SAS was modified and used to create an output SAS data base from the SAS listing of the regression program which contains the results of the regression analyses. The file name for this data base containing the regression results is RESULTS; the file type is the name of the SAS program used to calculate the regressions. For example, the results from the regression program REGFRRCH SAS are in the SAS data base REGFRRCH.RESULTS. The data bases are stored on tape. These RESULTS data bases were used to create the Appendix Tables D-1 through D-12. The SAS program REGTABR SAS was used to construct tables D-1 and D-2. The program REGTAB was used to construct tables D-3 through D-12.

Table D-1

Regressions of species richness of fish vs physical characteristics of reefs.

Source programs: REGFRRCH SAS
REGFRRCR SAS
Data bases: RICHNESS.DBRPFISH
SITEPHYS.DBRPSUBS

Table D-2

Regressions of species richness of fish vs algal characteristics of reefs.

Source programs: REGFRALM SAS
REGFRAMR SAS
REGFRALS SAS
REGFRALR SAS
Data bases: RICHNESS.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA
ALGADVRS.DBRPALGA

Table D-3

Regressions of fish density vs reef area.

Source programs: REGFDRCH SAS
REGFDRCR SAS
REGFBRCH SAS
REGFBRCR SAS
REGFCRCH SAS
REGFCRCR SAS

Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
SITEPHYS.DBRPSUBS

Table D-4

Regressions of fish density vs reef height.

SAME AS TABLE D-3

Table D-5

Regressions of fish density vs reef depth.

SAME AS TABLE D-3

Table D-6

Regressions of fish density vs foliose algal cover.

Source programs: REGFDALM SAS
REGFDALR SAS
REGFBALG SAS
REGFBALR SAS
REGFCALG SAS
REGFCALR SAS

Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA

Table D-7

Regressions of fish density vs density of understory kelp (large brown algae plus *Cystoseira* but without Macrocystis).

SAME AS TABLE D-6

Table D-8

Regressions of fish density vs density of *Macrocystis* on the benthos.

SAME AS TABLE D-6

Table D-9

Regressions of fish density vs density of *Macrocystis* in the canopy.

Source programs: REGFCALG SAS
REGFCALR SAS
Data bases: FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA

Table D-10

Regressions of fish density vs percent cover of algae (measured along the substrate transects).

Source programs: REGFDALC SAS
REGFDACR SAS
REGFBALG SAS
REGFBALR SAS
REGFCALG SAS
REGFCALR SAS
Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGASUBS.DBRPALGA
ALGADVRS.DBRPALGA

Table D-11

Regressions of fish density vs mean algal height.

SAME AS TABLE D-10

Table D-12

Regressions of fish density vs density of gorgonians.

Source programs: REGFINVT SAS
REGFINVR SAS
Data bases: RICHNESS.DBRPFISH
BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
INVTMEAN.DBRPINVT

Figures D-1 - D-16

Plots of species richness of fish vs physical characteristics of reefs.

Source program: PLOTRRCH SAS
Data bases: RICHNESS.DBRPFISH
SITEPHYS.DBRPSUBS
PLOTCODE.DBRPSITE

Figures D-17 - D-33

Plots of species richness of fish vs algal characteristics of reefs.

Source programs: PLOTRALM SAS
PLOTRALS SAS
Data bases: RICHNESS.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA
ALGADVRS.DBRPALGA
PLOTCODE.DBRPSITE

Figures D-34 - D-89

Plots of fish density vs reef area.
Plots of fish density vs reef height.
Plots of fish density vs reef depth.

Source programs: PLOTDRCH SAS
PLOTBRCH SAS
PLOTCRCH SAS
Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
SITEPHYS.DBRPSITE
PLOTCODE.DBRPSITE

Figures D-90 - D-106

Plots of fish density vs foliose algal cover.

Source program: PLOTFOLI SAS
Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA
PLOTCODE.DBRPSITE

Figures D-107 - D-142

Plots of fish density vs density of understory kelp.
Plots of fish density vs density of *Macrocystis* on the benthos.

Source programs: PLOTDALM SAS
PLOTBALG SAS
PLOTCALG SAS
Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA
PLOTCODE.DBRPSITE

Figures D-143 - D-152

Plots of fish density vs density of *Macrocystis* in the water column.

Source program: PLOTCALG SAS
Data bases: FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGAMEAN.DBRPALGA
ALGASUBS.DBRPALGA
PLOTCODE.DBRPSITE

Figures D-153 - D-182

Plots of fish density vs percent cover of algae.
Plots of fish density vs mean algal height.

Source programs: PLOTDALS SAS
PLOTBALG SAS
PLOTCALG SAS
Data bases: BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
CNPYCHAR.DBRPFISH
ALGASUBS.DBRPALGA
ALGADVRS.DBRPALGA
PLOTCODE.DBRPSITE

Figures D-183 - D-195

Plots of fish density vs density of gorgonians.

Source program: PLOTINVT SAS
Data bases: RICHNESS.DBRPFISH
BNTHMEAN.DBRPFISH
FISHMEAN.DBRPFISH
INVTMEAN.DBRPINVT
PLOTCODE.DBRPSITE