# An experimental investigation of the use of artificial reefs to mitigate the loss of giant kelp forest habitat

A case study of the San Onofre Nuclear Generating Station's artificial reef project

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*Cover photo by Richard Hermann*

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# FORWARD

For centuries, artificial reefs have been used to enhance fishing, and that remains a major goal of most reefs built today. Over the past few decades their role has expanded to include resource enhancement (usually for reef communities) and to provide recreational opportunities. California has been a leader in artificial reef construction, building its first designed reefs in the 1950s and having a particularly active program in the 1980s. Given that among California's contributions was the early consideration of using artificial reefs to mitigate impacts to a natural reef, it is perhaps not surprising that mitigation would be considered early in California, where urban development has resulted in extensive impacts to coastal resources. As the use of artificial reefs has expanded, so has the need for understanding their ecology. This is particularly true when the artificial reef is constructed as mitigation, as is the case with the San Clemente Artificial Reef (SCAR) discussed in this book. Mitigation projects are allowed on the promise that they will produce resources that adequately compensate for the resources lost to an impact and their success in fulfilling this promise depends greatly on understanding the ecology of the habitat that is being restored. Rather than construct the entire SCAR mitigation reef with a design that might not be successful, the reef is being constructed in two phases—a smaller experimental phase and a larger build-out phase.

Despite the hundreds of artificial reefs constructed worldwide for fisheries or resource enhancement, remarkably few have incorporated a statistically rigorous study design. Most reefs are never studied, resulting in lost opportunities to learn what works and what does not. Most of the studies that are undertaken follow opportunistically from artificial reefs built for other purposes and, as a result, their conclusions are limited by lack of replication and systematic variation in factors of interest. The SCAR experimental reef is unique is its scale (with 56 different modules covering a total of nine hectares of bottom, this is the largest and most intensive artificial reef experiment ever attempted) and incorporation of an experimental design that allows clear determination of the effects of different design features (substrate type, substrate amount, and location). In addition to its scientifically rigorous design, the SCAR experimental reef has been monitored extensively, with careful consideration of appropriate levels of replication, and additional process-oriented studies have been incorporated into its study. Finally, the communities at SCAR have been compared to communities on nearby natural ("reference") reefs. It is a long-standing question whether communities on artificial reefs are similar to those on natural reefs, and relatively few studies have addressed this issue, which is particularly important for mitigation reefs that must replace resources lost at an impacted reef. The research on the SCAR experimental reef was extensive, targeting giant kelp, benthic algae and invertebrates, and fish. This was a monumental effort that yielded a rich and complex data set.

Experiments on the scale of SCAR are rare in marine ecology and unprecedented in artificial reef studies, but they can help resolve issues that otherwise would be debated endlessly. Take, for example, the effect of using different reef materials. In the mid-1980s, I conducted a survey of artificial and natural reefs in Southern California and came to some tentative conclusions about how communities on concrete reefs compared to those on quarry-rock reefs. However, the comparison was difficult because the reefs were built at different times at different depths using different configurations of reef built with materials having different dimensions. Other researchers drawing on other observations came to different conclusions about the communities on concrete reefs. There really was no way to reconcile differing opinions because the observation data were inadequate to resolve this question scientifically. Now, by using a controlled experimental approach, the SCAR project has finally been able to answer this question definitively.

Although the SCAR experimental reef was built specifically to help with the design of the build-out mitigation reef, it has also provided new insights into artificial reef functions and marine ecological processes in general. Some of the most interesting results concern recruitment processes. In essence, SCAR was a huge settling experiment: nine hectares of new substrate spread over 3.5 km of coastline. This provided a unique opportunity to determine the distances over which kelps and other reef organisms are capable of colonizing, information of basic scientific value as well as value for determining how far away artificial reefs can be constructed from natural reefs. Two recruitment patterns stand out. First, giant kelp recruited extensively over the entire experimental reef within the first year (with a clear spatial pattern related to distance from the nearby natural reef). This confirms the previous work by Dan Reed and others of kilometer-scale dispersal in giant kelp despite a prevailing view that its dispersal is limited to a few meters. Second, a few years after SCAR was constructed there was widespread recruitment of the gorgonian coral *Muricea californica*. None of the previous studies on gorgonians in California indicated a recruitment event like this would occur. That there was higher recruitment on the modules closer to the natural kelp forest was particularly surprising and provided much needed insight into the dispersal of this common sea fan.

The conclusion of the experimental phase of SCAR will be followed by the full mitigation reef. The Coastal Commission scientists responsible for this study have made a variety of recommendations that will guide Southern California Edison’s design of the build-out reef. Although this reef will not be constructed as a replicated experiment, the rigorous monitoring of reef performance will continue. New aspects of artificial reef ecology, including fish reproductive success and fish production, will be assessed. Development of the entire artificial reef community will be tracked and evaluated with respect to the communities on nearby natural reefs. With proper management, oversight (and perhaps a little luck), the full mitigation reef will function like a natural reef, thereby contributing to the rich coastal resources of California.

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# EXECUTIVE SUMMARY

The operation of the San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 has been shown to adversely impact the San Onofre kelp forest community. The California Coastal Commission (CCC) has required the operators of SONGS (i.e., Southern California Edison and its partners) to mitigate this impact by constructing an artificial reef that will provide in-kind replacement for the loss of kelp forest habitat caused by SONGS' operations. Thus, the overall goal of the SONGS artificial reef mitigation project is to compensate for the loss of kelp bed resources including giant kelp, understory algae, invertebrates, and fishes. The success of the mitigation project in attaining its goal will be evaluated using a set of physical and biological performance standards adopted by the CCC in 1991.

The SONGS artificial reef mitigation project is being done in two phases: a short-term, small-scale, experimental phase followed by a longer-term, larger-scale mitigation phase. Results from the initial experimental phase will be used to: (1) assess the feasibility of using an artificial reef as mitigation for replacing the kelp forest resources lost at San Onofre, and (2) provide insight into the artificial substrate types and configurations that will have the greatest chance of meeting the performance standards used to evaluate the success of the mitigation reef. Construction of the experimental reef was completed in fall 1999 and the five-year monitoring period was completed in December 2004.

This document summarizes the findings from the experimental phase of the SONGS artificial reef mitigation project and provides recommendations (based on these findings) for the design of specific features of the reef to be constructed during the mitigation phase of the SONGS artificial reef mitigation project.

### Findings of the experimental phase of the SONGS artificial reef mitigation project

<u>Hard substrate</u>

- The footprint area of the artificial reef modules remained relatively constant over time and was close to the design specifications of 1600 $m^2$.
- The mean percent cover of artificial substrate on the experimental modules was substantially greater in the summer of 2000 than the design specifications of 17%, 34% and 67% averaging 42%, 60% and 86% for the low-, medium- and high-coverage designs respectively.
- The percent cover of natural hard substrate at the two reference reefs in the summer of 2000 was 49% and 54%.
- Except for modules at the northern end of the artificial reef (Block 7), there was little evidence of material subsidence, sand accretion, or erosion on the artificial reef modules.
- All six artificial reef designs, which incorporated different combinations of substrate type and coverage, were consistently near or above the performance standard that requires at least 90% of the initial cover of hard substrate to remain exposed for colonization by reef biota.

- Five of the seven blocks were above the standard that requires at least 90% of the initial cover of hard substrate to remain exposed for colonization by reef biota. Block 1 (the southern-most location) was slightly below the standard with 89% of the initial remaining in 2004, while Block 7 (the northern-most location) was significantly below the standard with only 80% of the initial artificial substrate available for colonization by reef biota.
- The small-scale topography (i.e., rugosity on the scale of one meter) of rock and concrete modules was quite similar despite rock and concrete having different dimensions. The small-scale topography of rock and concrete modules was substantially greater than that of the reference reefs.

Giant kelp

- *Macrocystis* recruitment on the artificial reef modules was highly variable among years and among locations.
- High densities of kelp recruits were only observed on the artificial reef during the summer of 2000. Recruitment density during this period was inversely related to distance from San Mateo. Nonetheless, substantial numbers of recruits were observed at the most distant modules located 3.5 km from the nearest population of adult kelp.
- All evidence suggests that the initial colonization of SCAR by giant kelp resulted from the widespread dispersal of spores rather than limited dispersal from adult plants that drifted onto the experimental reef.
- The density of *Macrocystis* recruits in the summer of 2000 increased with the bottom cover of artificial substrate and was unaffected by the type of artificial substrate.
- Low to moderate recruitment was observed in most years at the northern blocks where adult densities were relatively low, but still above the performance standard of 4 adult plants per 100 $m^2$. Little to no recruitment was observed in the southern blocks in most years where adult densities were very high.
- Patterns of adult density on the artificial reef reflected patterns of juvenile density in the previous year.
- Adult density declined over time and by 2004 there was little difference in the density of adults on the different artificial reef designs and on the different blocks.
- All artificial reef designs and blocks have exceeded the performance standard for adult kelp since 2001 (i.e., > 4 four adults / 100 $m^2$).
- Adult density was consistently higher on the artificial reef modules than on the natural reference reefs.
- Reproductive potential (i.e., number of spores produced per area of bottom) near the end of the experiment was similar among the six artificial reef designs.
- Approximately 40% of individuals on the artificial reef that reached adulthood in 2001 survived to 2004.
- Adult survivorship was lower on modules with higher cover of hard substrate, which had higher initial densities of adults.
- Results from a short-term experiment coupled with data from the longer term five-year artificial reef experiment indicate that populations of giant kelp (and understory algae) will likely be sustainable over the long term, but will

undoubtedly undergo large fluctuations in absolute and relative abundance depending on the size and frequency of physical disturbance.

Kelp forest fishes

- The density and species richness of kelp forest fishes (such as blacksmith, senoritas, and kelp perch) was positively related to the cover of hard substrate and largely unrelated to the type of hard substrate.
- The species composition and relative abundance of kelp forest fishes on the artificial reef modules was very similar to that of the natural reference reefs.
- The projected standing stock of fishes on all artificial reef designs and at all locations (i.e., blocks) was near or above the 25.4-metric-ton performance standard for each year of the five-year experiment.
- There is a better than 80% chance that five of the six reef designs would support a standing stock of 25.4 metric tons if built out to 61 ha. A 61-ha reef constructed of low cover rock has approximately a 50% chance of meeting the standing stock standard for kelp forest fishes.
- All six artificial reef designs met the performance standards for density and species richness of resident and young-of-year (YOY) fish.
- All seven blocks met the performance standards for density and species richness of resident and YOY fish.
- Collectively, the results indicate that all of the reef designs and all blocks tested in the experiment are likely to provide adequate in-kind compensation for the loss of kelp forest fishes caused by SONGS's operation. However, densities and species richness of resident adult and YOY fish were generally higher on the artificial reef than on the two reference reefs. While fish densities on the artificial reef that are above the range of densities on the reference reefs would not constitute a failure to meet fish performance standards, fish densities that are too high could adversely affect other components of the kelp forest assemblage.

Understory algae

- Algae (such as small juvenile red algae, short filamentous red algae and the understory kelp, *Laminaria*) rapidly colonized SCAR soon after construction.
- The density and percent cover of algal colonists on SCAR was positively related to the bottom cover of artificial substrate, and unrelated to the type of hard substrate and the distance from San Mateo kelp forest, the nearest natural reef.
- Since 2001 the abundance and species richness of understory algae on SCAR has steadily declined and by 2003 understory algae were uncommon on all artificial reef designs.
- Results from removal experiments indicated that shading by the kelp canopy and competition for space with sessile invertebrates played an important role in contributing to the steady decline in the abundance and species richness of understory algae on SCAR during the period 2001–2004.
- The percent similarity in species composition and relative abundance of understory algae between SCAR and the reference sites appears to have leveled off at around 35% from an initial value of about 17%.

- All six of the artificial reef designs tested failed to meet the performance standards for the percent cover, density and number of species of understory algae established for the mitigation reef.
- All seven locations (i.e., blocks) failed to meet the performance standards for percent cover and number of species of understory algae established for the mitigation reef. Block 7 was the only location to meet the performance standard for density of understory algae using the Universe approach (in which the two reference reefs, San Mateo and Barn, constitute the entire population of sites to which the artificial reef is compared), while Blocks 6 and 7 met the standard for algal density using the Sample approach (in which San Mateo and Barn constitute a sample from a larger population of possible reference reefs).

<u>Benthic Invertebrates</u>

- The abundance, percent cover, density, and number of species of benthic invertebrates on all artificial reef designs increased throughout the five-year experiment.
- Invertebrate percent cover and density was positively related to the cover of artificial substrate and unrelated to the type of hard substrate and to distance from San Mateo.
- The percent similarity in the invertebrate assemblages on SCAR and the reference reefs displayed an asymptotic increase over time to ~ 50% and was largely unaffected by the bottom cover and type of artificial substrate.
- The most abundant invertebrate taxa on SCAR after five years were the compound tunicate *Chelyosoma productum* and the brittle star *Ophiothrix spiculata.*
- All six artificial reef designs met the performance standards for percent cover, density, and species richness of benthic invertebrates, and in all cases exceeded the range of values at the reference reefs established by the Universe and Sample approaches.
- All seven blocks met the performance standards for percent cover, density, and species richness of benthic invertebrates, and in all cases exceeded the range of values at the reference reefs established by the Universe and Sample approaches.

<u>Undesirable or invasive species</u>

- High densities of the sea fan, *Muricea* recruited to SCAR in 2002 and 2003; lower densities recruited in 2004.
- The recruitment density of *Muricea* was not affected by the type or bottom cover of artificial substrate and declined with distance from San Mateo, the nearest reference reef.
- Tagged sea fan colonies grew faster on modules with low bottom cover of rock than on modules where bottom cover was high. In addition, growth rates were unrelated to local sea fan density.
- The distribution of sizes of *Muricea* was very similar on modules of the different artificial reef designs, and sizes tended to be much smaller on the artificial reef compared to the reference reefs.

- The percent of tagged sea fan colonies surviving from 2003 to 2004 typically averaged 80% or more for the 2002 cohort and slightly less for the 2003 cohort. The one exception to this pattern was the 2003 cohort on high-cover rock, which had a much lower survival rate of 40%.
- *Muricea* survivorship was largely independent of the bottom cover of rock, rock size, substrate slope, and sea fan density.
- *Muricea* density (but not percent cover) on the artificial reef modules in 2004 was at or above densities known to exclude algae and other benthic invertebrates. Density was unrelated to substrate, type, cover and depth, and negatively related to distance from San Mateo.
- The data collected on sea fan recruitment, growth, and survivorship indicate that it is reasonable to expect that high densities of large *Muricea* will eventually invade the mitigation reef.

<u>Kelp Transplantation</u>

- 80% of the transplant substrates remained in place after one year, at which time the experiment was abandoned.
- On average > 70% of the surviving plates on rock and concrete modules supported living *Macrocystis* one year after transplantation.
- Growth of transplanted kelp was similar to, or slightly less than, that of naturally recruited kelp.
- The method of transplanting juvenile kelp tested in the experiment may be a viable, but labor intensive, means of augmenting the density of naturally recruited kelp on the mitigation reef if remediation is determined necessary.

## Recommendations for the design of the mitigation phase of the SONGS artificial reef mitigation project

<u>General recommendations</u>

Results from the five-year experimental phase of the artificial reef mitigation project were quite promising in that all six artificial reef designs and all seven locations tested (i.e., blocks) showed a near equally high tendency to meet the performance standards established for the mitigation reef. We conclude from these findings that a low relief concrete rubble or quarry rock reef constructed off the coast of San Clemente, California has a good chance of providing adequate in-kind compensation for the loss of kelp forest biota caused by the operation of SONGS Units 2 and 3.

<u>Recommendations on specific design features</u>

The probability that the losses of kelp forest resources incurred at San Onofre due to SONGS operations will be fully compensated will depend on the design and location of the artificial reef. We recommend the following features be incorporated into the design of the mitigation reef to ensure full compensation for the lost resources.

*Substrate type*
The mitigation reef should be built of quarry rock or rubble concrete having dimensions, size structures, and specific gravities similar to those of the rock and concrete used to construct the SONGS experimental artificial reef.

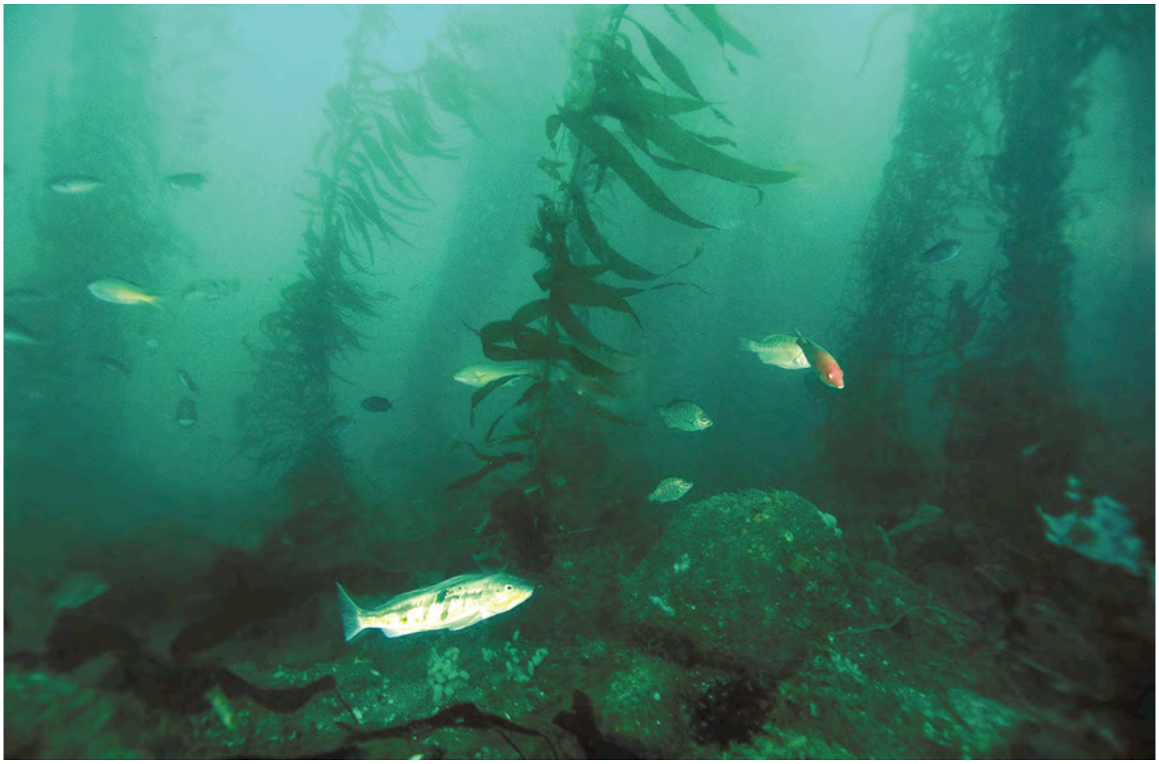
*Substrate coverage and bottom relief*
The percent of the bottom covered by quarry rock or rubble concrete on the mitigation reef should average a minimum of 42% and a maximum of 86% (as determined by divers using the uniform point contact method employed in this study). The vertical relief of the bottom should not exceed 1 m.

*Location*
All 61 ha of the mitigation reef should be built within the existing 144-ha project site located off the coast of San Clemente, California. The quarry rock or concrete rubble used to construct the mitigation reef should not be placed on any hard bottom areas known to support kelp forest biota and commercial and recreational fisheries. The most northern portion of the project site should be avoided if possible because the pattern of sand movement in this area may cause higher rates of burial of artificial reef material.

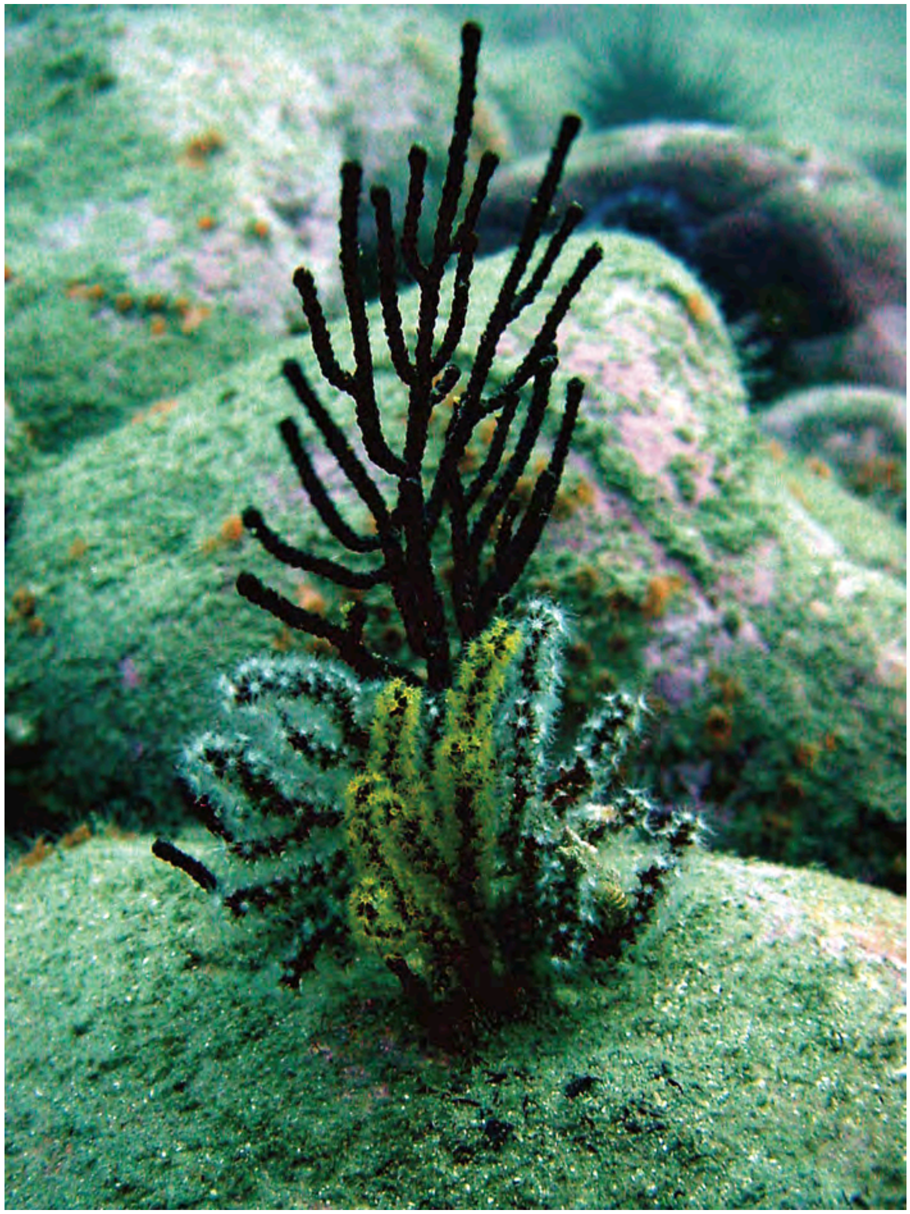
<u>Other considerations</u>
*Timing and phasing of construction*
The timing and phasing of construction of the mitigation reef will probably not have any long-term effects on the biological communities that develop on the artificial reef.

<u>Outstanding issues</u>
*Dominance by Muricea*
Data collected on sea fan recruitment, growth, and survivorship during the experimental phase of the SONGS artificial reef mitigation project indicate that it is reasonable to expect high densities of large *Muricea* to eventually invade the mitigation reef. None of the artificial reef designs tested appeared to substantially deter *Muricea* recruitment, growth or survivorship. Additional studies should be pursued during the interim period prior to start of reef construction to determine the factors most important in controlling the distribution and abundance of *Muricea* and the most cost-effective means of managing it.

Giant kelp (*Macrocystis pyrifera*) growing on a rubble concrete module of the San Clemente Artificial Reef. Photo by Richard Hermann



Kelp bass (*Paralabrax clathratus*) and other reef associated fishes in a giant kelp forest on a quarry rock module of the San Clemente Artificial Reef. Photo by Richard Hermann



Small recruits of the sea fans *Muricea californica* (yellow polyps) and *Muricea fructicosa* (white polyps) on quarry rock boulders of the San Clemente Artificial Reef. Photo by Greg Welch


Satellite image showing the surface canopy of giant kelp (*Macrocystis pyrifera*) on the 56 experimental reef modules of the San Clemente Artificial Reef (SCAR), and on the nearby natural reefs at San Mateo (SM) and San Onofre (SO). San Mateo was one of two reference reefs used to evaluate the performance of SCAR. San Onofre is the reef that is adversely impacted by the discharge plume of the San Onofre Nuclear Generating Station (SONGS) and for which SCAR is intended to mitigate. Image courtesy of Google Earth

# I. INTRODUCTION

This document summarizes the findings from the experimental phase of the San Onofre Nuclear Generating Station's (SONGS) artificial reef mitigation project and provides recommendations (based on these findings) for the design of the mitigation phase of the SONGS artificial reef mitigation project. Below is a brief history of the SONGS mitigation project, its various components, and how it is administered.

## *A. HISTORY OF THE SONGS MITIGATION PROJECT*

In 1974, the California Coastal Zone Conservation Commission (the predecessor of the California Coastal Commission or CCC) issued a coastal development permit (No. 6-81-330- A, formerly 183-73) to Southern California Edison Company (SCE) and its partners for Units 2 and 3 of SONGS. Presented with conflicting testimony about the likely impacts of the new units, the CCC established the Marine Review Committee (MRC) as an independent body to conduct definitive studies first predicting and then measuring the impacts of the new units. In 1989, the MRC reported its findings to the Commission, including recommendations for how to mitigate the negative impacts it had found. Based on these findings, the CCC added new conditions to the SONGS permit in 1991 requiring that the adverse impacts of the power plant on the marine environment be mitigated. These conditions required SCE and its partners to: (1) create or substantially restore at least 150 acres of Southern California wetlands, (2) install fish barrier devices at the power plant, and (3) construct a 300-acre kelp reef (Conditions A through C). The 1991 conditions also require SCE to provide the funds necessary for Commission contract staff, technical oversight and independent monitoring of the mitigation projects (Condition D). In 1993, the Commission added a requirement for SCE to partially fund construction of an experimental white sea bass hatchery. Due to its experimental nature, the Commission did not assign mitigation credit to the hatchery requirement.

In April 1997, after extensive review of new kelp impact studies, the Commission approved amended conditions that: (1) reaffirm the Commission's prior decision that San Dieguito is the site that best meets the permit's standards and objectives for wetland restoration, (2) allow up to 35 acres credit for enhancement of wetland habitat at San Dieguito Lagoon by keeping the river mouth permanently open, and (3) revise the kelp mitigation requirements in Condition C. Specifically, the revised Condition C requires construction of an artificial reef large enough to sustain 150 acres of medium- to high-density kelp bed community (that could result in a reef larger than 150 acres) together with funding for a mariculture/marine fish hatchery as compensation for the loss of 179 acres of high-density kelp bed community resulting from the operation of SONGS Units 2 and 3. The artificial reef is to consist of an initial small experimental reef (~ 22 acres) and a subsequent larger mitigation reef that meets the 150-acre requirement. The purpose of the experimental reef is to determine which combinations of substrate type and substrate coverage will most likely achieve the performance standards specified in the permit. The design of the mitigation reef will be contingent on the results of the experimental reef. The CCC also found in April 1997 that there is continuing importance for the independent monitoring and technical oversight required in Condition D to ensure full mitigation under the permit.

## *B. ADMINISTRATIVE STRUCTURE*

Condition D establishes the administrative structure to fund the independent monitoring and technical oversight of the mitigation projects. It specifically: (1) enables the CCC to retain contract scientists and technical staff to assist the CCC in carrying out its oversight and monitoring functions, (2) provides for a scientific advisory panel to advise the CCC on the design, implementation, monitoring, and remediation of the mitigation projects, (3) assigns financial responsibility for the CCC's oversight and monitoring functions to SCE and its partners, and sets forth associated administrative guidelines, and (4) provides for periodic public review of the performance of the mitigation projects in the form of an annual public workshop.

Condition D requires SCE and its partners to fund scientific and support staff retained by the Commission to oversee the site assessments, project design and implementation, and monitoring activities for the mitigation projects. Scientific expertise is provided to the CCC by a small, technical oversight team hired under contract. The technical oversight team members include three Research Biologists from UC Santa Barbara: Steve Schroeter, Ph.D., marine ecologist; Mark Page, Ph.D., wetlands ecologist (half time); and Dan Reed, Ph.D., kelp forest ecologist (half time). Ms. Jody Loeffler, a half-time administrator, completes the contract program staff. In addition, a science advisory panel advises the CCC on the design, implementation, monitoring, and remediation of the mitigation projects. Current science advisory panel members include Richard Ambrose, Ph.D., Professor, UCLA; Peter Raimondi, Ph.D., Professor, UC Santa Cruz; and Russell Schmitt, Ph.D., Professor, UC Santa Barbara. In addition to the science advisors, the contract program staff is aided by a team of field assistants hired under a contract with UC Santa Barbara to collect and assemble the monitoring data. Independent consultants and contractors also assist the contract program staff on occasion when expertise for specific tasks is needed. CCC's permanent staff also spend a portion of their time on this program, but their costs are paid by the CCC.

# II. OVERVIEW OF THE EXPERIMENTAL ARTIFICIAL REEF DESIGN AND MONITORING

## *A. MITIGATION REQUIREMENT*

Condition C of the SONGS permit requires construction of an artificial reef in two phases; an experimental phase that is relatively short in duration (i.e., five years) and small in size (~22 acres), and a mitigation phase that is larger in size (at least 150 acres) and of a duration equivalent to the operating life of SONGS Units 2 and 3 (i.e., 30 to 40 years).

The primary goal of the experimental reef is to determine the substrate types and configurations that best provide: (1) adequate conditions for giant kelp recruitment, growth and reproduction, and (2) adequate conditions for establishing and sustaining other reef-associated biota, including benthic algae, invertebrates and fishes. Originally the SONGS coastal development permit required that the mitigation reef be constructed of quarry rock, and that the rock cover at least two-thirds of the sea floor within the boundary of the mitigation reef. On April 9, 1997 the Commission agreed to allow the Executive Director to change these requirements if the results of the experimental reef indicated that a different coverage or substrate type would replace a minimum of 150 acres (i.e., 61 hectares) of medium- to high-density giant kelp and associated kelp forest biota. Thus, a major objective of the experimental reef is to determine whether substrate coverages less than two-thirds and substrate types other than quarry rock (e.g., rubble concrete) can be used to meet the performance standards for the mitigation reef. Information obtained from the experimental reef will form the basis of the Executive Director's decision on the type and percentage cover of hard substrate required for the mitigation reef.

## *B. EXPERIMENTAL REEF SITING AND DESIGN*

SCE submitted a conceptual preliminary plan to the CCC to build the experimental reef in June 1997. The plan was approved by the Executive Director and forwarded to state and federal agencies for review. The environmental review process was finalized in June 1999 and construction of the experimental reef was completed on September 30, 1999.

The experimental artificial reef for SONGS mitigation was located approximately 1 km offshore of the City of San Clemente, California, USA (Figure II.B.1). It was built on a mostly sand bottom at 13 to 16 m depth. The experimental artificial reef was designed as a stratified block of eight module types clustered at seven locations spaced relatively evenly along 3.5 km of coastline encompassing an area of approximately 144 ha. The eight module types at each location consisted of two kinds of reef material (quarry rock and rubble concrete), three levels of bottom coverage of each material type (low, medium, and high), and two levels of kelp abundance (natural and augmented with transplanted juvenile kelp) for the medium bottom-coverage modules (Table II.B.1). Each artificial reef module measured roughly 40 m x 40 m (0.16 ha in area) and the 56 modules collectively covered about nine hectares of the sea floor. All modules were constructed to form low-lying reefs (i.e., < 1 m tall) that mimicked natural reefs in the region.

## *C. MONITORING GOALS AND RATIONALE*

Deciding upon a design for the mitigation reef using information from the experimental reef entails uncertainties that stem from the length of the experiment (five years), which may not be sufficient for the development of a mature kelp forest community on a newly constructed reef. Moreover, because five years is short, relative to the generation times of most kelp forest species (other than giant kelp), there is no guarantee that reef designs that appear successful at the end of the experiment (i.e., those that meet the performance standards) will continue to perform successfully in the future. Given these uncertainties, it was possible that none of the experimental modules would develop a sustainable kelp community that met the performance criteria for the mitigation reef. In this event the Executive Director of the CCC would need to rely on information that best *predicted* which of the reef designs would meet the performance standards when applied to the mitigation reef.

To address this possible need, the CCC's contract scientists took a three-part approach to evaluating the results of the experimental reef. Evaluation of the experimental phase consisted of: (1) monitoring a variety of physical and biological variables to determine the degree to which the six artificial reef designs (and two kelp transplant treatments) achieve the performance criteria, which include comparisons to natural reference reefs as well as to fixed values, (2) using the monitoring data to evaluate the performance of the artificial reef designs relative to each other, and (3) collecting data from additional monitoring and experiments that aided in predicting which design(s) would most likely be successful if applied to the larger mitigation reef. These additional data related key physical and biological processes to: (1) specific aspects of community development, and (2) the degree of success in achieving the performance criteria. This last approach acknowledges that there are both processes that facilitate the development of kelp and related biota and those that suppress them. An example of the former is an adequate rate of dispersal and successful settlement of kelp spores. An example of the latter is too high a rate of recruitment and development of invasive species (e.g., sea fans) that can monopolize space on the artificial reef and prevent the establishment of kelp and other biota. Results from these process studies were used to predict whether the criteria for evaluating the performance of the different reef designs would likely be met and how long it would likely take to meet them. Information obtained from process studies also were used to gain insight into how physical and biological variables of interest are affected by specific reef characteristics that are not explicitly tested in the experiment (e.g., the size and shape of rocks and concrete rubble).

The three-fold approach depends in part on the idea that the dynamics of a kelp forest community can be predicted from: (1) the values of the variables that describe the state of the kelp forest community on which the performance standards for the mitigation reef are based (e.g., the area of medium-to-high density kelp, the density of fish and number of fish species, etc.), and (2) a knowledge of the physical and biological processes that control the average values and dynamics of the state variables (e.g., the effects of sand scour on community structure; lack of giant kelp due to insufficient spore dispersal, etc.).

Information on the values of variables that describe the state of the community was obtained from spatially representative monitoring of the experimental modules and reference reefs to describe "what was there." Additional insight into processes was obtained from focused sampling and experiments aimed at predicting "what will be there over the long term."

## *D. PERFORMANCE CRITERIA*

A number of biological and physical performance standards will be used to judge the success of the 61-ha mitigation reef to determine whether remediation is necessary. Not all of these standards are appropriate for evaluating the suitability of the different artificial reef designs tested during the experimental phase for mitigating SONGS impacts to kelp bed resources. For example, because fish are likely to move among different artificial reef modules, the relatively small size of the modules (0.16 ha) precluded obtaining reasonable estimates of fish production, and reproductive rates for the different reef designs that could be scaled up to the size of the mitigation reef. Given these kinds of constraints, only the following subset of the performance standards required for the mitigation reef were used as criteria for evaluating the performance of the different experimental reef designs:

1. *Substrate characteristics*
    a) At least 90% of the area of hard substrate (as determined by the first post-construction survey) must remain available for attachment of reef biota.

2. *Giant Kelp*
    a) There must be a sustained giant kelp density of at least 4 adult plants per 100 $m^2$.

3. *Kelp-bed fishes*
    a) Resident fish assemblage shall be similar in density and species number to natural reefs within the region.
    b) YOY fish assemblage shall be similar in density and species number to natural reefs within the region.
    c) The standing stock of fishes on the mitigation reef shall be at least 28 US tons (= 25.4 metric tons).

4. *Kelp-bed invertebrates and understory algae*
    a) Benthic community (both algae and macro-invertebrates) shall have coverage or density and number of species similar to natural reefs within the region.
    b) Important functions of the reef shall not be impaired by undesirable or invasive benthic species

These performance criteria fall into two categories: absolute standards, which require that the variable of interest attain or exceed a predetermined value, and relative standards, which require that the value of the variable of interest be similar to that measured on natural reference reefs. Absolute performance standards were based on estimated losses caused by SONGS operations (e.g., a 25.4-metric-ton reduction in the standing stock of kelp bed fishes) or on a minimum value below which the mitigation was considered not to be successful (e.g., 90% of the hard substrate remaining available for colonization). The rationale for requiring that the value of a resource be similar to that on natural reefs is based on the requirement that to be successful, the mitigation reef must provide the types and amounts of resources that occur on natural reefs. Resources on natural reefs, however, vary tremendously in space and time. Differences in physical characteristics of a reef (e.g., depth and topography) can cause plant and animal assemblages to differ greatly among reefs while seasonal and inter-annual differences in oceanographic conditions can cause the biological assemblages within reefs to fluctuate greatly over time. Ideally, the biological assemblages on a successful artificial reef should fluctuate in a manner similar to those on the natural reefs used for reference. One way to help ensure this will be the case will be to select reference reefs that are located nearby and are physically similar to the experimental reef. The premise here is that nearby reefs with similar physical characteristics should support similar biota, which should fluctuate similarly over time. Temporal variability, especially of the sort associated with changes in oceanographic conditions, can be accounted for more easily by sampling the experimental and natural reference reefs concurrently. Concurrent monitoring of the natural reefs helps ensure that regional changes in oceanographic conditions affecting the experimental reef are reflected in the performance criteria, since nearby natural reefs will be subjected to similar changes in oceanographic conditions.

San Mateo kelp bed (located adjacent to the southern end of the experimental reef) and Barn kelp bed (located approximately 12 km south of San Mateo kelp bed) were chosen as reference reefs for the artificial reef experiment (Figure II.B.1). A single transect was established at seven permanent stations at each reference reef. Data collected along these transects were used in comparisons with data collected along fixed transects on the experimental artificial reef modules. Coverage of hard substrate was not an explicit criterion for selecting these sites or for selecting the location of transects within them. Instead, the criteria used in choosing plots within reference reefs were that they: (1) have a history of sustaining giant kelp at medium to high densities, (2) be located at a depth similar to the experimental reef, and (3) be primarily low relief, preferably consisting of cobble or boulders. The criterion that the reference reefs have persistent stands of giant kelp was important because communities on reefs without giant kelp can differ dramatically from those with kelp. Because medium- to high-density giant kelp is required of the mitigation reef, it was important that it be present on the natural reference reefs during the five-year experiment. Because species composition and abundance vary greatly within and among natural reefs, it was also important that the number and spacing of reference transects be sufficient to allow the performance of different artificial reef designs to be compared to the wide range of variation that occurs naturally. In addition, kelp persistence can vary greatly within and among sites over a five-year period as a result of localized disturbances (e.g., sea urchin grazing, or sediment scour). This was a concern for the experimental reef because the plant and animal assemblages associated with persistent populations of kelp were needed to evaluate the performance of the different reef designs. The use of multiple reference plots helped to ensure that a standard for comparison for the experimental reef was maintained, even in the event of localized extinctions of giant kelp.

There are two general ways to use data collected from reference sites to assess similarity for purposes of evaluating relative performance standards. One method is to assume that sites selected for reference are the only suitable reefs for evaluating the different artificial reef designs and hence represent the "universe" of possible reference sites (hereafter referred to as the "Universe approach"). Such an argument could be made for the SONGS mitigation project given that the kelp forests at San Mateo and Barn are the only low-relief natural reefs in the vicinity of the experimental artificial reef that are removed from the influence of SONGS' operations. Using the Universe approach, a given artificial reef design might be considered similar to natural reference reefs with respect to a given performance standard if its mean value fell within the range of values defined by the means of the reference reefs. An alternate approach for evaluating similarity is to assume that the reference reefs represent a random sample of all possible natural reefs that are suitable for use as a standard for comparison (hereafter referred to as the "Sample approach"). Here a range of statistical methods could be used to determine whether a given artificial reef design is similar to (i.e., not significantly different from) natural reference reefs.

We evaluated similarity in the relative performance standards between the different artificial reef designs and the reference reefs at San Mateo and Barn using both the Universe and Sample approaches. Similarity was evaluated using the Universe approach by determining whether the mean of the dependent variable of interest of a given artificial reef design (e.g., resident fish density on low-coverage rock modules) fell within the range set by the mean values observed at San Mateo and Barn. Tests for similarity using the Sample approach were done by determining whether the mean value of the dependent variable of a given artificial reef design (N = 7 modules) fell within the 95% confidence interval of the mean averaged across all stations at San Mateo and Barn (N = 14 stations). All tests for similarity to the reference reefs were done using data from 2004, the last year of the five-year experiment.

While the degree of similarity between the species composition of the plant and animal assemblages of the artificial and reference reefs is not a standard that will be used to evaluate the performance of the SONGS mitigation reef, it is a useful measure for assessing whether a particular artificial reef design is more or less likely to attain the mitigation goal of replacing resources that are similar to natural reefs in the region. We estimated the percent similarity (S) in the relative species composition of fishes, invertebrates and algae between the different artificial reef designs and the reference reefs using the Czekanowski index of similarity (Pielou 1984) in which

$$S = \sum_{i=1}^{n} \min(P_{Xi}, P_{Yi})$$

where $P_{Xi}$ is the percent abundance of species *i* at artificial reef design $_X$. $P_{Yi}$ is the percent abundance of species *i* at reference site $_Y$. Using this index, S ranges from 0 (i.e., no species in common) to 100 (all species have identical percentages).

## *E. MONITORING*

CCC contract scientists prepared a monitoring plan for the experimental reef prior to its construction. It was reviewed by SCE, various resource agencies, and other technical specialists, and was included in the draft Programmatic Environmental Impact Report (PEIR) for general public review. The plan provided an overall framework to guide the monitoring and described the sampling methodology, analytical techniques, and methods for measuring performance of the different experimental reef designs relative to the performance criteria listed above. The monitoring plan for the experimental reef was approved by the Commission on July 15, 1999. The fieldwork required to do the monitoring was contracted out to UC Santa Barbara and done by a team of university scientists under the direction of Drs. Steve Schroeter and Dan Reed.

In the fall of 1999 four permanent 40-m transect lines were installed on each of the 56 modules and seven permanent 40-m transects were installed at each of the two reference reefs. These lines were used to mark the areas on each module that were routinely monitored. The abundance of giant kelp, kelp-bed fishes, large macro-invertebrates and understory algae were surveyed annually in a 2-m wide swath along the permanent transect lines. The abundances of smaller algae and invertebrates, cryptic fishes and area and coverage of hard and soft substrates were recorded annually in six permanent 1-m$^2$ quadrats spaced evenly along each transect. Analyses of data collected during the summer of 2000 and spring 2001 indicated a 50% reduction in sampling effort would result in little change in statistical power to detect the differences among the different artificial reef designs. Consequently, sampling effort beginning in the summer of 2001 was reduced from four transects per module to two. In addition, sampling of the 14 kelp transplant modules was suspended after 2001. This was done because the transplant experiment was successfully completed and concluded that the methods used to transplant juvenile kelp on SCAR were a feasible, albeit labor intensive, means of augmenting the abundance of adult giant kelp on the mitigation reef if the need ever arises (see section *III. G. Kelp Transplantation*). The experiment also found that transplanting had a negligible effect on establishment of adult kelp when compared to dense natural colonization, such as that which occurred during 2000.

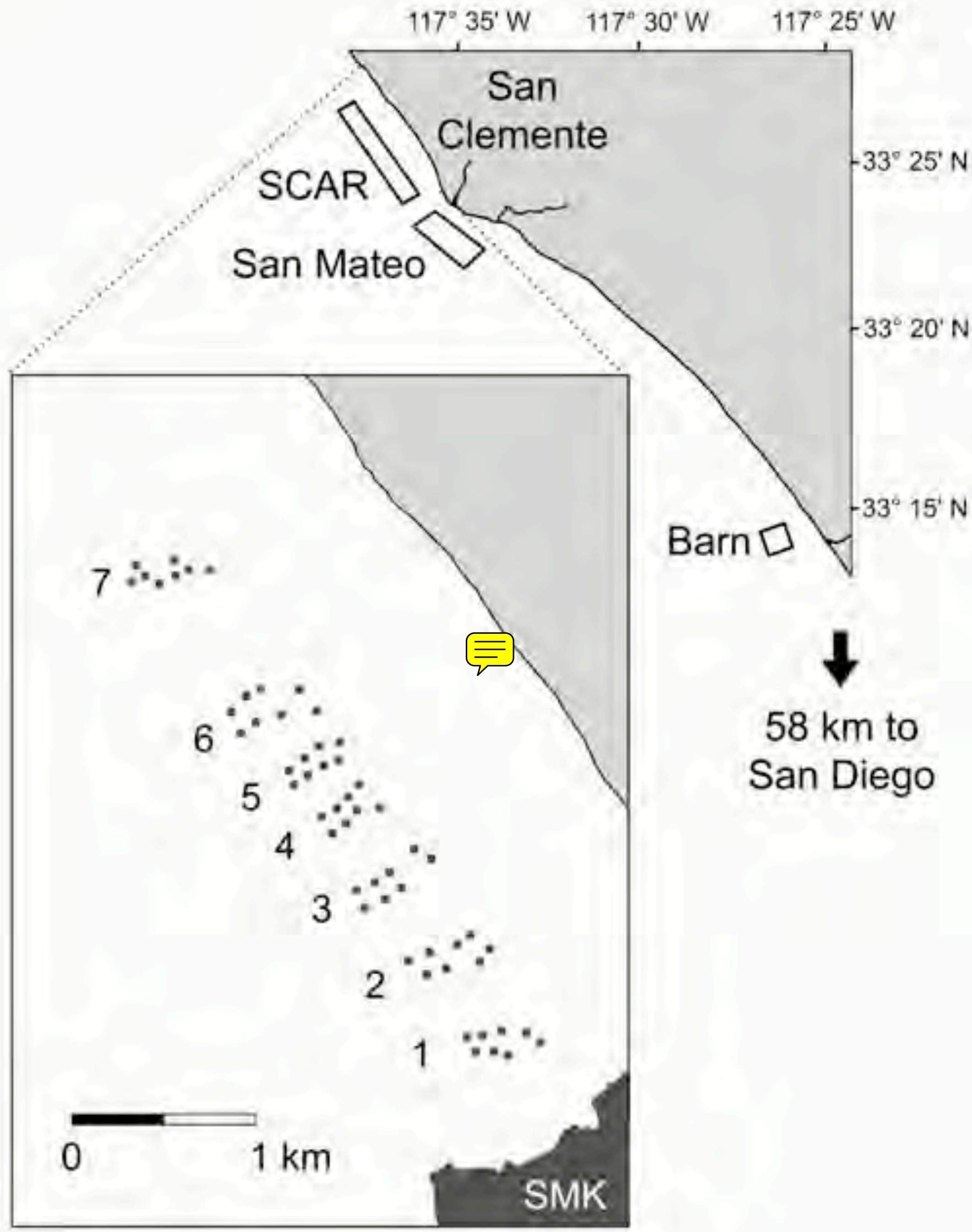
The experimental modules of the six artificial reef designs and the two natural reference reefs were monitored for the entire five-year experiment. The purpose of collecting data throughout the experiment was to assess differences in rates of development (and processes affecting development) between the different artificial reef designs and reference reefs, and to determine whether the biota on the different artificial reef designs had stabilized. Permanently fixed quadrats and transects were used to ensure that differences observed over time reflected temporal rather than spatial variability in the performance of the experimental modules and natural reference reefs.

During the five-year experiment (January 1, 2000 through December 31, 2004), UC Santa Barbara scientists made a total of 8521 dives (amounting to 6058 hours underwater) on the artificial reef modules and reference reefs.

Table II.B.1. The six artificial reef designs and two kelp transplant treatments tested in the experimental phase of the San Clemente Artificial Reef. The targeted values for high-, medium- and low-bottom coverages of reef material identified in the final plan for the experimental reef were 67%, 34%, and 17%, respectively.

| Coverage | Reef Material |
|---|---|
| High | Quarry rock |
| Medium | Quarry rock |
| Low | Quarry rock |
| High | Concrete rubble |
| Medium | Concrete rubble |
| Low | Concrete rubble |
| Medium | Quarry rock with transplanted kelp |
| Medium | Concrete rubble with transplanted kelp |

Figure II.B.1.  Map showing the location and layout of the SONGS San Clemente Artificial Reef (SCAR), and the natural reefs at San Mateo and Barn.



# III. FINDINGS OF THE EXPERIMENTAL PHASE OF THE SONGS ARTIFICIAL REEF PROJECT

## *A. HARD SUBSTRATE*

**Mitigation requirement**

The SONGS coastal development permit requires that the mitigation reef be constructed of rock, concrete, or a combination of these materials at a coverage that is suitable for sustaining giant kelp and associated kelp forest biota similar in abundance and diversity to nearby reference reefs, as determined by results from the experimental artificial reef. The total area of exposed artificial substrate of the mitigation reef shall be no less than 61 ha of which at least two-thirds shall be covered by exposed hard substrate. Should the results of the experimental artificial reef indicate that a different coverage of hard substrate is necessary or adequate to meet this goal (as determined by the Executive Director of the CCC), the Executive Director may change the coverage requirement. In addition, at least 90% of the area of exposed artificial substrate must remain available for the attachment of reef biota. SCE will be required to add sufficient artificial reef material to the mitigation reef to replace lost or unsuitable hard substrate, if at any time the Executive Director determines that more than 10% of the artificial reef material has become covered by sediment, or has become unsuitable for growth of attached biota due to scouring, and there is no sign of recovery within three years. In accordance with Condition D, scientists contracted by the Commission shall initiate surveys to monitor the amount and distribution of exposed artificial reef substrate. These surveys shall begin immediately after construction of the mitigation reef is complete and continue for at least 10 years.

**Methods**

<u>Area of artificial substrate</u>

The amount and distribution of artificial reef material was surveyed on the experimental reef modules to determine the likelihood of the different experimental reef designs meeting the performance standard for hard substrate required of the mitigation reef. The area of exposed artificial reef substrate for a given module was estimated as the product of the area defined by the perimeter of the module (i.e., the module footprint) and the percent cover of artificial substrate within the module's perimeter. Footprint area was estimated using side-scan sonar. Percent cover of artificial substrate was estimated by divers using a uniform point contact method in fixed quadrats.

Ecosystems Management Inc. was issued a contract by the CCC to monitor changes in the footprint areas of the 56 artificial reef modules using side-scan sonar. The navigation for the side-scan sonar surveys was performed using a Differential Global Positioning System (DGPS) in conjunction with vessel navigational software. The side-scan sonar data were collected using a Side-Scan Data Acquisition System that consisted of the data acquisition software, computer with A/D Data Acquisition Board, and the 500 kHz Klein Digital Side-Scan Sonar Model 595.

Each of the 56 modules was pre-plotted with a line about 10 m on the outside of each of the four sides of the module. The vessel ran transects along each of the pre-plotted lines until a "good" image was obtained. The criterion for a "good" image was that the image was not distorted, the vessel track was relatively parallel to the edge of the module, and that the entire module was visible. This digital image was stored on hard disk and processed at a later date. The processing involved the justification of the image. The two axes of each image were the axis of the vessel track and the axis perpendicular to the vessel track.

The vessel track axis was corrected for slant range within the side-scan sonar processing software. The dimensions of the vessel track axis varied because of vessel speed changes and were corrected using the dimensions measured from the perpendicular passes to justify the image. Consequently, the north and south passes were used to justify the dimensions of the east and west passes, and conversely, the east and west passes were used to justify the dimensions of the north and south passes. The justified image was then digitized and the area and perimeter of the module was determined. The mean of the four images was calculated (in some cases, an image was not used due to distortion, or indistinct boundaries) and used to estimate the footprint area. Side-scan sonar surveys of module footprint areas were done in September and October 1999 immediately following construction, October 2000, July 2001, and July 2004. Side-scan sonar surveys were suspended in 2002 and 2003 to reduce costs.

<u>Percent cover of artificial substrate</u>

The percent cover of hard substrate on each module was measured by divers using a uniform grid of 20 points placed in the six permanent 1-m$^2$ quadrats that were uniformly arranged on each permanent 40-m transect. The grid of 20 points consisted of five points spaced every 20 cm on each of four uniformly spaced lines that were positioned parallel to the transect line. The observer sighted an imaginary line through each of the points that was perpendicular to the bottom, and recorded the substrate type intercepted by the line extending below the point. Substrates were classified as natural or artificial and categorized as bedrock (continuous rocky reef), mudstone, large boulder (largest diameter ≥ 100 cm), medium boulder (≥ 50 and < 100 cm), small boulder (≥ 26 and < 50 cm), cobble (≥ 7 and ≤ 25 cm), pebble (≥ 2 mm and < 7 cm), sand (< 2 mm), and shell hash. Categorization of artificial substrate only included small, medium and large boulders. Hard substrates covered with 1 cm or less of silt or sand was noted as being silted. Silted artificial substrates were considered available for the attachment of reef biota for the purpose of evaluating the performance standard for hard substrate.

Sediment accretion and erosion on the artificial reef modules and at the reference sites were estimated from steel stakes positioned on the artificial and natural reefs. Five stakes were placed at distances of 0, 10, 20, 30, and 40 m on each of the two transects on each artificial reef module and along the single transect at each reference reef sampling station. Additional stakes were centered on the offshore, upcoast and downcoast edges of each artificial reef module, resulting in a total of 13 stakes per artificial reef module and five stakes per reference reef sampling station. Stake height was surveyed by divers by measuring the vertical distance from the top of the stake to the sea floor. Change in sand depth was determined by calculating the difference in stake height between consecutive surveys. Increases in sand depth were attributed to accretion and decreases in sand depth were attributed to erosion.

Topographic complexity of artificial substrate

Much of the concern about using quarry rock vs. rubble concrete to build the mitigation reef was not based on toxicity or longevity; there are numerous examples that show both materials are quite suitable for supporting marine life. Rather, the concern about using rock vs. concrete to build the mitigation reef arose from uncertainties pertaining to how reefs built from materials having different sizes and shapes alter the topographic features of a reef, which in turn influence the abundance and composition of reef biota. Although widely used, the method of assessing percent cover described above does not fully capture the topographic complexity of the different artificial reef designs. Therefore, a second sampling method aimed at providing information on the small scale topographic complexity of the different reef types and designs was employed.

In this second method, small link chain was laid out in the quadrats in the same four locations as the knotted line used in the first method. One end of the chain was attached to the distal side of the quadrat frame (i.e., the side farthest from the zero end of the transect) and the chain was laid out parallel to the transect line such that it followed the contour of the bottom and extended to the proximal side of the quadrat (i.e., the side of the quadrat closest to the zero end of the transect). The substrate category beneath the chain was recorded at each 20-cm increment of chain creating a uniform grid of nonplanar points in each quadrat. The surface slope of the substrate was recorded at each point sampled using an underwater level consisting of a graduated arc and a small piece of line attached to a float. These angles were categorized as vertical (90° ± 15°), approaching vertical (45° – 75°), approaching horizontal (15° ≤ 45°), horizontal (0° ± 15°), and overhanging (angle less than vertical, facing the bottom). The total length of chain needed to traverse the quadrat was recorded for each of the four lengths of chain. Substrate rugosity within a quadrat was estimated as the ratio of the average contour length of the bottom (as measured by the average length of chain needed to traverse the quadrat; N = 4 chain lengths per quadrat) to the planar length of the quadrat (which in this case was equal to 1 m).

**Results**

Changes in the area of artificial substrate

The module footprint areas of all reef designs increased an average of 8% to 15% during the first year following construction (Figure III.A.1). The footprint area of the modules changed very little in subsequent years and remained close to the design specifications of 1600 $m^2$ for all artificial reef designs. The slight increasing trend observed during the first year may have been due to redistribution of quarry rock and rubble concrete by wave action and scour that exposed underlying natural hard substrate (mudstone and shell hash). Observations by divers of artificial reef material deposited on permanent transect lines confirmed that some redistribution had occurred. Divers also observed scour and exposure of natural substrata. Initially, the footprint areas of the low-coverage quarry rock and concrete modules were noticeably smaller than those of the medium- and high-coverage modules. Differences in the footprint areas of quarry rock modules with different bottom coverages diminished over time, and by summer 2001 there was little difference in the areas of quarry rock modules having different bottom coverages. In contrast, slight differences in the footprint areas of concrete modules with different bottom coverages persisted throughout the five-year experiment.

Estimates of the cover of artificial substrate

The mean percent cover of artificial substrate for the low-, medium-, and high-cover modules measured by divers in the first survey done in the summer of 2000 was 41.9% (± 2.5 SE), 68.6% (± 6.0 SE), 87.8% (±0.8 SE) for rock, and 42% (± 3.1 SE), 51.6% (± 2.4 SE), 84.1% (± 2.5 SE) for concrete (Figure III.A.2a). By comparison, the mean percent cover of naturally occurring hard substrate at the two reference reefs was 53.6% (± 0.4 SE) and 49.2% (± 6.0 SE) for Barn and San Mateo, respectively (Figure III.A.2b). The coverage of natural substrate on the artificial reef modules was < 1%. The coverage of hard substrate on the natural reefs was intermediate between that of the combined coverage of natural and artificial hard substrate on the low- and medium- coverage artificial reef designs (Figure III.A.2c).

Not only were our estimates of the coverage of artificial substrate for the different artificial reef designs substantially higher than the targeted values of 17%, 34% and 67%, but they were also higher than those estimates obtained by Coastal Environments immediately following the construction of the modules in August and September 1999 (Figure III.A.3). Our higher estimates could have been caused by differences in methodology or changes in the distribution of reef material that occurred between the 1999 and 2000 surveys, which resulted in increased bottom cover. Coastal Environments employed three different methods to estimate the coverage of artificial substrate on the newly created modules in 1999: (1) side-scan sonar, (2) visual estimates by divers, and (3) a line/point contact method by divers (Coastal Environments 1999). Coastal Environments' estimates of the percentage cover of hard substrate on the modules in 1999 differed substantially depending on the method used. Values of percentage cover obtained using side-scan sonar were the most similar to the target values of 17%, 34% and 67% and the most different from our diver estimates in 2000, whereas Coastal Environment's diver line/point contact method produced values that were much more similar to our 2000 estimates obtained using a uniform point contact method (Figure III.A.3).

To attempt to untangle methodological effects from temporal changes in substrate cover we sampled the cover of hard substrate on the six modules of Block 7 in summer 2003 using both Coastal Environment's line/point contact method and our uniform point contact method. Values of percentage cover using the two methods were very similar on all but one of the modules (medium cover concrete, Figure III.A.4) indicating that the slightly higher values of percent cover obtained by UC Santa Barbara divers in 2000 relative to those obtained by Coastal Environments' divers in 1999 were real and may have been caused by the redistribution of boulders soon after reef construction. This hypothesis is consistent with the slight increases observed in footprint area and diver observations indicating that boulders near permanently installed transect lines had moved.

Accuracy of methodology

Initially we had hoped to use side-scan sonar to estimate bottom coverage of artificial substrate (i.e., quarry rock and rubble concrete). However, this method proved to be unreliable because of its inability to distinguish between hard artificial substrates and various naturally occurring substrates such as boulders, bedrock, mudstone, and shell hash (Tim Norall, Ecosystems Management Associates, personal communication). Consequently, we decided to estimate the percent cover of different substrate types on each module using a uniform point contact method employed by divers that consisted of recording the substrate type at 20 uniform points in 12 regularly spaced 1-$m^2$ quadrats. We evaluated the accuracy of this method by comparing values obtained using it to those obtained using a diver point contact method consisting of a uniform grid of 1600 points spaced 1 m apart on a given module. The large number of sampling points (1600 vs. 240) spread evenly over an entire module (as opposed to being clumped in twelve 1-$m^2$ quadrats) was assumed to provide a relatively accurate measure of the percentage of the bottom covered by hard substrate on a module and a good standard for comparison. Six modules (one of each combination of substrate type and cover) were sampled in the summers of 2000 and 2001 using the two methods (i.e., 20 points sampled in 12 quadrats vs. 1600 uniformly spaced on a module). Results show that the two methods produced very similar estimates of the percent cover of hard substrate (Figure III.A.5), indicating that fixed quadrat method used by divers during the five-year experiment provided accurate estimates of the percentage of the bottom covered by hard substrate on the artificial reef modules and the natural reference reefs.

Changes in the cover of artificial substrate

The percent cover of artificial reef material changed very little during the period 2000–2004 (Figure III.A.2), indicating that subsidence of reef material and accretion of sand in the vicinity of the modules was minimal. The observation that percent cover of natural and total hard substrate on the artificial reef modules remained quite constant over time indicated that the placement of artificial substrates on the sand did not result in an appreciable increase in the bottom cover of hard substrate via erosion and subsequent exposure of previously buried natural hard substrate. Diver measurements of sand depth at fixed stakes corroborate this conclusion. Although changes in sand depth at fixed stakes gradually increased over time in some instances, increases and decreases never exceeded 4 cm for any artificial reef design or block (Figures III.A.6 and III.A.7).

All artificial reef designs have been consistently near or above the standard that requires at least 90% of the initial cover of hard substrate to remain exposed for colonization by reef biota (Figure III.A.8a). Importantly, none of the designs showed significant declining trends in the cover of available substrate, though the high-cover rock treatment showed a marginally significant declining trend (Figure III.A.8b). In 2004, five of the seven blocks met the performance standard requiring 90% of the initial cover of artificial substrate remain exposed for colonization by reef biota (Figure III.A.9). Block 1 was slightly under the standard at 89%, and Block 7 was significantly below the standard at

80%. Divers noted substantially more inundation by sand on modules in Block 7 compared to the other blocks.

Topography

Measurements of concrete and rock taken on land before the material was deployed to the ocean showed that the pieces used to build the concrete modules were on average 50 % longer and 47% wider than pieces used to build the rock modules (Figure III.A.10). The thickness of the two materials was quite similar. Data collected by divers on the size frequency distributions of the artificial substrates in permanent 1-$m^2$ quadrats showed that concrete modules were composed primarily of large pieces (Figure III.A.11). Nearly one third of the concrete substrates were longer than 100 cm and over 70% were longer than 50 cm. In contrast, nearly 40% of the rock was less than 50 cm in length and only 3% was greater than 100 cm.

The relatively large flat pieces of concrete used to construct the reef resulted in concrete modules having proportionally more horizontal surfaces than rock modules, but less than that of the reference reefs (Figure III.A.12). In general, the surface slopes of rock reefs were more evenly distributed than those of concrete reefs. This highly diverse array of vertical and horizontal surface slopes on rock modules contrasted sharply with that observed for the reference reefs, which were characterized by a large proportion of horizontal surface. The greater rate of change in surface slopes observed for rock reefs compared to concrete reefs indicated that the large percentage of horizontal surface on concrete occurs primarily in relatively large continuous patches (Figure III.A.13). That the rate of change in surface slope generally increased with the percent cover of artificial substrate reflects the flat, featureless nature of soft sediments that reduce the topographic complexity of reefs in direct proportion to their abundance. Despite the differences seen in the size and surface slope of rock and concrete modules, the small scale rugosity (measured as the frequency of change in the surface slope within a 1-$m^2$ quadrat) of quarry rock reefs was only slightly greater than that of concrete reefs (Figure III.A.13). Importantly, the small-scale rugosity of both quarry rock and concrete reefs was substantially greater than that of the reference reefs.

Summary of results for hard substrate

- The footprint area of the artificial reef modules remained relatively constant over time and was close to the design specifications of 1600 $m^2$.
- The mean percent cover of artificial substrate on the experimental modules was substantially greater than the design specifications of 17%, 34% and 67% averaging 42%, 60% and 86% for the low-, medium- and high-coverage designs in the summer of 2000.
- The percent cover of natural hard substrate at the two reference reefs in the summer of 2000 was 49% and 54%.
- Except for modules at the northern end of the artificial reef (Block 7) there was little evidence of material subsidence, sand accretion, or erosion on the artificial reef modules.
- All six artificial reef designs, which incorporated different combinations of substrate type and coverage, were consistently near or above the performance

standard that requires at least 90% of the initial cover of hard substrate to remain exposed for colonization by reef biota.

- Five of the seven blocks were above the standard that requires at least 90% of the initial cover of hard substrate to remain exposed for colonization by reef biota. Block 1 (the southern-most location) was slightly below the standard with 89% of the initial remaining in 2004, while Block 7 (the northern-most location) was significantly below the standard with only 80% of the initial artificial substrate available for colonization by reef biota.
- The small-scale topography of rock and concrete modules was quite similar despite rock and concrete having different dimensions. The small-scale topography (rugosity on the scale of one meter) of rock and concrete modules was substantially greater than that of the reference reefs.

Figure III.A.1. Mean (± SE) footprint area ($m^2$) of the artificial reef modules over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high). Data are from side-scan sonar. N = 7 modules per artificial reef design.

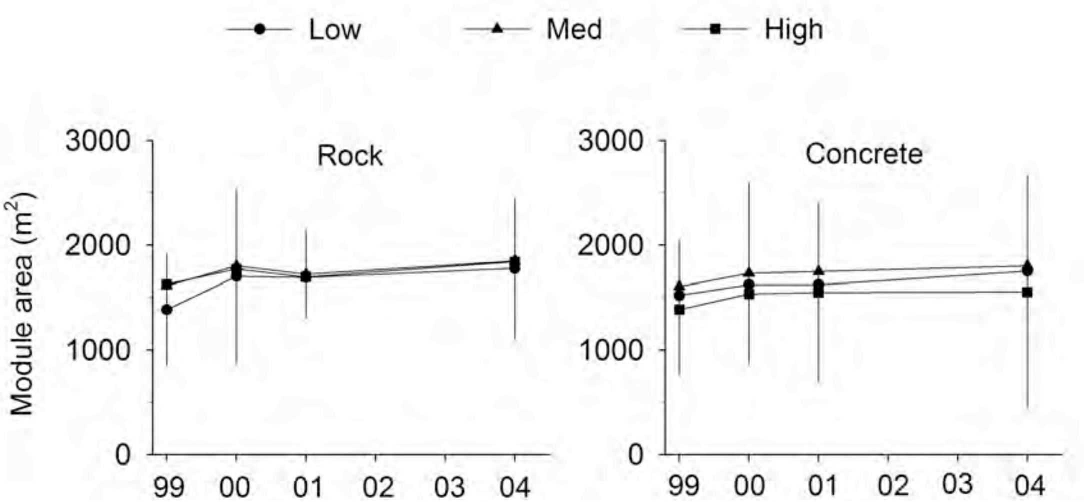


Figure III.A.2. Mean (± SE) percent cover of the amount of (a) artificial, (b) natural, and (c) total (natural + artificial) hard substrate over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high) and for the reference reefs, Barn (B) and San Mateo (SM). Data are from diver surveys. N = 7 artificial reef modules or natural reef locations.

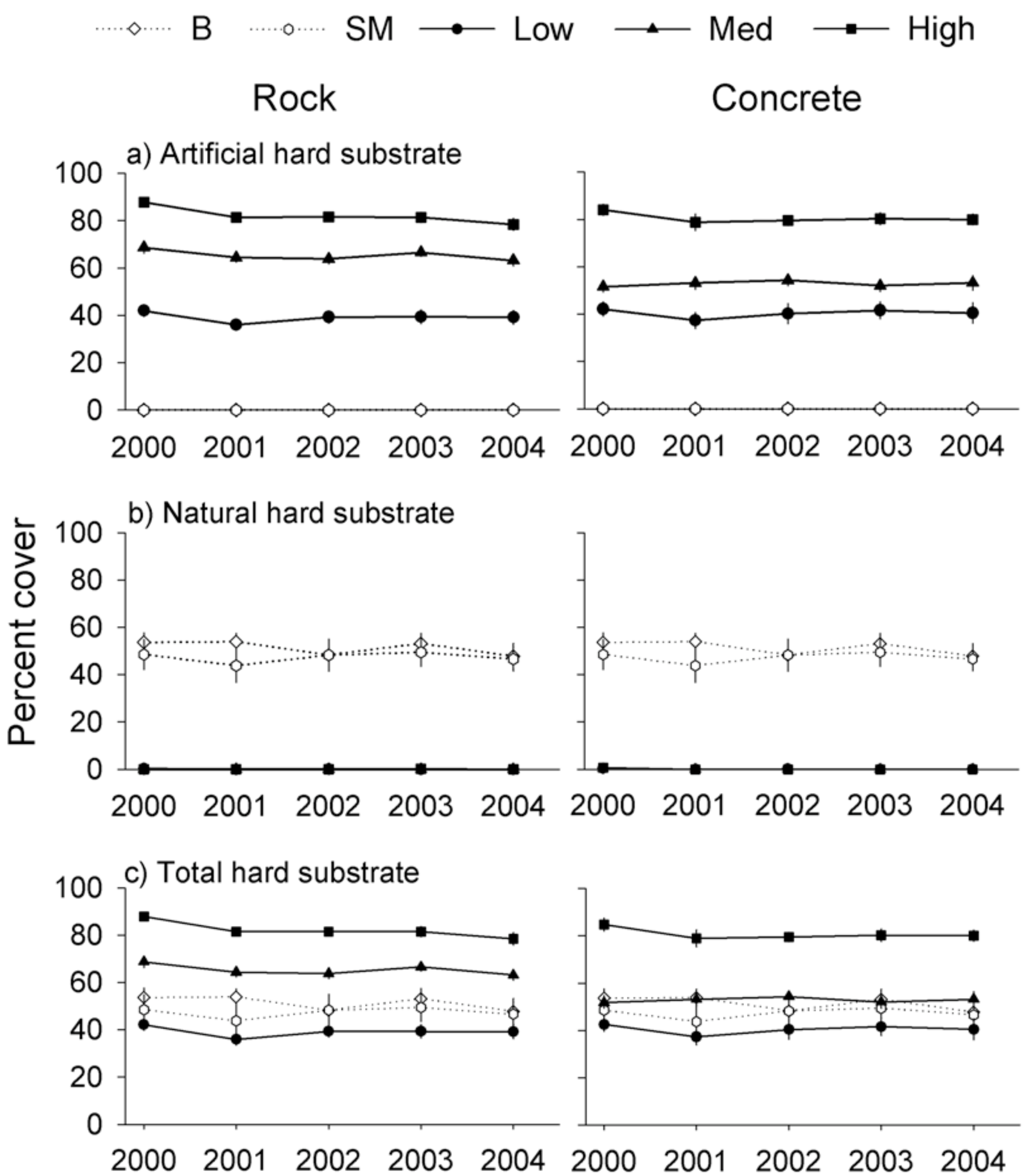


Figure III.A.3. Mean (± SE) percent cover of the amount of hard substrate of the different artificial reef designs estimated by Coastal Environments in 1999 using side-scan sonar (CE sidescan 99), diver visual estimates (CE visual 99), diver line/point contact method (CE pc 99) and by UCSB in 2000 using a diver uniform point contact method (UCSB pc 00). N = 7 artificial reef modules.

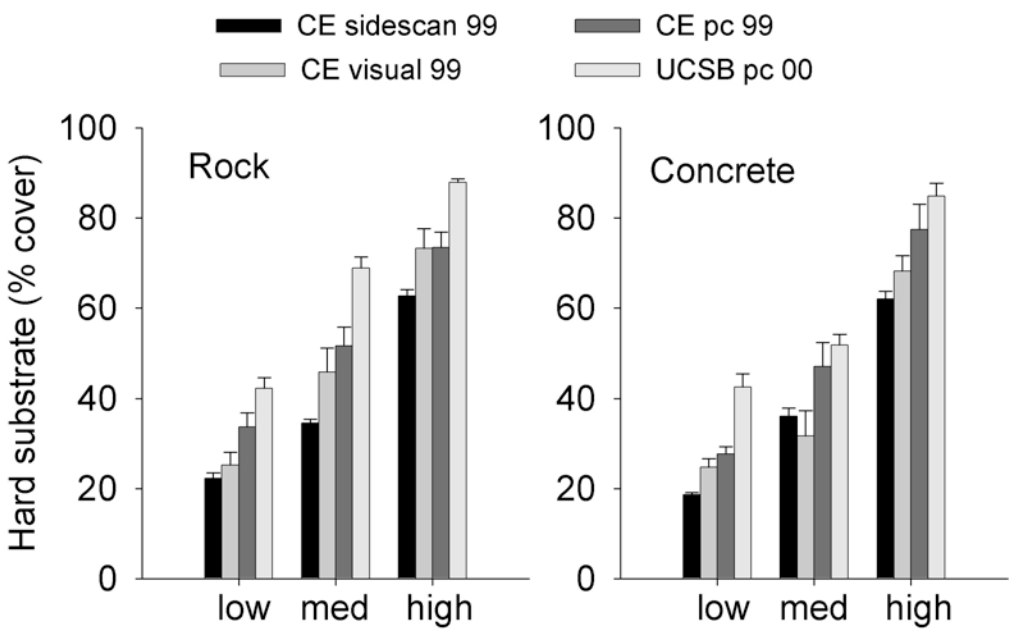



Figure III.A.4. Percent cover of hard substrate on the six artificial reef designs on Block 7 estimated in summer 2003 using Coastal Environments line/point contact method (CE) and UCSB's uniform point contact method (UCSB).

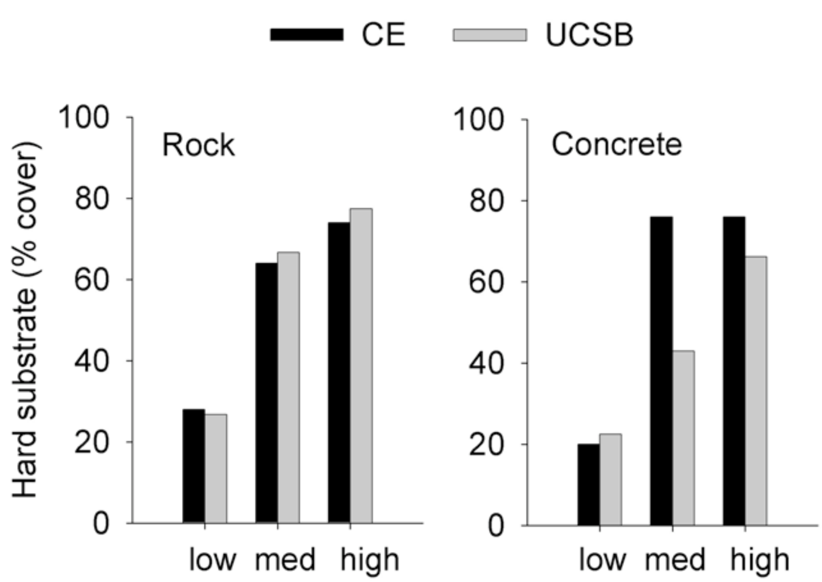


Figure III.A.5. Percent cover of hard substrate of six modules with different types and coverages of artificial reef material. Percent cover was estimated from 20 uniform points in twelve 1-$m^2$ quadrats (240 points) and from a uniform grid of 1600 points spaced 1 m apart.

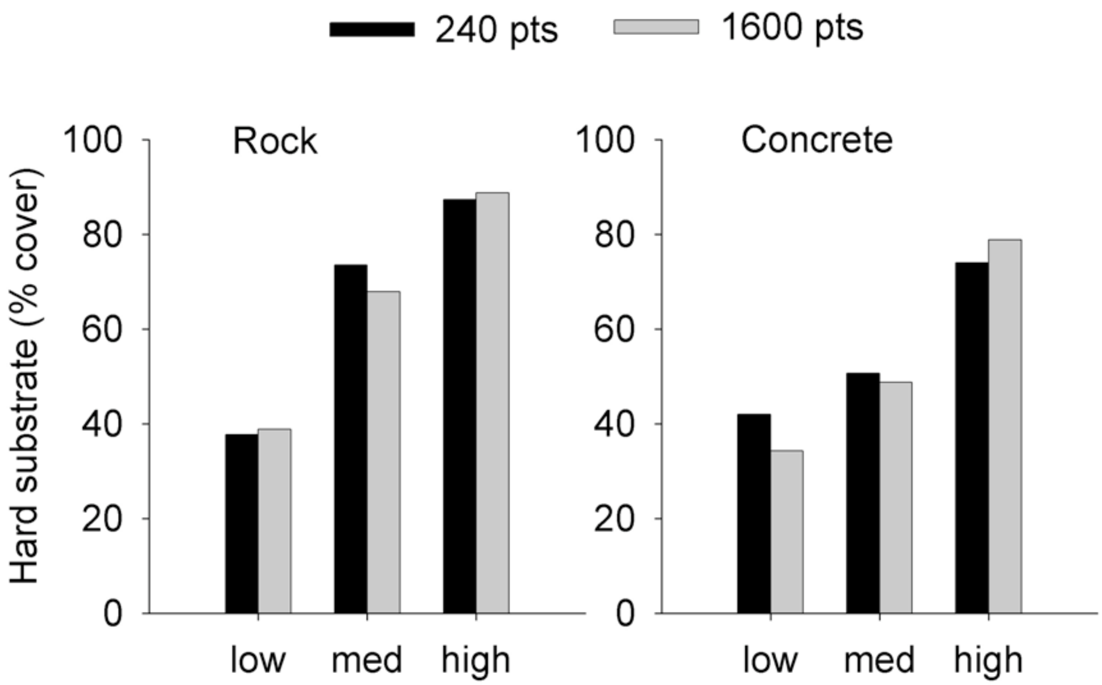



Figure III.A.6. Change in the mean (± SE) initial depth of sand measured at fixed stakes on artificial reef modules with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and on the natural reference reefs Barn (B) and San Mateo (SM). Positive values indicate accretion, negative values indicate erosion. N = 7 modules per artificial reef type or 7 locations per reference reef.

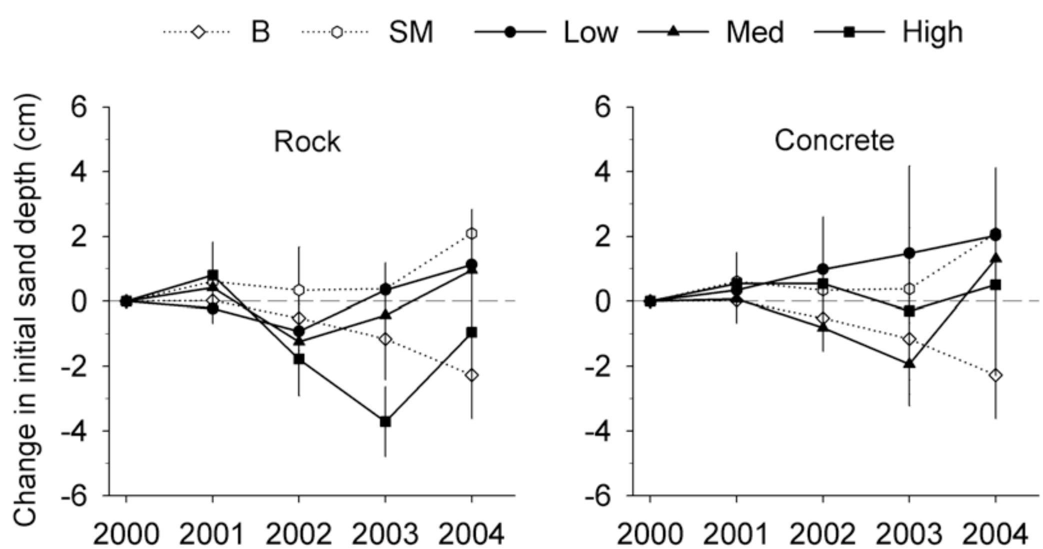


Figure III.A.7. Change in the mean (± SE) initial depth of sand measured at fixed stakes on artificial reef modules at different locations (blocks) and on the natural reference reefs Barn (B) and San Mateo (SM). Positive values indicate accretion, negative values indicate erosion. N = 6 modules per block or 7 locations per reference reef.

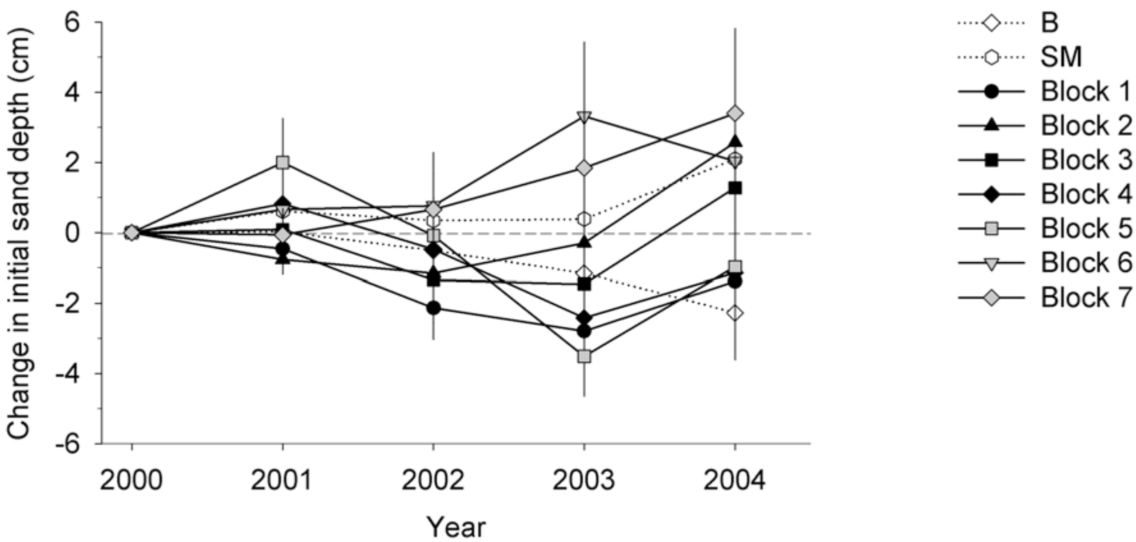
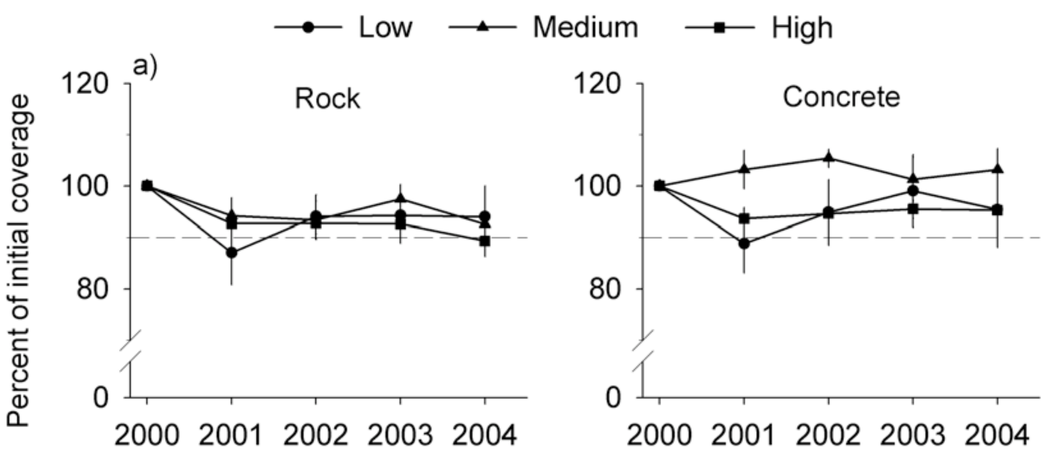


Figure III.A.8. (a) Change in the mean (± SE) percent of the initial coverage of artificial substrate over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high). N = 7 modules per artificial reef design. Dashed horizontal line indicates the performance standard of 90%. (b) regression lines of change in the mean percent of the initial cover of artificial substrate over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high).



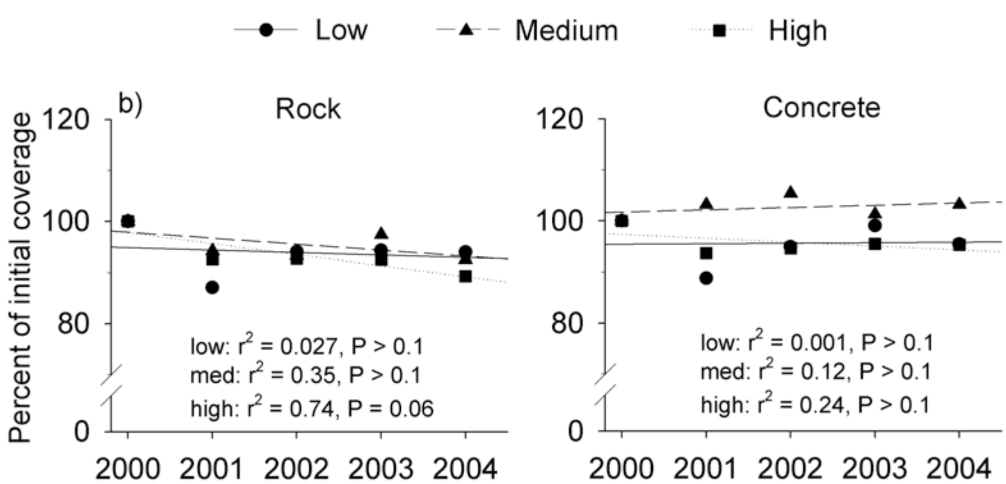



Figure III.A.9. Mean (± SE) percent of the initial cover of artificial substrate on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. Dashed horizontal line indicates the performance standard of 90%.

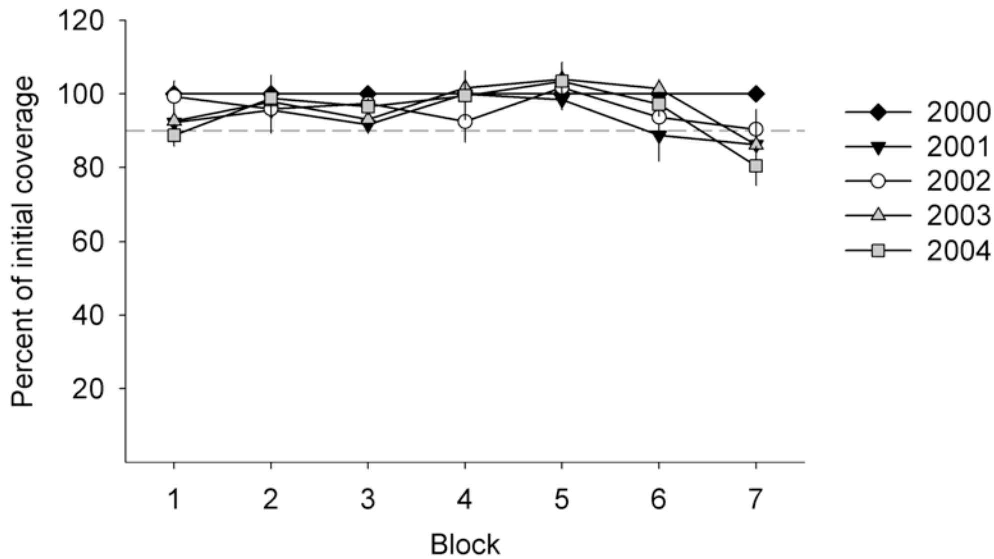



Figure III.A.10. Mean (± SE) dimensions (cm) of quarry rock and rubble concrete boulders used to build SCAR. Data are from boulders measured in the construction yard prior to deployment to the ocean.

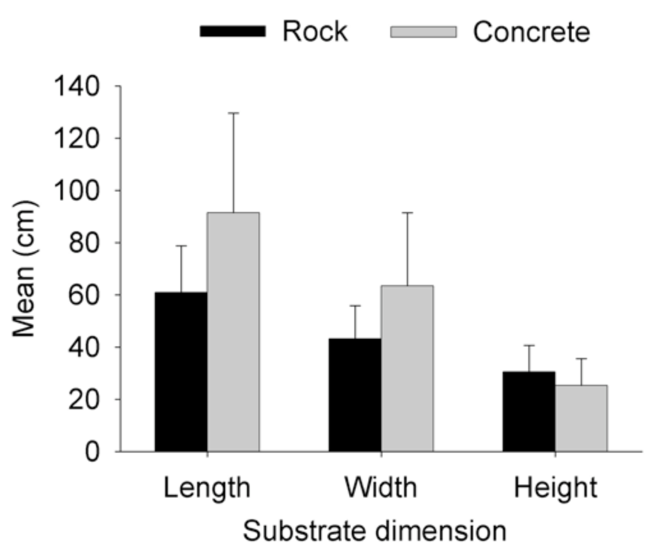


Figure III.A.11. Frequency distribution of the lengths of quarry rock and concrete rubble on SCAR. Data are from diver surveys.

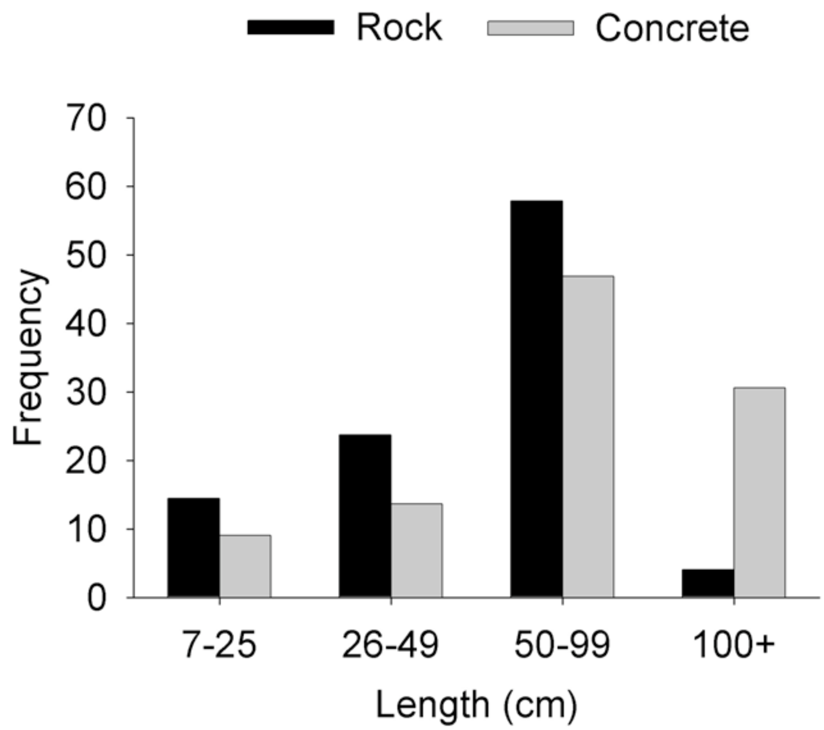



Figure III.A.12. Frequency distribution of the surface slope of quarry rock and concrete on the artificial reef modules. Surface slope was recorded by divers at uniformly distributed points within regularly spaced 1-$m^2$ quadrats on each module. Data are percentages. N = 3816 and 3104 points for rock and concrete, respectively.

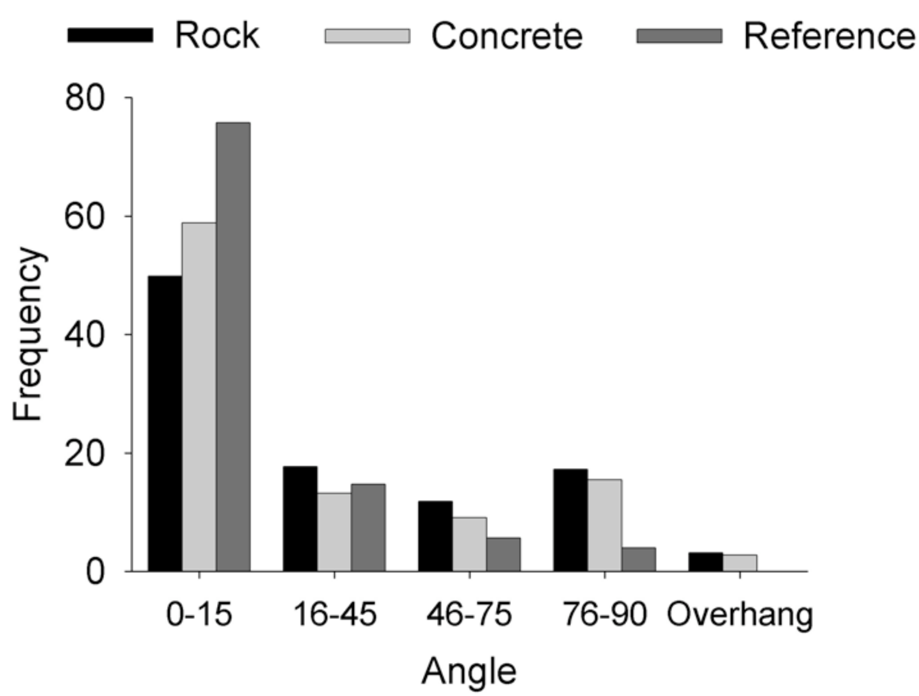
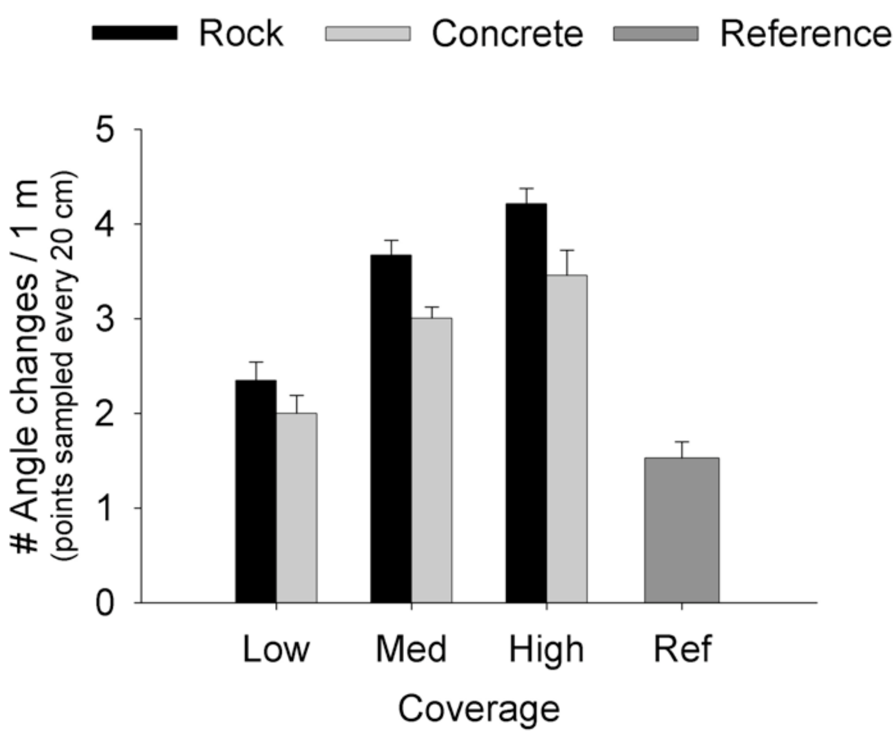


Figure III.A.13. Mean (± SE) surface irregularity of rock and concrete modules. Surface irregularity was estimated by divers by draping four regularly spaced chains across 12 regularly spaced 1-$m^2$ quadrats on selected modules and measuring the surface slope at 20-cm intervals along each chain. Surface irregularity within quadrats is expressed as the mean proportion of observations where the slope category (as shown in Figure III.A.8) differed between contiguous 20-cm intervals. N = 228 and 204 quadrats for rock and concrete, respectively.



## *B. GIANT KELP*

**Mitigation requirement**

An important performance standard for the mitigation reef is that it sustain 61 ha of the giant kelp, *Macrocystis pyrifera,* at medium to high densities. For purposes of the SONGS coastal development permit, medium- to high-density kelp is defined as more than four adult plants per 100 $m^2$, which was the definition used by the Marine Review Committee to estimate the amount of kelp loss attributed to SONGS during the impact assessment phase of the SONGS monitoring program.

**Methods**

A multi-component approach to monitoring giant kelp was used during the experimental phase to obtain the pertinent information needed to evaluate the performance of the different reef designs with respect to the standard for giant kelp. The monitoring involved collecting information on the following range of size classes of giant kelp:

- *Adult* – an individual having eight or more fronds *or* having haptera extending up to or above the primary dichotomy.
- *Sub-adult* – an individual exceeding 1 m in height, having fewer than eight fronds *and* having no haptera that extend up to or above the primary dichotomy.
- *Juvenile* – a small blade having a split *or* an individual consisting of only fronds that are < 1 m tall.
- *Recruit* – a small blade lacking a split that can be identified as *Macrocystis* by the undulation at the base of the blade.
- *Unidentified kelp blade* – a small kelp blade (generally < 2 cm tall) that cannot be identified to species.

Data collected on adults in the experimental phase of the artificial reef mitigation project were used to evaluate how well the different experimental reef designs met the performance standard for giant kelp that will be applied to the mitigation reef. Data collected on the abundances of sub-adults, juveniles, and recruits provided insight into the biological processes needed to sustain adult giant kelp at densities at or above the performance standard.

Adult and sub-adult plants were sampled annually in spring in permanently located 40-m x 2-m transects on the artificial reef modules of SCAR and at San Mateo and Barn kelp beds in each year of the experiment. All transects were marked with lead line anchored to the bottom with stakes. A pair of divers swimming on opposite sides of the 40-m long lead line recorded information on all adult and sub-adult plants encountered in a 1-m-wide swath adjacent to the lead line. Frequently, only a portion of a plant was located within the 1-m swath. Of special concern was the case when a plant recruited outside the swath and then encroached into the swath on subsequent surveys via the spreading of its holdfast. To avoid counting "encroaching" plants that were not located in the swath in previous surveys, divers only counted adult and sub-adult plants if their primary dichotomy was located within 105 cm of the lead line.

Every adult plant encountered along each transect was counted, tagged and its survivorship was followed on subsequent surveys. Tags consisted of a white plastic label containing a unique alphanumeric identification number. Tags were fastened with a nylon cable tie to either the holdfast or the secondary dichotomy. The dimensions of the reef substrate to which the plant was attached were recorded at the time of initial tagging. These dimensions were used to categorize the substrates as follows: large boulder (largest diameter ≥ 100 cm), medium boulder (≥ 50 and < 100 cm), small boulder (≥ 26 and < 50 cm), cobble (≥ 7 and ≤ 25 cm), and pebble (≥ 2 mm and < 7 cm). Data on the size of all tagged adults were collected on each survey. Plant size was measured in two ways: by the number of fronds > 1 m tall, and by the basal area of the holdfast. Holdfast area was calculated from measurements of holdfast length and width using the equation for an ellipse (area = length x width x $\pi/4$). Data on fecundity were recorded for the first 30 adult plants encountered on each transect. The fecundity of an adult kelp plant was based on its total sorus area (spore-bearing areas on specialized blades called sporophylls), which was estimated as the product of the number of sporophylls having sori and the average length and width of all of its sori.

Sub-adults were not tagged until they reached adulthood. Data collected on sub-adults included the number of fronds greater than 1-m tall and the category of substrate to which the plant was attached.

Juveniles and recruits of giant kelp were sampled once per year in the summer. Juveniles were counted in the same 40-m x 2-m areas in which adults and sub-adults were counted. Because it was inefficient to count numerous small kelp plants in an area as large as that delineated by the transects, recruits of *Macrocystis* were counted in six fixed 1-m$^2$ quadrats that were evenly spaced along each transect.

**Results**

Colonization

Relatively sparse colonization by *Macrocystis* occurred on SCAR during the first six months of the experiment. At the time of the first survey in March 2000 the mean density of giant kelp on SCAR was 10% of that at San Mateo and 2% of that at Barn (mean numbers of *Macrocystis* 100 m$^{-2}$ ± SE were 40.8 ± 7.8, 10 ± 2.6. and 0.9 ± 0.1 for Barn, San Mateo, and SCAR, respectively). All the *Macrocystis* observed on SCAR at this time appeared to be intact adults that drifted to the artificial reef from nearby natural reefs. The vast majority of *Macrocystis* at SCAR were relatively small individuals (both in terms of frond number and holdfast area; Figure III.B.1a and b) that were attached to cobbles and small boulders made of natural rock (Figure III.B.1c). In contrast, adult *Macrocystis* growing in San Mateo and Barn were present in a wide range of sizes, but were attached mostly to bedrock and large boulders, suggesting that the vast majority of these plants recruited directly to San Mateo and Barn from spores (as opposed to drifting in from other kelp beds). Follow-up observations revealed that the few drifters on SCAR recorded as being attached to large boulders were actually attached to smaller natural rocks that became wedged among larger quarry rock or concrete boulders. No recruitment by *Macrocystis* to quarry rock or concrete rubble was observed at this time.

High densities of *Macrocystis* recruits were first observed on SCAR in July 2000 (Figure III.B.2a). Interestingly, relatively low numbers of recruits were found in the cluster of modules located closest to San Mateo. Aside from this, densities of *Macrocystis* recruits on SCAR dropped off rapidly with distance from San Mateo much in the same way that drifters did. Nevertheless, mean densities of giant kelp recruits still exceeded 0.5 per $m^2$ of artificial substrate and 0.3 per $m^2$ of the sea floor on the most distant modules (Block 7), which were located an average of 3.4 km from the nearest source population. The density of recruits on quarry rock and concrete rubble was generally similar regardless of distance. The effects of reef type on the density of recruits per area of bottom, however, varied inconsistently with distance from the San Mateo kelp bed (Figure III.B.2b).

The number of kelp recruits on a module tended to be higher on modules having a greater cover of rock and concrete (Figure III.B.3). However, the density of *Macrocystis* recruits per unit area of quarry rock and concrete substrates was unrelated to the amount of quarry rock or concrete on a module. The strength of this positive relationship varied inexplicably and nonmonotonically with distance from the San Mateo kelp bed. Unlike that at other distances, recruitment of *Macrocystis* on modules located 2.1 and 2.5 km from San Mateo (i.e., Blocks 5 and 6) was consistently low and did not vary with the bottom cover of artificial reef habitat (Figure III.B.3).

The sparse density and reduced fecundity of drifters coupled with a relatively small area of reef resulted in a spore source at SCAR during winter 2000 that was approximately two and one half orders of magnitude smaller than that at San Mateo and Barn (Reed et al. 2004). Also, there was no relationship between the total fecundity on a module in March 2000 and the number of *Macrocystis* recruits observed on it in July 2000. Finally, multiple regression results showed that recruitment to the artificial reef modules was strongly and negatively related to their distance from San Mateo (Reed et al. 2004). Importantly, the density of drifters was not a significant source variation in the regression model. Together these results indicate that the local dispersal of spores released from drifters contributed very little to the dense recruitment of giant kelp observed on SCAR in summer 2000, and that the initial colonization of giant kelp resulted from widespread dispersal of spores from a large spore source to the south (most likely San Mateo).

<u>Adults</u>

The cohort of plants that recruited in summer 2000 appeared in the adult survey of winter/spring 2001. Patterns of adult *Macrocystis* abundance in this survey resembled those of juvenile recruitment observed in the summer of 2000. Adult abundance increased with increasing cover of artificial substrate and decreased with distance from the San Mateo kelp bed (Figures III.B.4 and III.B.5). Adult densities on rock modules were initially higher than those on concrete modules; adult kelp abundance on both types of artificial reef modules was substantially greater than that observed at San Mateo and Barn. Adult kelp densities have declined beginning in 2002 and were very similar on all artificial reef designs and in all blocks by 2004. Despite these declines, the density of adult giant kelp in 2004 was well above the standard of four plants per 100 $m^2$ for all artificial reef designs and substantially greater than that at San Mateo and Barn. The densities of kelp fronds > 1-m tall (that for giant kelp is a better predictor of biomass than plant density) showed the same spatial and temporal patterns of abundance as adult plant density (Figures III.B.6 and III.B.7).

Sustainability

The performance standard for giant kelp stresses *sustainability* of medium- to high-density kelp. Sustainability requires adult reproduction, juvenile recruitment, and survivorship to the adult stage. The reproductive potential of giant kelp on the artificial reef modules was very low during the first two years of the experiment, but increased over time as adult plants became larger and more mature (Figure III.B.8). Despite having lower adult densities during 2002 and 2003 (Figure III.B.4), artificial reef designs with lower bottom coverage of rock and concrete tended to support slightly higher standing crops of fertile kelp reproductive tissue than artificial reef designs with higher bottom coverages of rock and concrete (Figure III.B.8). These differences were diminished in 2004 when adult densities on the different reef designs converged. Adult fecundity varied somewhat among blocks but there was no sign of a spatial gradient in kelp reproduction (Figure III.B.9). The reproductive potential of giant kelp at the reference reefs also tended to increase over time, but unlike that of the artificial reef modules they displayed a large peak in 2003 before abruptly declining in 2004 (Figure III.B.8). Aside from this large peak in sorus area in 2003, the standing crops of fertile kelp tissue on the reference reefs were generally similar to that observed on the artificial reefs.

The temporal patterns of giant kelp recruitment differed greatly within locations on SCAR (Figure III.B.10) and between SCAR and the two reference reefs (Figure III.B.11). As mentioned above (Figure III.B.2) a large recruitment event of giant kelp occurred at SCAR during the first year (2000) with substantially less recruitment observed in subsequent years. Recruitment density was inversely related to distance from San Mateo during this initial colonization event. Low to moderate recruitment was observed in subsequent years in the more northern blocks where adult density was relatively low (Figure III.B.10). The opposite temporal pattern was observed at San Mateo and Barn where the only significant recruitment event occurred in 2004 (Figure III.B.11). Data on kelp reproduction (Figures III.B.8 and 9) indicate that the strength of kelp recruitment observed at SCAR and the reference reefs was unrelated to the local production of spores. Rather, the most likely factor contributing to the different patterns of kelp recruitment observed at SCAR and the reference reefs was temporal and spatial differences in the level of shading by the kelp canopy, which is known to have a profound effect on giant kelp recruitment (Reed and Foster 1984, Dayton et al. 1984). The observed pulses in giant kelp recruitment at SCAR and the reference reefs occurred when the biomass of giant kelp (as estimated by the density of fronds) at these sites was relatively low (Figure III.B.6).

Adult survivorship was examined in the fraction of plants that recruited to SCAR in 2000 and reached adulthood in spring 2001. Little difference was observed between rock and concrete modules in the survivorship of adults in this cohort (Figure III.B.12). Thirty to 40% of the adults present in 2001 survived to 2004, and the mean life span of a plant once it reached adulthood was slightly greater than two years. The survivorship of adult *Macrocystis* on SCAR was greater than that on the two reference reefs, which were similar to each other (Figure III.B.12). Survivorship of adult *Macrocystis* tended to be inversely related to the cover of hard substrate and to the density of adult *Macrocystis* (compare Figure III.B.12 to Figure III.B.4), suggesting that patterns of adult kelp survivorship on SCAR were influenced by density dependence. Spatial patterns of adult kelp survivorship are consistent with this view. In 2003 and 2004, survivorship was lowest in the more southerly blocks (i.e., small numbered blocks), which supported the densest populations of adult kelp (Figure III.B.13).

An important consideration in the design of the mitigation phase is the size of the material used to construct the reef. Our results show that the effects of substrate size on kelp survivorship varied somewhat between rock and concrete (Figure III.B.14). In the case of concrete, survivorship was noticeably lower on cobbles compared to larger-sized substrates (rocks > 25-cm diameter), which showed little difference in kelp survivorship. In contrast, the percent of adult kelp surviving to 2004 on quarry rock was lowest on large boulders (rocks > 1-m diameter) and greatest on small cobbles. It is important to note, however, that many fewer kelp plants growing on cobble reached adulthood compared to plants growing on larger-sized boulders (the small sample sizes for cobble reflect this fact) indicating that survival from the recruit to the adult stage was lower on cobbles.

Summary of results for giant kelp

- *Macrocystis* recruitment on the artificial reef modules was highly variable among years and among locations.
- High densities of kelp recruits were only observed on the artificial reef during the summer of 2000. Recruitment density during this period was inversely related to distance from San Mateo. Nonetheless, substantial numbers of recruits were observed at the most distant modules located 3.5 km from the nearest population of adult kelp.
- All evidence suggests that the initial colonization of SCAR by giant kelp resulted from the widespread dispersal of spores rather than limited dispersal from adult plants that drifted onto the experimental reef.
- The density of *Macrocystis* recruits in summer 2000 increased with the bottom cover of artificial substrate and was unaffected by the type of artificial substrate.
- Low to moderate recruitment was observed in most years at the northern blocks where adult densities were relatively low, but still above the performance standard of 4 adult plants per 100 $m^2$. Little to no recruitment was observed in the southern blocks in most years where adult densities were very high.
- Patterns of adult density on the artificial reef reflected patterns of juvenile density in the previous year.
- Adult density declined over time and by 2004 there was little difference in the density of adults on the different artificial reef designs and on the different blocks.
- All artificial reef designs and blocks have exceeded the performance standard for adult kelp (i.e., > 4 four adults / 100 $m^2$) since 2001.
- Adult density was consistently higher on the artificial reef modules than on the natural reference reefs.
- Reproductive potential (i.e., number of spores produced per area of bottom) near the end of the experiment was similar among the six artificial reef designs.

- Approximately 40% of individuals on the artificial reef that reached adulthood in 2001 survived to 2004.
- Adult survivorship was lower on modules with higher cover of hard substrate, which had higher initial densities of adults.

Figure III.B.1. Frequency distributions of: (a) *Macrocystis* frond number per plant, (b) *Macrocystis* holdfast area, and (c) the size of the rock to which *Macrocystis* was attached for Barn (B), San Mateo (SM) and SCAR. Data are from March 2000. N = 294, 72, and 165 plants for B, SM, and SCAR, respectively, in (a) and (c), and N = 290, 72, and 150 plants for B, SM, and SCAR, respectively, in (b).

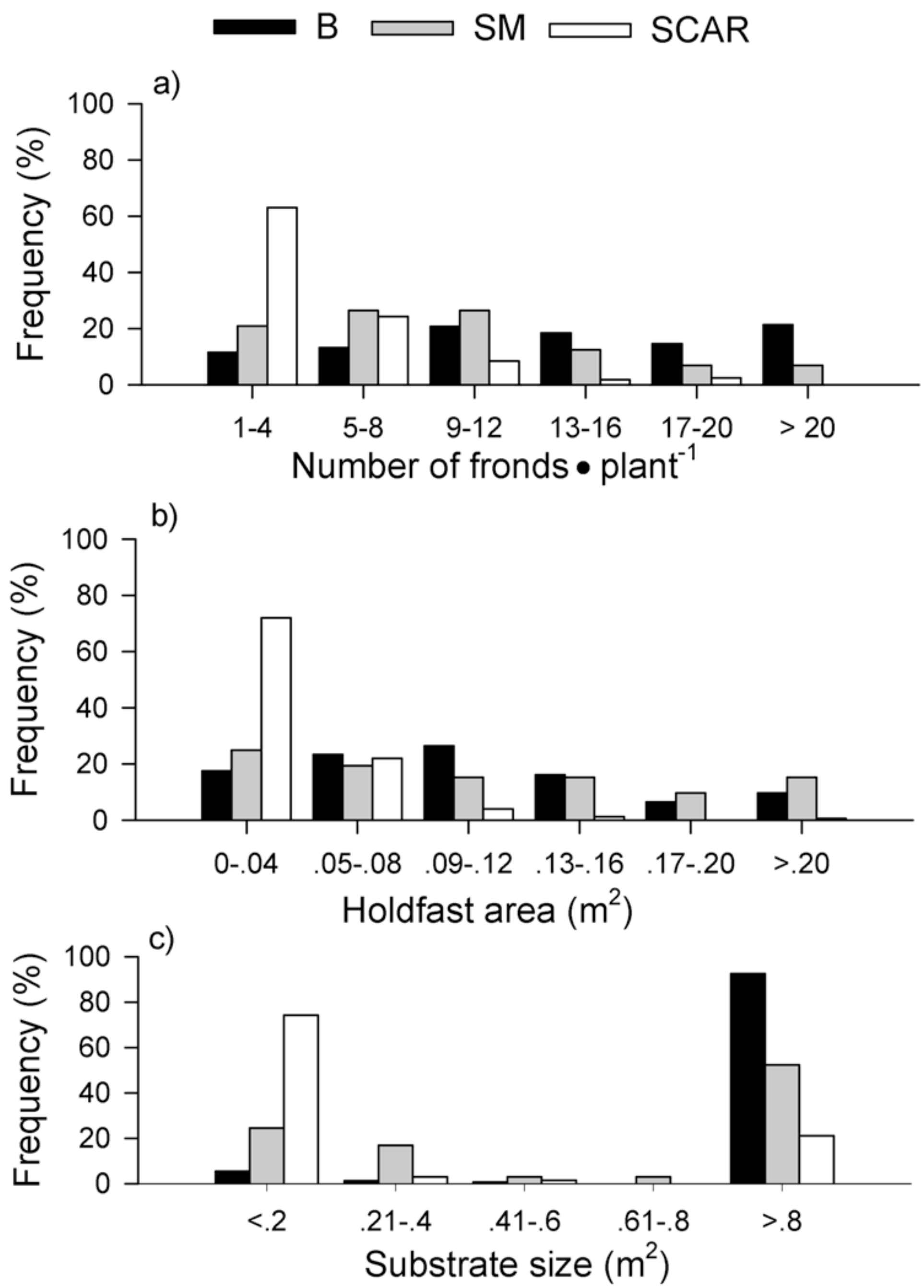


Figure III.B.2. Abundance of *Macrocystis* recruits at SCAR in summer 2000 vs. distance from the San Mateo (SM) kelp bed. (a) Mean (± SE) density of recruits $m^{-2}$ of artificial substrate. N = 8 modules (rock and concrete combined). (b) Mean (± SE) density of recruits $m^{-2}$ of bottom on rock and concrete modules. N = 4 modules per reef type for each distance.

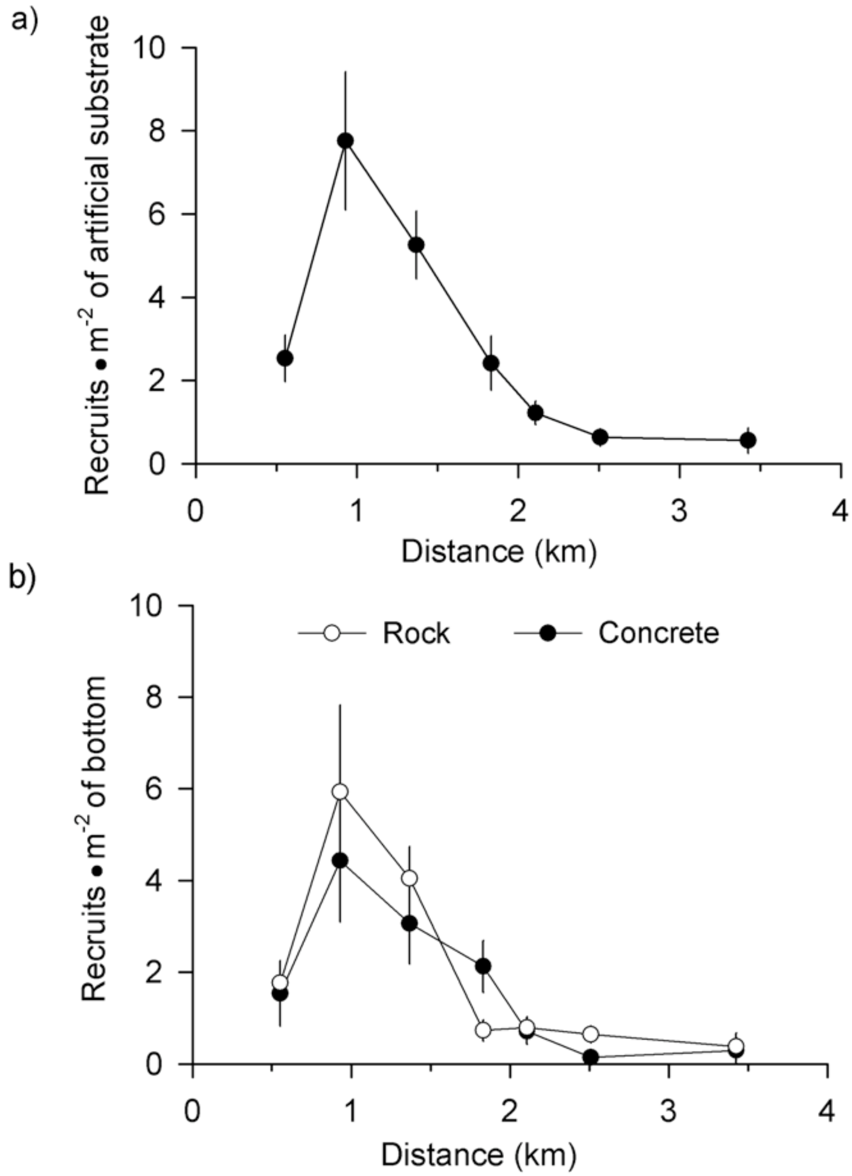


Figure III.B.3. Relationships between the density of *Macrocystis* recruits and the bottom coverage of artificial reef substrate for the seven locations at SCAR in the summer of 2000. The distance of each location is given to the right of each regression line. N = 8 module means per location.

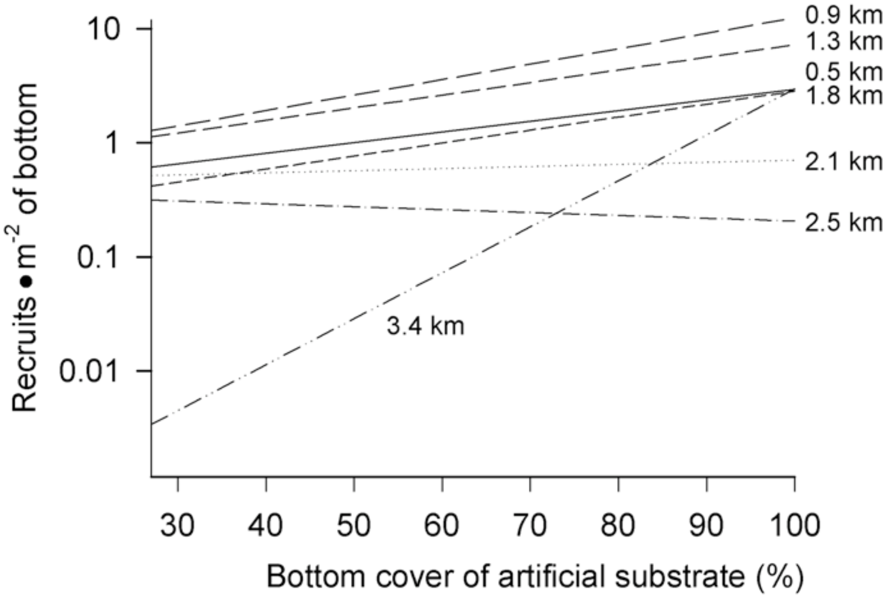



Figure III.B.4. Change in the mean (± SE) density of adult giant kelp over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). The dashed horizontal line indicates the performance standard of 4 plants per 100 $m^2$.

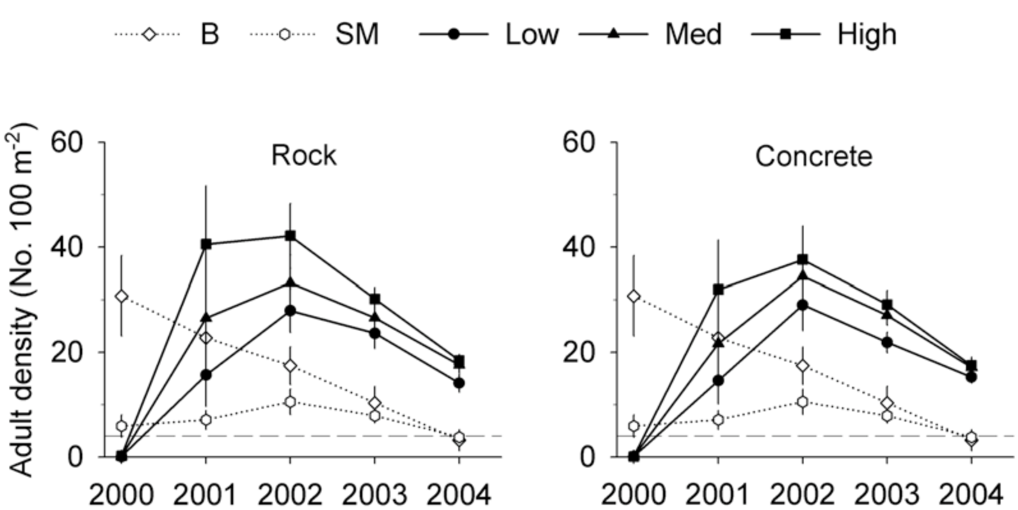


Figure III.B.5. Mean (± SE) abundance of adult giant kelp on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef.

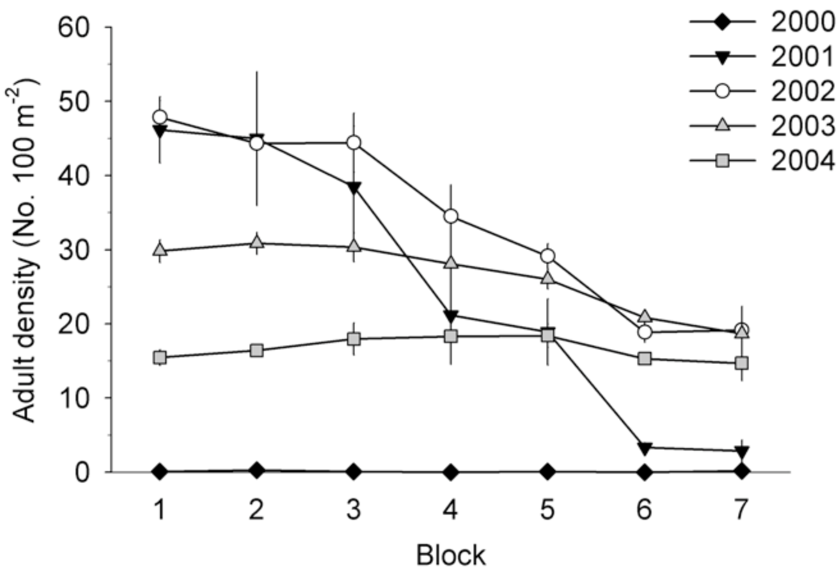



Figure III.B.6. Change in the mean (± SE) density of giant kelp fronds > 1-m tall over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

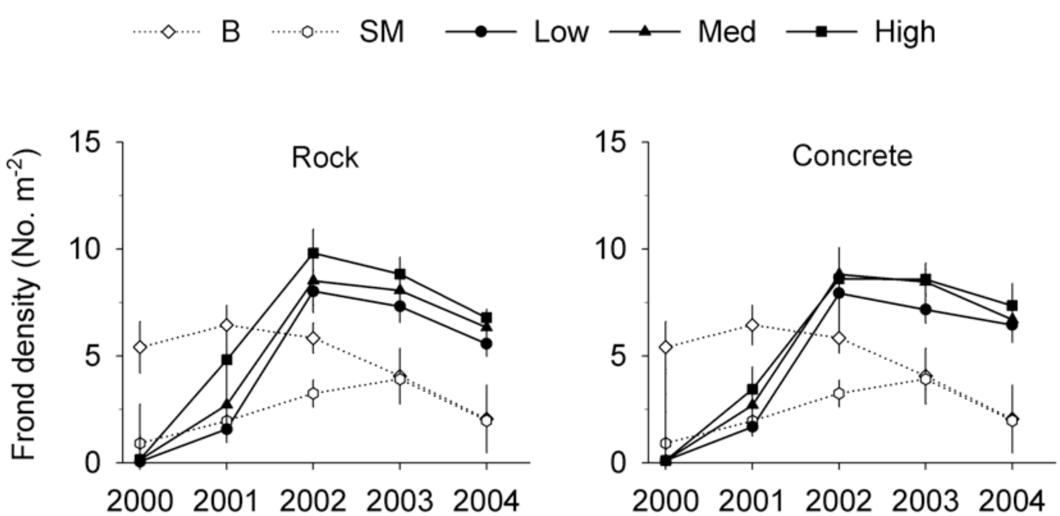


Figure III.B.7. Mean (± SE) abundance of giant kelp fronds > 1-m tall on the different blocks of artificial reef modules for the years 2000 to 2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef.

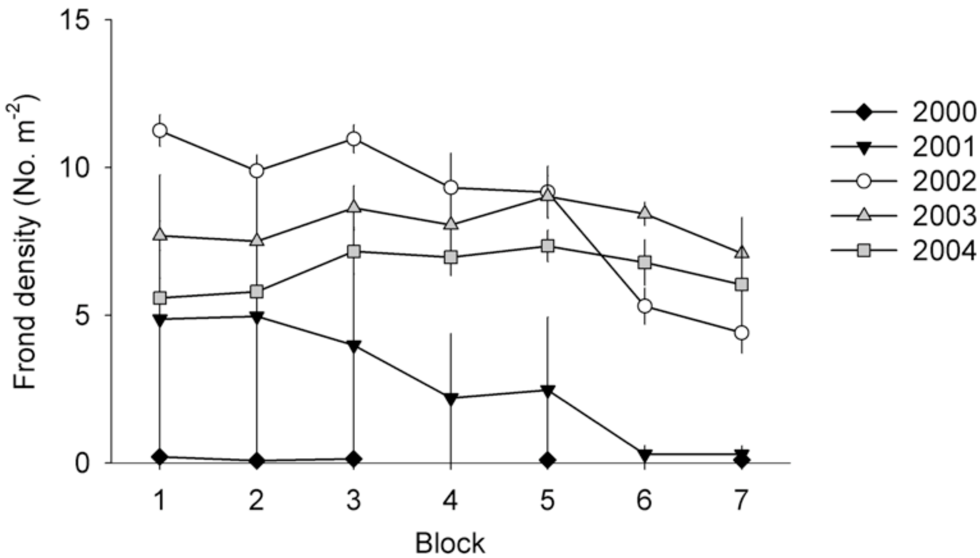



Figure III.B.8. Change in the mean (± SE) area of giant kelp sori ($cm^2$) per $m^2$ of reef for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). N = 7 artificial reef modules or reference reef locations.

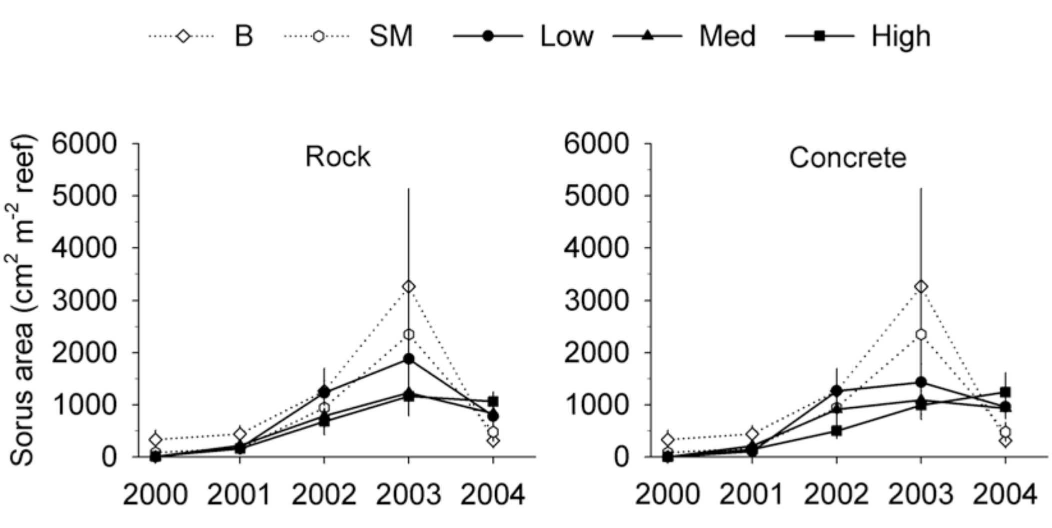


Figure III.B.9. Mean (± SE) area of giant kelp sori ($cm^2$) per $m^2$ of reef for the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef.

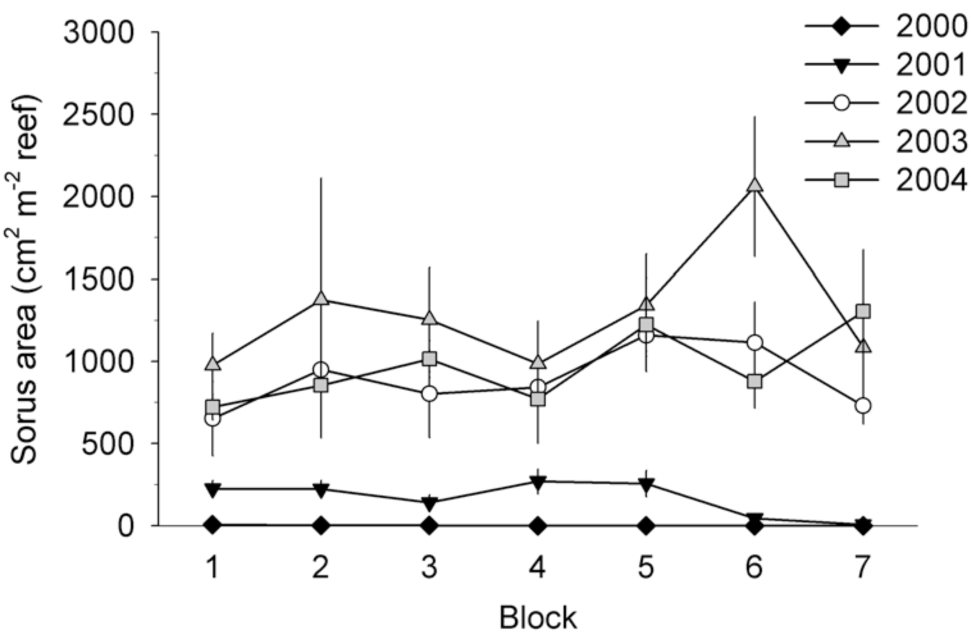



Figure III.B.10. Change in the mean (± SE) density of YOY giant kelp (recruits + juveniles) over time for the different blocks of artificial reef modules. Blocks are numbered 1 to 7 from south to north.

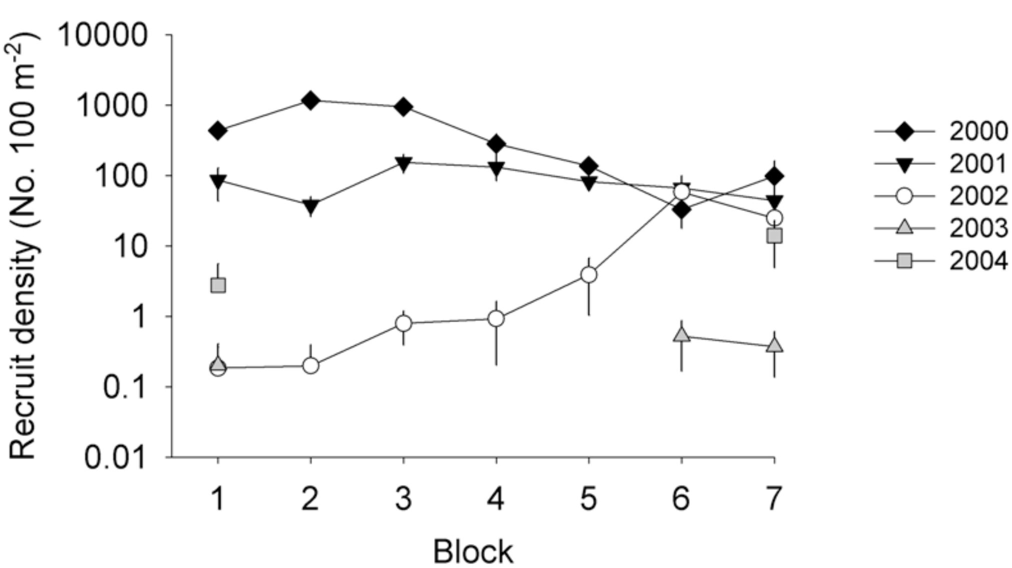


Figure III.B.11. Change in the mean (± SE) density of YOY giant kelp (recruits + juveniles) over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

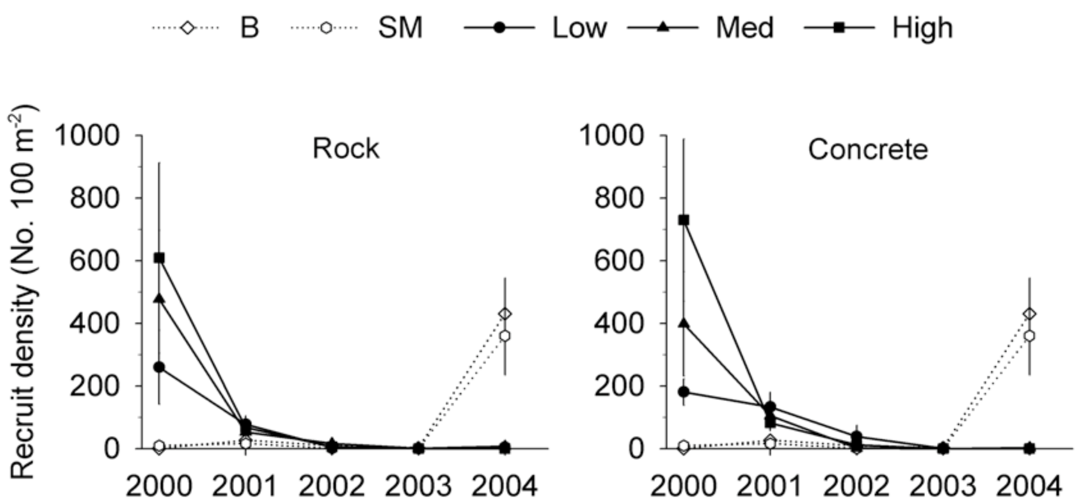



Figure III.B.12. Survivorship curves for the cohort of giant kelp that recruited in 2000 and reached adulthood in 2001. Data are for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). Initial sample sizes (number of adult plants) were as follows: B = 198, SM = 40, low rock = 195, med rock = 324, high rock = 526, low concrete = 168, medium concrete = 255 and high concrete = 383.

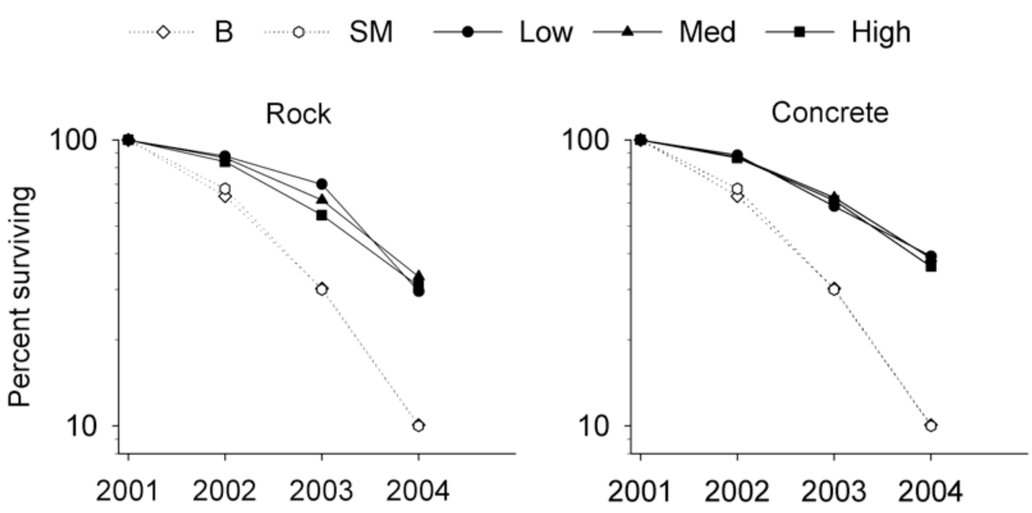


Figure III.B.13. Change in the mean (± SE) survivorship of adult giant kelp that recruited in 2000 and reached adulthood in 2001 over time for the different blocks of artificial reef modules. Blocks are numbered 1 to 7 from south to north.

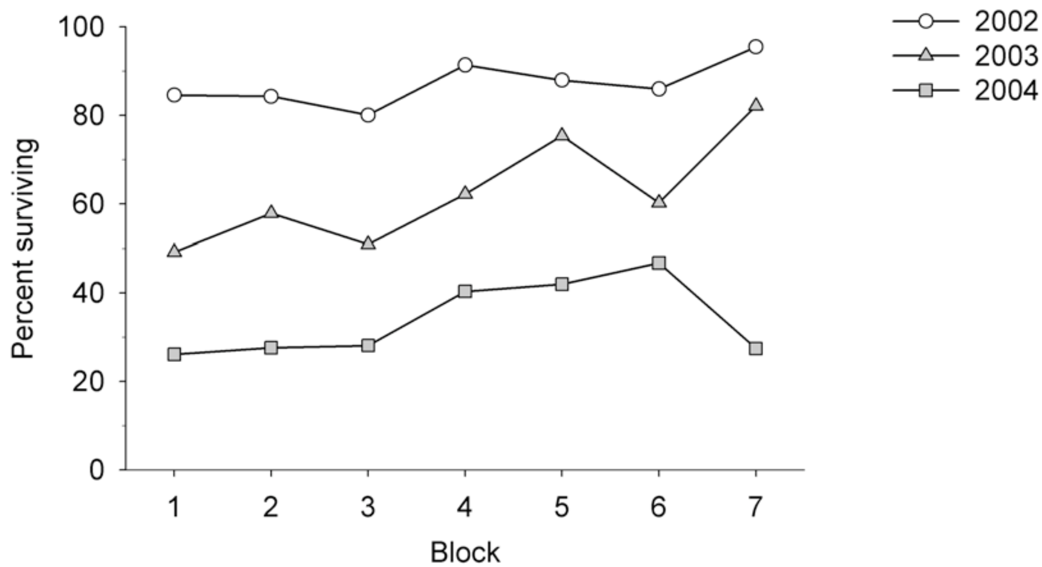
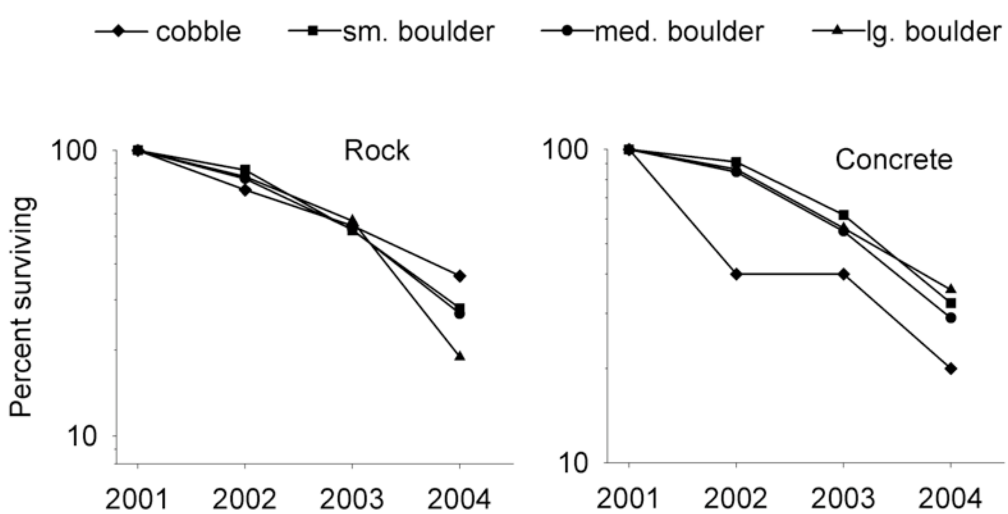



Figure III.B.14. Survivorship curves for the cohort of giant kelp that recruited in 2000 and reached adulthood in 2001. Data are for different sizes of rock and concrete to which kelp was attached. The sizes of cobble, small boulder, medium boulder and large boulder are given in Section III.B. *GIANT KELP*, **Methods**. Initial sample sizes (number of adult plants) for cobble, small boulder, medium boulder and large boulder were 11, 200, 670, 37 and 5, 102, 427, 171 for rock and concrete, respectively.



## *C. KELP FOREST FISHES*

**Mitigation requirement**

The abundance of fishes in the San Onofre kelp bed was reduced by approximately 70% relative to the San Mateo kelp bed during the impact assessment phase of SONGS Units 2 and 3. The Marine Review Committee concluded that this reduction was caused by the operation of the power plant. This reduction in the relative abundance of fish in the San Onofre kelp forest translates into an estimated loss of about 200,000 fish (weighing about 25.4 metric tons) that would be present in the absence of SONGS. Hence the CCC established a performance standard that the standing stock of kelp forest fishes at the mitigation reef must be at least 25.4 metric tons to ensure proper compensation for this estimated loss. In addition to this fixed requirement, the CCC established the following four relative performance standards for the mitigation reef that pertain to kelp forest fishes: (1) the resident fish assemblage (defined here as reef associated species > 1 year old) shall have a total density and number of species similar to natural reefs within the region, (2) the total density and number of species of YOY fish (i.e., fishes less than 1 year old) shall be similar to natural reefs within the region, (3) fish reproductive rates shall be similar to natural reefs within the region, and (4) fish production shall be similar to natural reefs in the region. The relatively small size of the experimental reef modules (0.16 ha) coupled with the mobility of many reef fishes made it difficult to obtain reasonable estimates of fish reproductive rates and production for the different artificial reef designs that could be scaled up to the size of the mitigation reef (61 ha). Consequently, we did not use standards (3) and (4) as criteria for evaluating the performance of the different artificial reef designs.

**Methods**

Fish abundance and size were recorded at three depth strata along the permanent transects on the artificial reef modules and reference reefs annually in the fall. Sampling was done near the surface in the region of the kelp canopy (0- to 2-m depth below the water surface), midwater (approximately 7 m depth between the surface and bottom), and at the bottom (14- to 15-m depth) at all locations (exceptions to this sampling regime occurred during 2000 when the midwater was not sampled, and during 2002 when none of the concrete modules were sampled). Two transects were sampled on each artificial reef module during each survey for a total of 14 transects for each reef design per survey. Similarly, we sampled two transects at each of seven sampling stations at Barn and San Mateo during each survey for a total of 14 transects per survey for each reference reef (except in 2000 when only one transect was surveyed at each reference reef station). Each transect was 2-m wide x 2-m high x 40-m long representing a total sample volume of 320 $m^3$ per depth strata for each artificial reef module or reference reef station (except during 2000 when 160 $m^3$ were sampled at each reference reef station). To avoid disturbance of fishes by air bubbles expelled from divers, the surface stratum was sampled first, followed sequentially by the midwater and bottom strata. Every reef-associated fish encountered along each transect was recorded and its total length was estimated to the nearest centimeter. For aggregating species such as the blacksmith (*Chromis punctipinnis*) and salema (*Xenistius californiensis*), the number and mean size of individuals in a group were estimated. Cryptic fishes such as the blackeye goby (*Rhinogobiops nicholsii)* and the California scorpionfish (*Scorpaena guttata*) were recorded along the two bottom transects at each artificial reef module and reference reef station as divers returned along the bottom after completing the sampling of less cryptic fishes. Fish were categorized as resident adult (reef associated > 1-year old) or YOY based on published size classes, unless an investigator noted specifically that a fish was YOY due to size and morphological characteristics observed in the field.

Evaluations of the two performance standards relating to fish density were based on mean densities calculated from means of the three depth strata (N = 2 transects per module or reference reef station) weighted by their proportional volume of the water column, thus providing a mean estimate of the number of fishes in the water column over 160 $m^2$ of bottom for each artificial reef design and for each natural reference reef. Density data were transformed to $\log_{10}[x+1]$ to meet assumptions of normality. Mean values for each artificial reef module or reference reef station used in evaluating the performance standards relating to species richness were calculated from the combined number of distinct species present in two replicate transects of the three depth strata thus providing an estimate of the number of species of fishes in the water column over 160 $m^2$ of bottom for each artificial reef design and for each natural reference reef.

The performance standard for fish standing stock was evaluated in two ways. First, for each reef design the biomass of fishes throughout the water column was estimated per $m^2$ of reef and scaled up to 61 ha. This was done by converting the fish density and size data collected on the permanent transects to mass using species-specific length-weight regressions obtained from the literature (Gnose, 1967; Quast, 1968a, 1968b; Mahan, 1985; Wildermuth, 1983; Stepien, 1986; DeMartini et al., 1994). These values were then used to estimate the mean mass of all fish species per cubic meter of bottom, midwater and surface habitats. The amount of midwater habitat was defined as the depth in meters minus the two meter strata at the surface and bottom (i.e., midwater = Z – 4 m). The mass of fish in the surface, midwater and bottom habitats were weighted by the amount of water column the habitat included and then summed to obtain the standing stock of fish throughout the water column per $m^2$ of reef. This value was converted to metric tons per 61 ha for the purpose of evaluating the performance standard for standing stock.

The second approach estimated the likelihood that a given reef design or reference reef would attain a standing stock of 25.4 metric tons for a given area of reef. This was done by first calculating the biomass of fish throughout the water column per $m^2$ of reef as was done in the first method for each reef design on each survey. These estimates were then scaled to various reef areas ranging from 0 to 300 hectares. This analysis was motivated by the desire to know the relationship between reef size and the probability of meeting the 25.4-metric-ton performance standard for fish standing stock for the different artificial reef designs and the reference reefs. This second approach also allows a comparison between the performance of the various artificial reef designs (in terms of fish standing stock) to those of the reference reefs, whose much smaller perimeter to area ratios are more likely to closely approximate the perimeter: area ratio of the mitigation reef. Using this approach fish standing stock (SS) was calculated as:

$$SS_{ijk} = M_{ij} \times S_k,$$

where $SS_{ijk}$ = estimated standing stock throughout the water column for design 'i', survey 'j', and total reef area 'k', $M_{ij}$, = estimated standing stock throughout water column per $m^2$ of reef for design 'i' on survey 'j'; and $S_k$ = scaling factor to convert standing stock per $m^2$ to standing stock for entire reef area 'k'.

Means and standard errors were calculated for each design 'i' and total reef area 'k', using surveys 'j' as replicates. These were then used to calculate the probability of supporting a fish standing stock ⩾ 25.4 metric tons for each total reef area and design based on a 't' distribution. Probabilities were plotted as a function of reef size for each artificial reef design and natural reference reef and were visually compared.

**Results**

Temporal patterns of abundance and species richness of resident fishes

Reef-associated fishes greater than 1-year old rapidly colonized the bottom two meters of the artificial reef modules and by fall 2000 all six reef designs displayed densities of resident fishes that were similar to or greater than those observed on the nearby reference reefs (Figures III.C.1 and III.C.2). The most abundant species at this time included the senorita (*Oxyjulis californica*), sand bass (*Paralabrax nebulifer*), pile perch (*Damalichthys vacca*), and the blacksmith (*Chromis punctipinnis*). In contrast, resident fishes did not colonize the mid and surface portions of the water column until the following year (2001) when fronds of adult giant kelp (*Macrocystis pyrifera*) were dense enough to form a surface canopy on all the artificial reef modules (Figure III.B.6). Usually fish abundance near the bottom on the artificial reef was positively related to the bottom coverage of hard substrate for both rock and concrete modules. The most glaring exceptions to this pattern occurred in 2002 when a large school of Salema (*Xenistius californiensis*) were observed near the bottom on two of the low-cover rock modules, and in 2004 when large numbers of the small wrasse *Oxyjulis californica* were observed on one of the medium-cover concrete modules. These uncommon observations resulted in unusually high mean densities for these artificial reef designs for the surveys in which they occurred. In the last year of the experiment, mean densities of resident fishes on all the artificial reef designs increased throughout the water column, while remaining relatively constant at the reference reefs. Fish were relatively uniformly distributed throughout the blocks on SCAR during the five-year experiment (Figure III.C.3). The exception to this pattern was the summer of 2004 when substantially higher densities of fishes were observed on Block 6 (and to a lesser extent on Block 3) than at other locations of SCAR.

All the artificial reef designs typically supported more species of resident fishes than the natural reference reefs (Figures III.C.4 and III.C.5). Species richness was greatest near the bottom, where roughly twice as many species were observed compared to the midwater and surface regions. The effects of material type on species richness were less pronounced than those of material coverage. The number of species of resident fishes supported by rock and concrete reefs was very similar. In contrast, species richness of resident fishes tended to be greatest on modules with high bottom coverage of reef material. This was true for all three depth strata on both rock and concrete modules. This effect of bottom coverage on species richness was most evident during the first two years, and by the end of the five-year experiment differences in species richness among modules with different bottom coverages were less obvious, particularly on concrete modules. Species richness was largely similar at different locations within SCAR , except during 2002 when richness tended to increase with distance from San Mateo (Figure III.C.6).

The overall assemblages of resident fishes on the artificial reefs generally showed a high degree of similarity to that of the natural reefs (Figure III.C.7). Percent similarity between the six different artificial reef designs and the reference reefs ranged between 61 and 92% with the mean similarity for all designs over the five-year experiment averaging 78%. The blacksmith (*Chromis punctipinnis*), the senorita (*Oxyjulis californica*), and the kelp perch (*Brachyistius frenatus*) were the most numerically abundant fishes on the artificial reef modules in 2004, accounting for nearly 65% of all the fishes observed (Figure III.C.8). Senorita and blacksmith were also among the most abundant species at the reference reefs; however kelp perch were conspicuously absent. This small perch associates with the near surface fronds of giant kelp, which were nearly three times more numerous on SCAR compared to the reference reefs (Figure III.B.6). Another noteworthy difference in the fish assemblages on the artificial and natural reefs is that the relative abundance of predatory basses (*Paralabrax clathratus* and *P. nebulifer*) was about three times less on SCAR compared to Barn and San Mateo (7% vs. 20%; Figure III.C.8). Other studies in Southern California also found that the species assemblages of fishes on the artificial reef modules displayed a high degree of similarity to the natural reference reefs (Stephens et al., 1984; Ambrose and Swarbrick, 1989).

<u>Temporal patterns of abundance and species richness of young-of-year fishes</u>

The recruitment of YOY fishes was temporally variable (Figures III.C.9 and III.C.10). Densities of YOY were usually quite low on all artificial reef modules and at the reference sites. The exception to this pattern occurred during the first year (2000) when large numbers of blacksmith (*Chromis punctipinnis*) and senorita (*Oxyjulis californica*) recruited to the bottom habitat of the artificial reef modules and to a lesser extent to the natural reefs. As was observed with older fishes, the density of YOY during this recruitment pulse was strongly correlated to the bottom coverage of reef material with the greatest densities of YOY observed on high-coverage rock and concrete modules. Much smaller pulses of YOY were sporadically seen at the surface and in the midwater of some of the artificial reef designs and reference sites when senorita occasionally recruited to these habitats. YOY were relatively evenly distributed among blocks (Figure III.C.11).

Species richness of YOY was generally low at the artificial reef and reference reefs throughout the study and rarely averaged more than two species for every two transects sampled (Figure III.C.12). Only a total of 12 species of YOY were observed at the artificial and natural reefs combined during the entire experiment compared to 27 species of resident fishes observed. Much like the patterns seen for YOY abundance, YOY species richness was similar on rock and concrete modules and was greatest near the bottom. However, unlike YOY abundance, YOY species richness was unrelated to the bottom coverage of reef material (Figures III.C.12). The number of species of YOY was highly variable in space, and did not vary systematically with distance from the nearest natural reef (Figure III.C.13).

Standing stock of kelp forest fishes

Much like fish density and species richness, the standing stock of kelp forest fishes tended to be higher on artificial reefs with greater bottom coverage (Figure III.C.14). Material type had little effect on fish standing stock except for early on in the experiment when biomass was twice as high on reefs with high cover of concrete compared to reefs with high cover of rock. Differences in fish size rather than fish density caused the initial two-fold difference in standing stock between high-cover concrete and rock reefs. Fish biomass on the experimental artificial reef rapidly reached values that were similar to or greater than those observed on the natural reefs. The projected standing stock of fish on all the artificial reef designs and at all blocks within SCAR was near or above the 25.4-metric-ton performance standard for each year of the five-year experiment (Figures III.C.14 and III.C.15). By contrast, estimates of fish standing stock on the nearby natural reefs were almost always less than the performance standard.

Probability analyses based on standing stock estimates averaged over the five-year experiment suggest that there is a better than 80% chance that five of the six artificial reef designs would meet the standing stock performance standard of 25.4 metric tons if built out to 61 ha (Figure III.C.16). A 61-ha reef of low-cover rock has about a 50% chance, while a 61-ha high-cover concrete reef appears certain to meet the standard. Surprisingly, a 61-ha portion of the reference reef at Barn has essentially no chance of supporting a fish standing stock of 25.4 metric tons. It is important to note the performance standard for fish standing stock is not a relative measure. Rather the fixed value of 25.4 metric tons is based on the estimated reduction in the relative abundance of fishes in the San Onofre kelp forest caused by SONGS' operations.

Our initial analyses indicated that the density of resident fishes was a poor predictor of fish standing stock ($R^2$ = 0.139). This poor relationship resulted from the sightings of two adult (165 and 180 cm TL) giant sea bass (*Stereolepis gigas*) at one of our stations at San Mateo in 2001 (Figure III.C.14). This once abundant large grouper has been over fished throughout most of its range and until recently has been uncommon in California. The effect of these two individuals on standing stock was exaggerated because they were observed in a midwater transect, and their biomass was multiplied throughout the midwater (as per the methods described above) to obtain a standing stock estimate for the entire water column. When these rare sightings of giant sea bass were removed from our analyses, the standing stock at San Mateo was similar to that on the artificial reefs (Figure III.C.14), and the overall relationship between standing stock and density of resident fishes improved dramatically ($R^2$ = 0.587).

Evaluation of relative performance standards for kelp forest fishes

The critical ranges established by the Sample approach for assessing similarity between the natural and artificial reefs were consistently larger than those set by the Universe approach (Figures III.C.17 and III.C.18; see section II.D. *PERFORMANCE CRITERIA* for a description of the Sample and Universe approaches). However, the differences between the two approaches had little effect on the conclusions pertaining to compliance of the performance standards for either resident or YOY kelp forest fishes, as none of the artificial reef designs or experimental blocks had mean density and richness values of either resident, or YOY fishes that were below the performance standards. In the case of resident fishes, total density and species richness were well above the critical ranges set by both approaches for all six artificial reef designs (Figure III.C.17) and all seven blocks (Figure III.C.18). These findings are consistent with those of previous studies that found the numerical and biomass densities of fishes to be higher on artificial reefs compared to natural reefs in Southern California (Jessee et al. 1985; Ambrose and Swarbrick 1989, DeMartini et al., 1989) and elsewhere (reviewed in Bohnsack and Sutherland, 1985).

The pattern differed for YOY fishes where only three of the six reef designs were consistently above the performance standards for density and species richness (Figure III.C.17). Densities and number of species of YOY were slightly above the critical ranges for medium-cover rock reefs and substantially above the ranges for medium- and high-cover concrete reefs. Densities and number of species of YOY were consistently within the critical ranges for Blocks 1, 3, and 4 and consistently above the ranges for Blocks 2 and 5 regardless of the analytical approach used.

An artificial reef that produces a greater number and diversity of fishes than its intended target would be considered a success if its sole purpose was to mitigate for the loss of fish (Reed et al. *in press*). The SONGS mitigation reef, however, is intended to compensate for the loss of an entire kelp forest community of fishes, invertebrates and algae. A situation in which over-compensation for one component of the community results in under-compensation for another component of the community is not without precedent and is of considerable concern for the SONGS mitigation reef. For example, intensive grazing that accompanies high fish densities has been implicated as the cause preventing the establishment of kelp and understory algae on artificial reefs in Southern California (Carlisle et al. 1964; Turner et al. 1969; Grant et al., 1982; Carter et al., 1985; Patton et al.; 1994). Higher rates of fish grazing on artificial reefs may also indirectly inhibit algal development by altering the outcome of competition between algae and sessile invertebrates for space. This may explain why the nearby Torrey Pines and Pendleton Artificial Reefs have been dominated by suspension feeding invertebrates for many years (Patton et al., 1996; Deysher et al., 2002).

<u>Summary of results for kelp forest fishes</u>

- The density and species richness of kelp forest fishes (such as blacksmith, senoritas, and kelp perch) was positively related to the cover of hard substrate and largely unrelated to the type of hard substrate.
- The species composition and relative abundance of kelp forest fishes on the artificial reef modules was very similar to that of the natural reference reefs.
- The projected standing stock of fishes on all artificial reef designs and at all locations (i.e., blocks) was near or above the 25.4-metric-ton performance standard for each year of the five-year experiment.

- There is a better than 80% chance that five of the six reef designs would support a standing stock of 25.4 metric tons if built out to 61 ha. A 61-ha reef constructed of low cover rock has approximately a 50% chance of meeting the standing stock standard for kelp forest fishes.
- All six artificial reef designs met the performance standards for density and species richness of resident and YOY fish.
- All seven blocks met the performance standards for density and species richness of resident and YOY fish.
- Collectively, the results indicate that all of the reef designs and all blocks tested in the experiment are likely to provide adequate in-kind compensation for the loss of kelp forest fishes caused by SONGS' operation. Fish densities that are too high, however, could adversely affect other components of the kelp forest assemblage.

Figure III.C.1. Change in the mean (± SE) concentration of resident kelp forest fishes over time at the bottom, mid depth and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

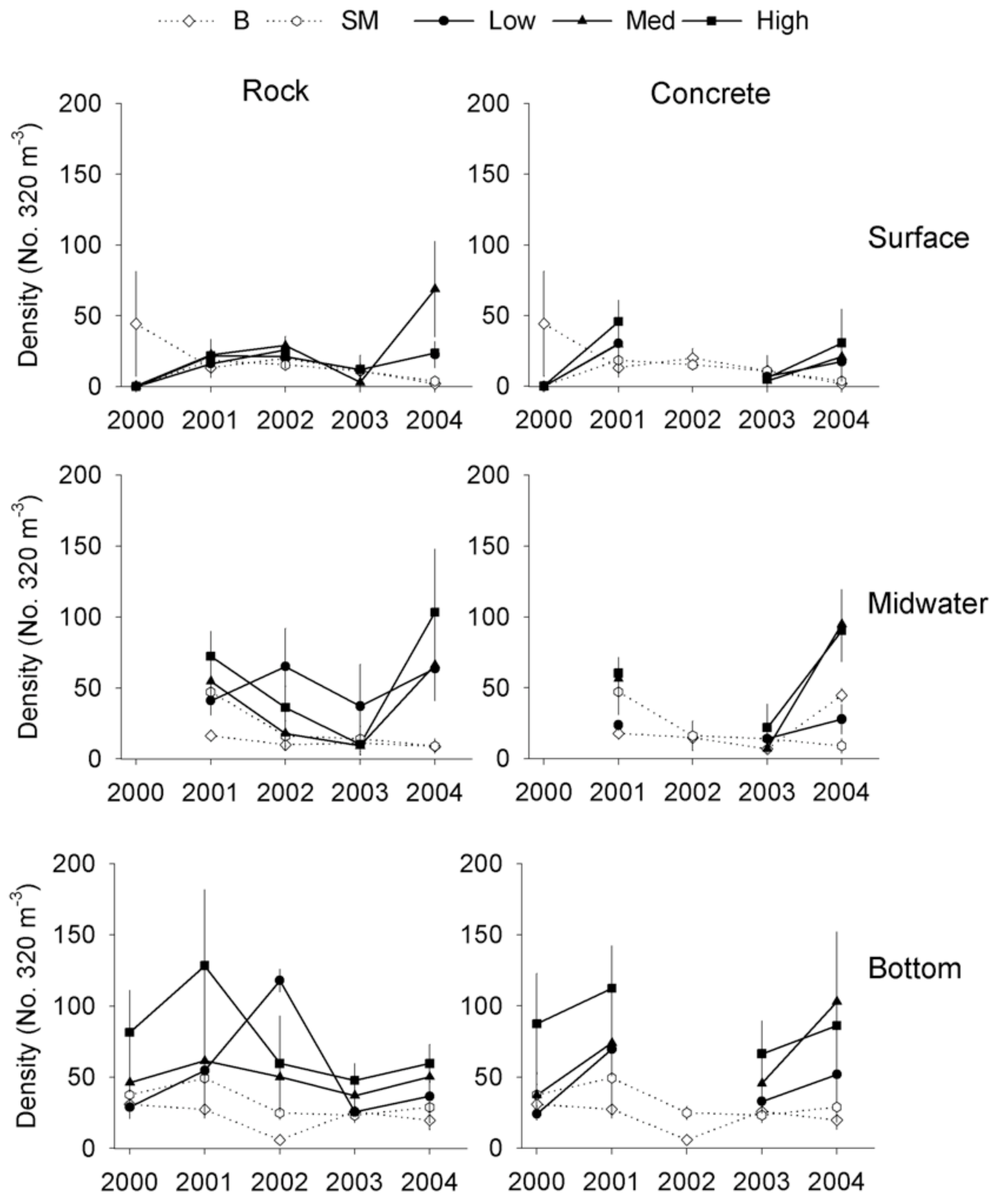


Figure III.C.2. Change in the mean (± SE) density of resident kelp forest fishes over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). Densities are integrated over all depths to produce the number of fishes in the water column per 160 m$^2$ of bottom.

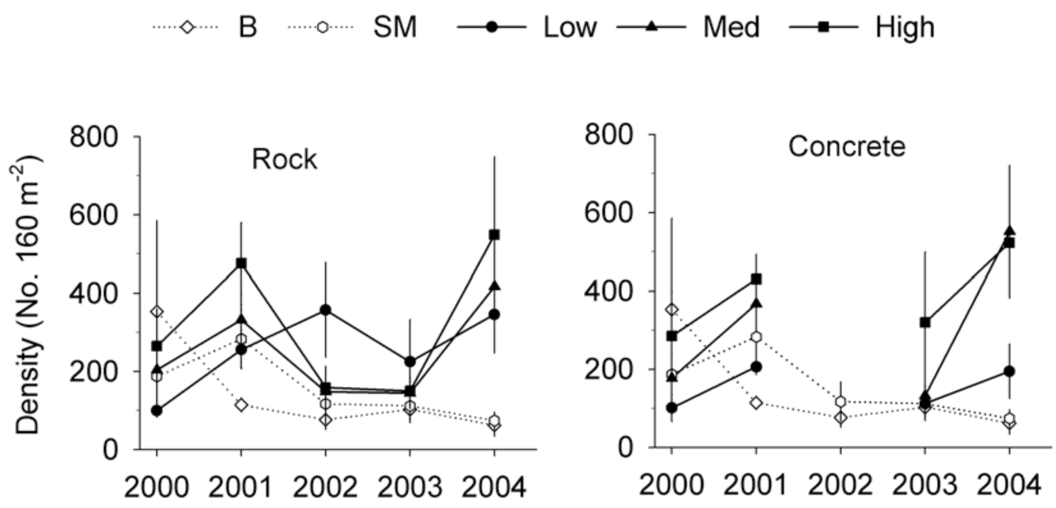



Figure III.C.3. Mean (± SE) density of fishes on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. Densities are integrated over all depths to produce the number of fish in the water column per 160 m$^2$ of bottom.

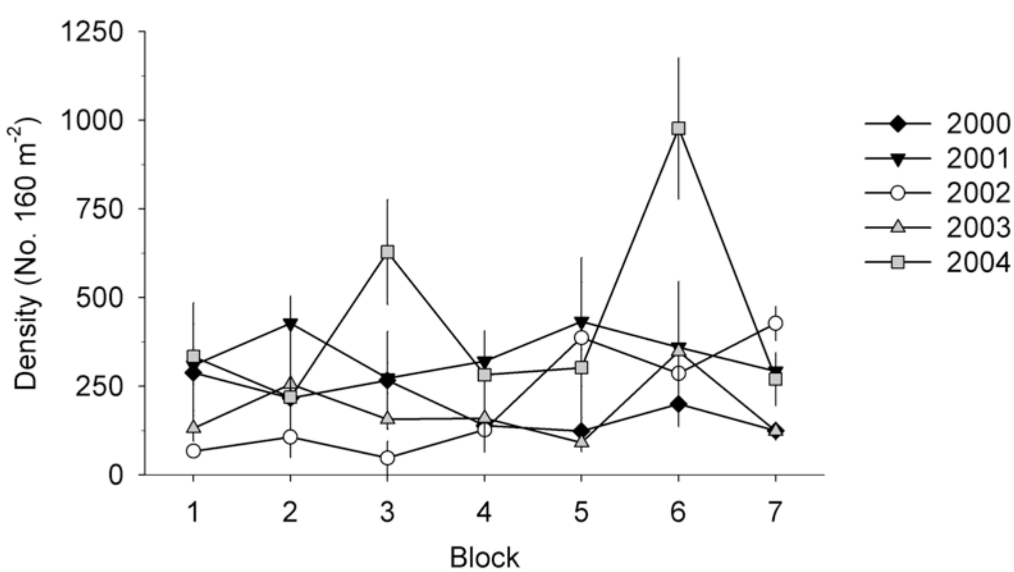


Figure III.C.4. Change in the mean (± SE) number of species of resident kelp forest fishes over time at the bottom, midwater and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

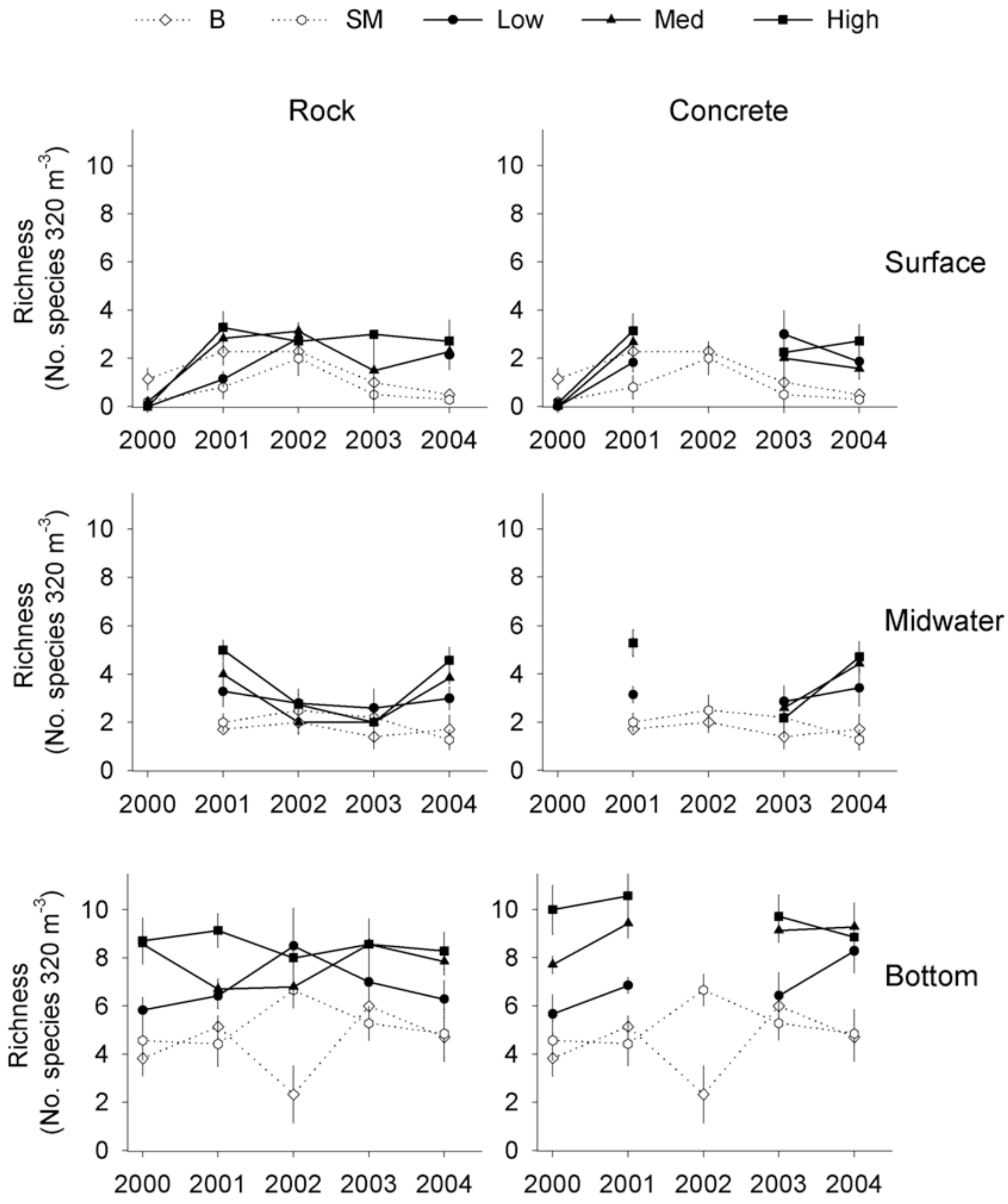


Figure III.C.5. Change in the mean (± SE) number of species of resident kelp forest fishes over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). Means are integrated over all depths to produce the number of species of resident fishes in the water column per 160 $m^2$ of bottom.

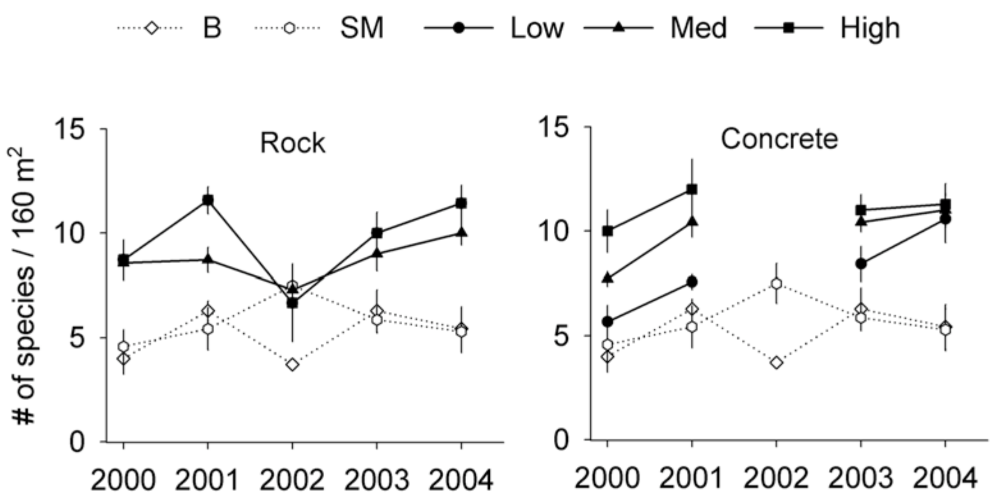



Figure III.C.6. Mean (± SE) number of species of resident kelp forest fishes on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. Means are integrated over all depths to produce the number of species of resident fishes in the water column per 160 $m^2$ of bottom.

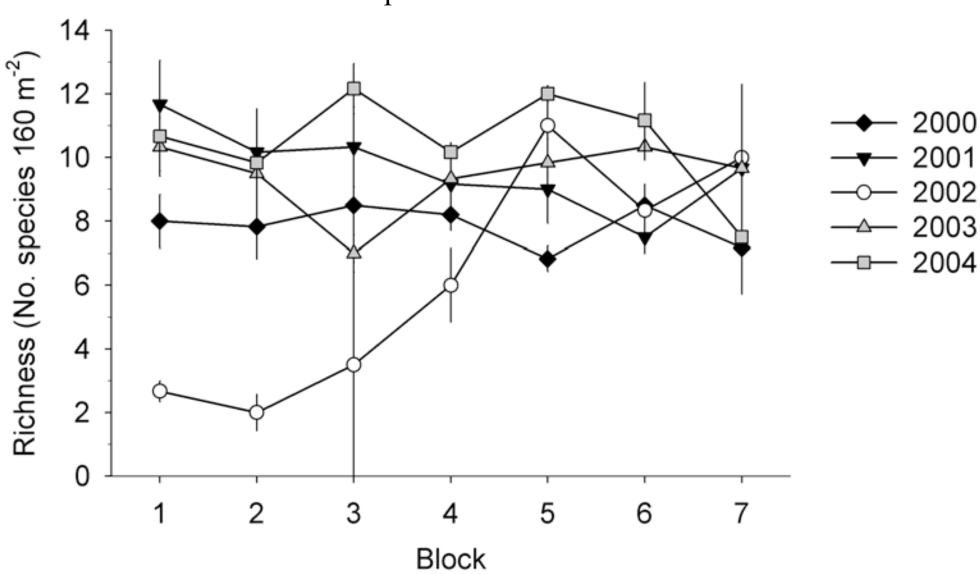


Figure III.C.7. Percent similarity in the assemblages of resident kelp forest fishes between the mean of the reference reefs Barn (B) and San Mateo (SM) and artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high).

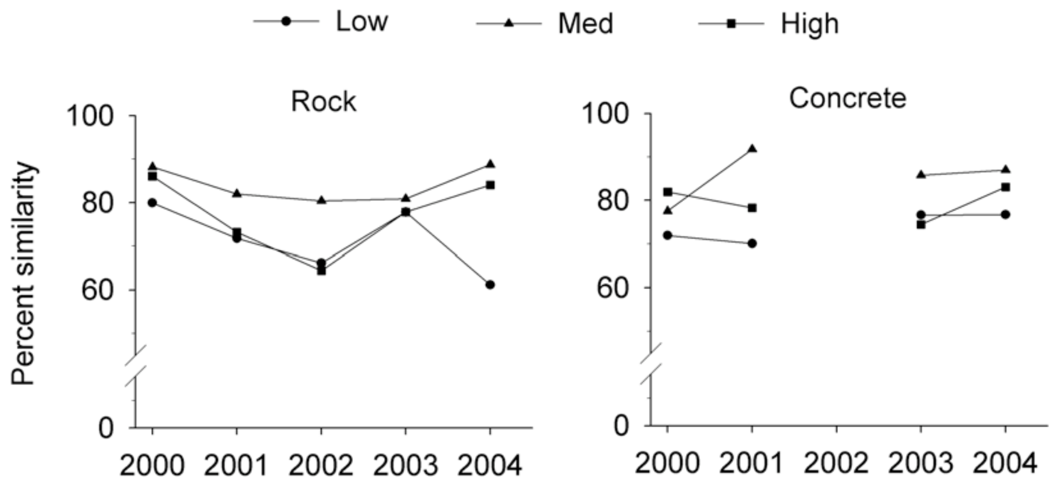



Figure III.C.8. Relative abundance of the most common species of resident fish on the artificial reef (SCAR) and the reference reefs, Barn and San Mateo (REF) in summer 2004.

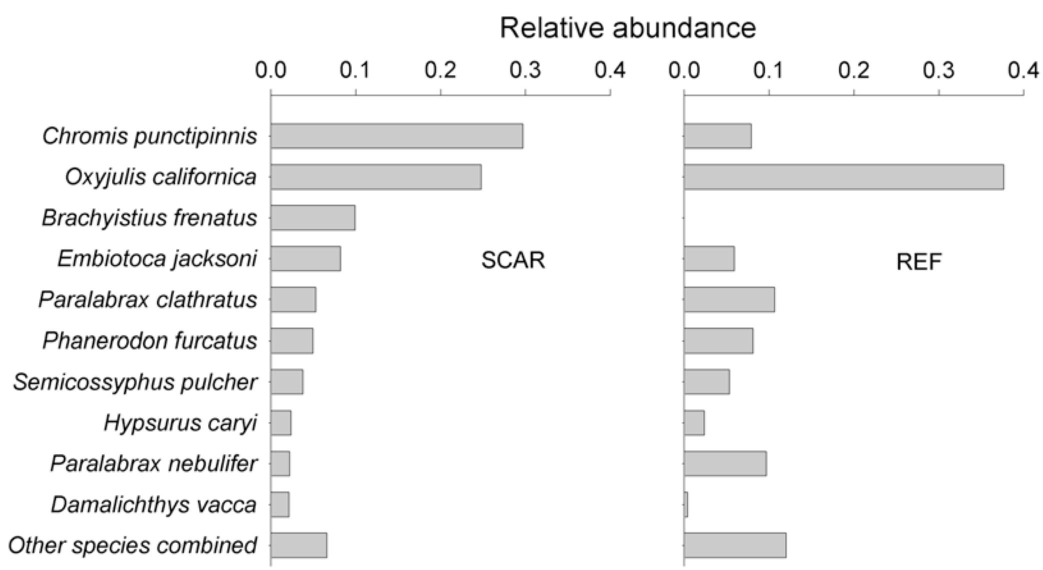


Figure III.C.9. Change in the mean (± SE) concentration of YOY kelp forest fishes over time at the bottom, mid depth and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

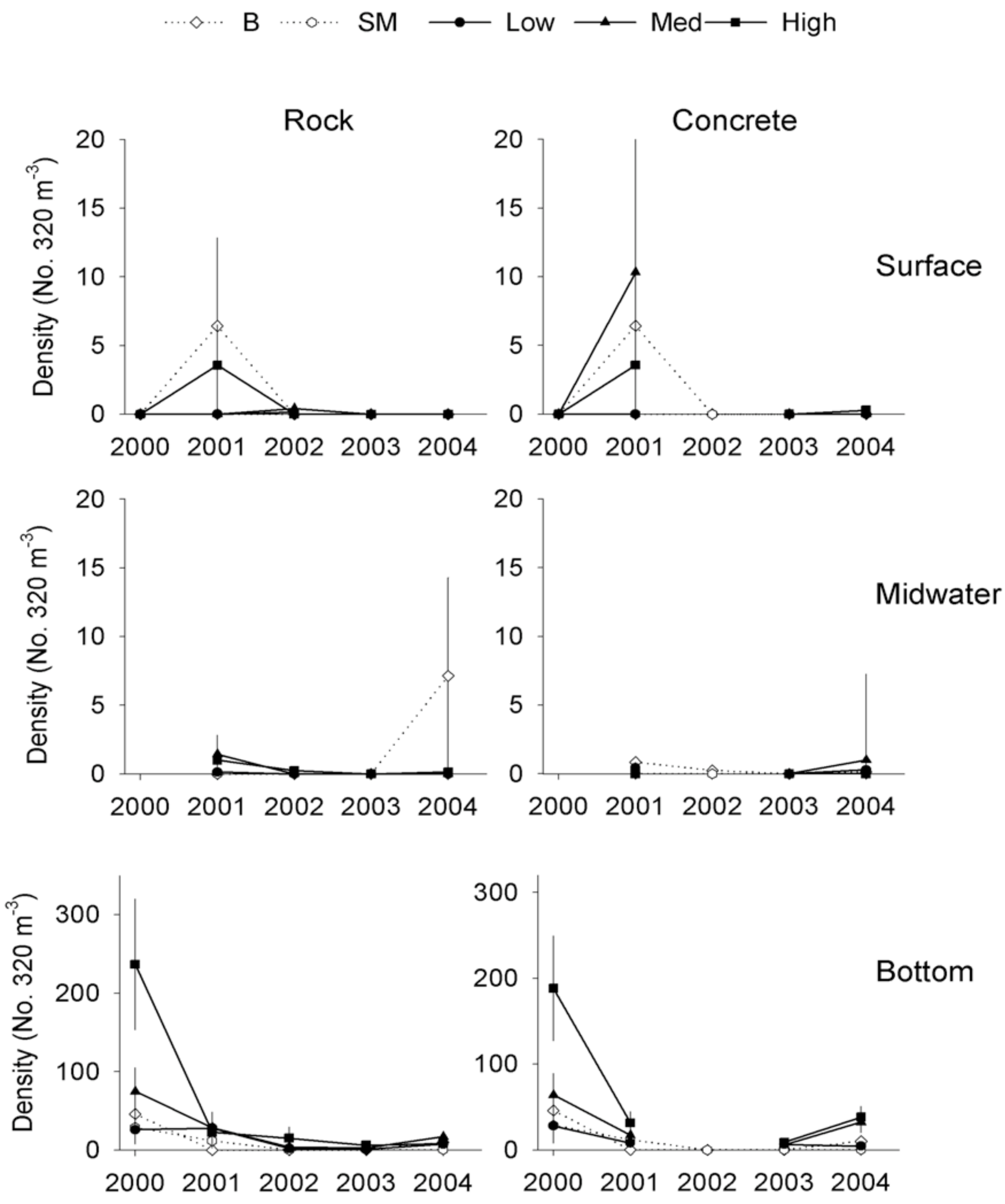


Figure III.C.10. Change in the mean (± SE) density of YOY kelp forest fishes over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). Densities are integrated over all depths to produce the number of fish in the water column per 160 $m^2$ of bottom.

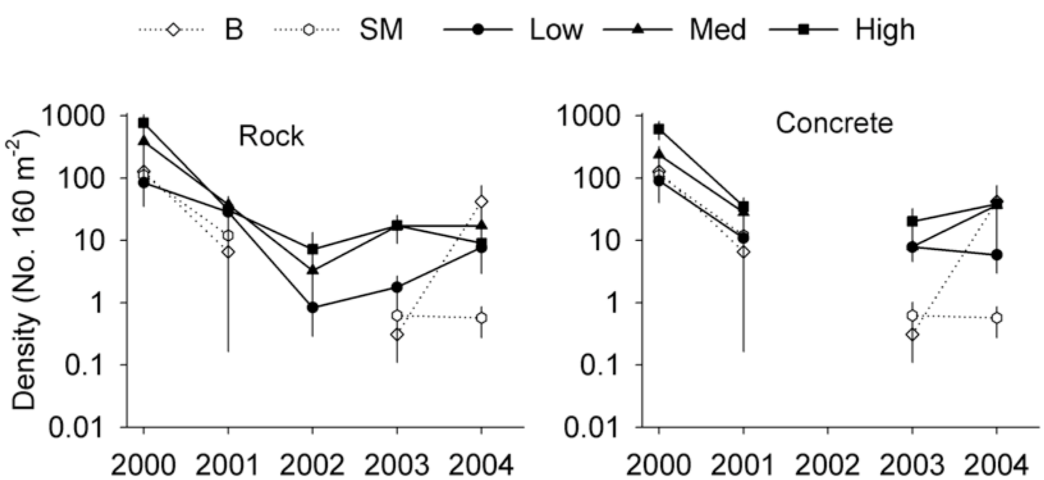



Figure III.C.11. Mean (± SE) density of YOY fishes on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. Densities are integrated over all depths to produce the number of fish in the water column per 160 $m^2$ of bottom.

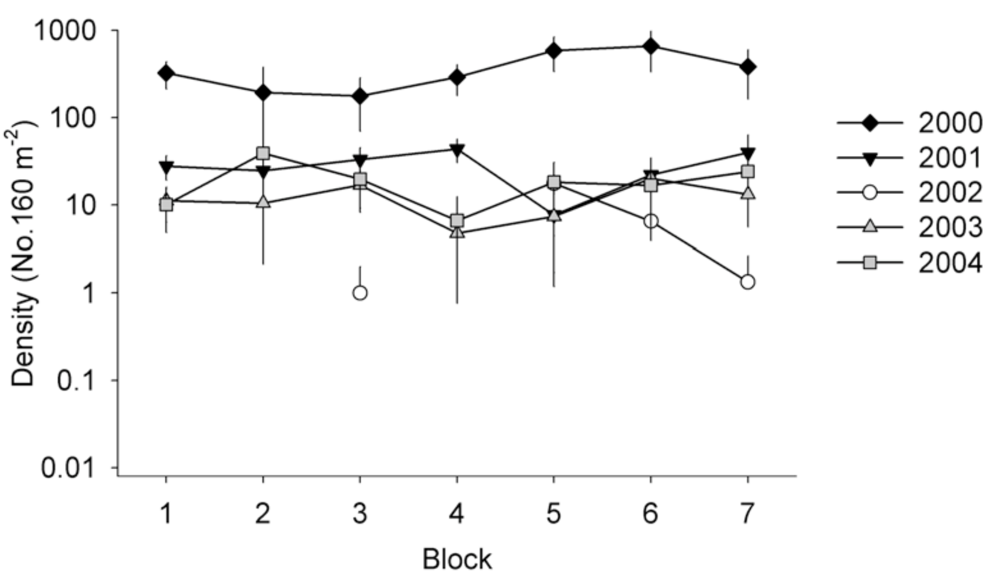


Figure III.C.12. Change in the mean (± SE) number of species of YOY kelp forest fishes over time at the bottom, mid depth and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

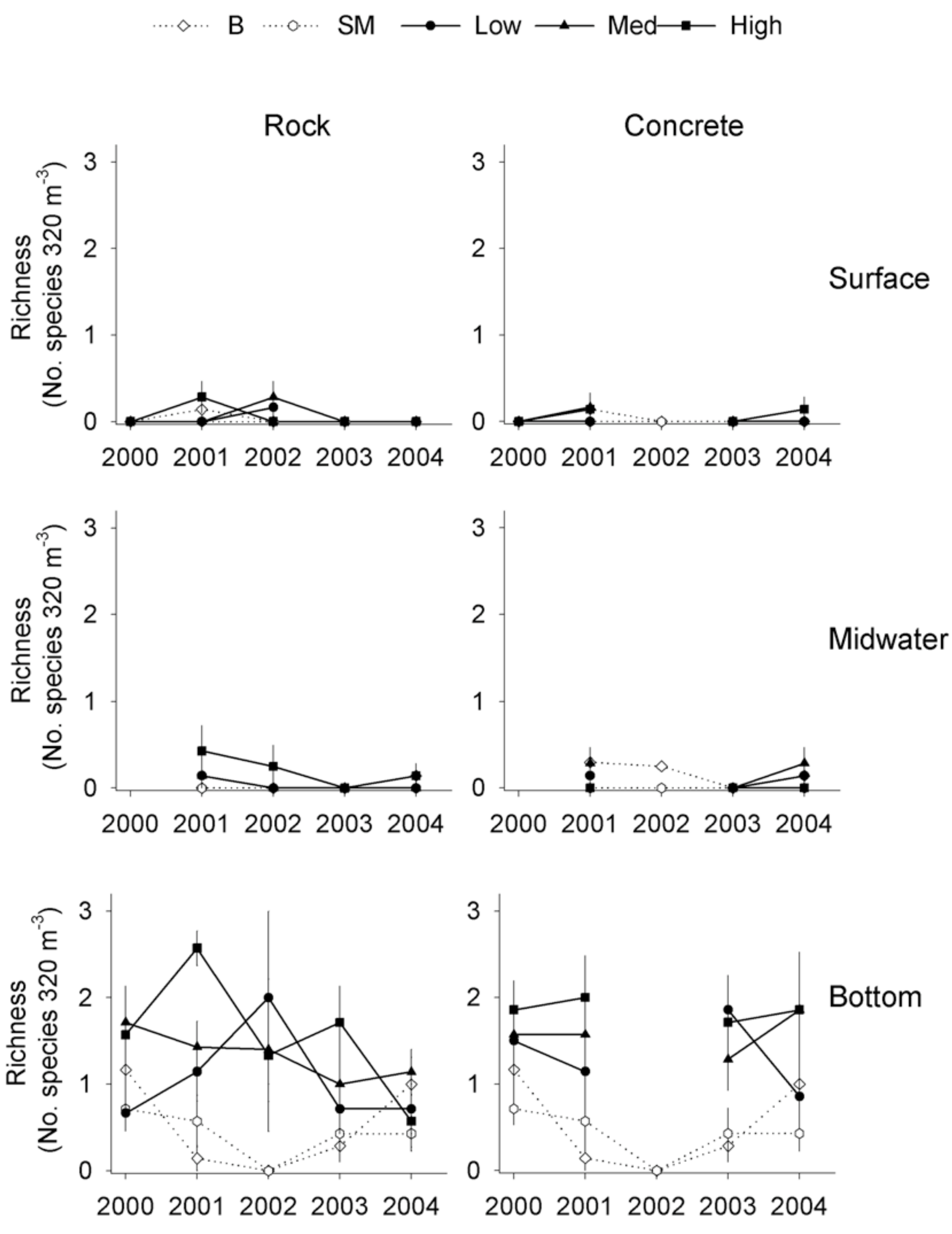


Figure III.C.13. Mean (± SE) number of species of YOY kelp forest fishes on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. Means are integrated over all depths to produce the number of species of YOY fishes in the water column per 160 $m^2$ of bottom.

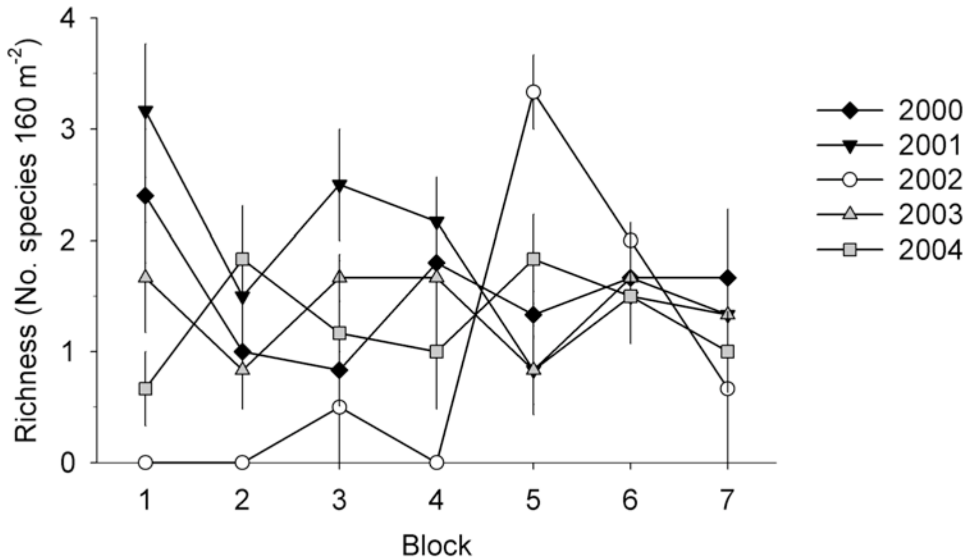



Figure III.C.14. Change in the projected standing stock of kelp forest fishes over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). The dashed horizontal line indicates the permit standard of 25.4 metric tons for the 61-ha mitigation reef. See text for how projections were made.

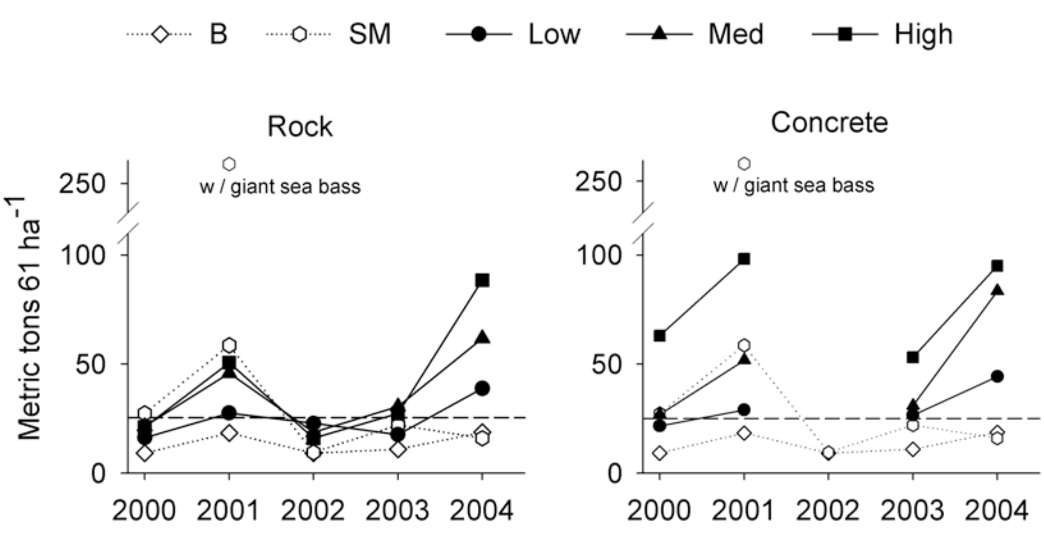


Figure III.C.15. Change in the projected standing stock of kelp forest fishes on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. The dashed horizontal line indicates the permit standard of 25.4 metric tons for the 61-ha mitigation reef. See text for how projections were made.

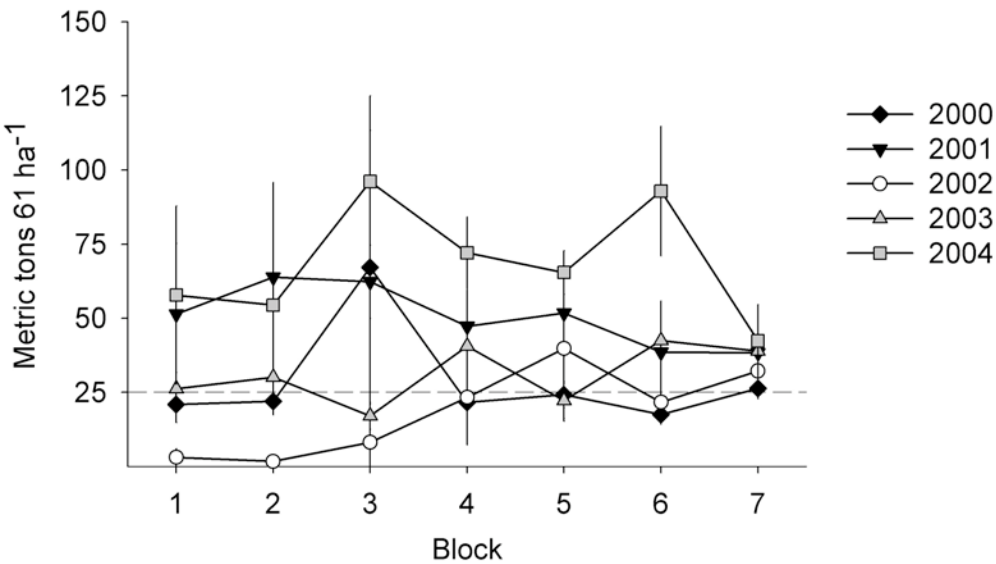


Figure III.C.16. The relationship between the probability that a particular artificial reef design or reference reef will meet the performance standard of supporting 25.4 M tons of kelp forest fishes vs. reef area. Probabilities are based on mean biomass density (kg/m$^2$) estimates for the different artificial reef designs and reference reefs averaged over the period 2000–2004.

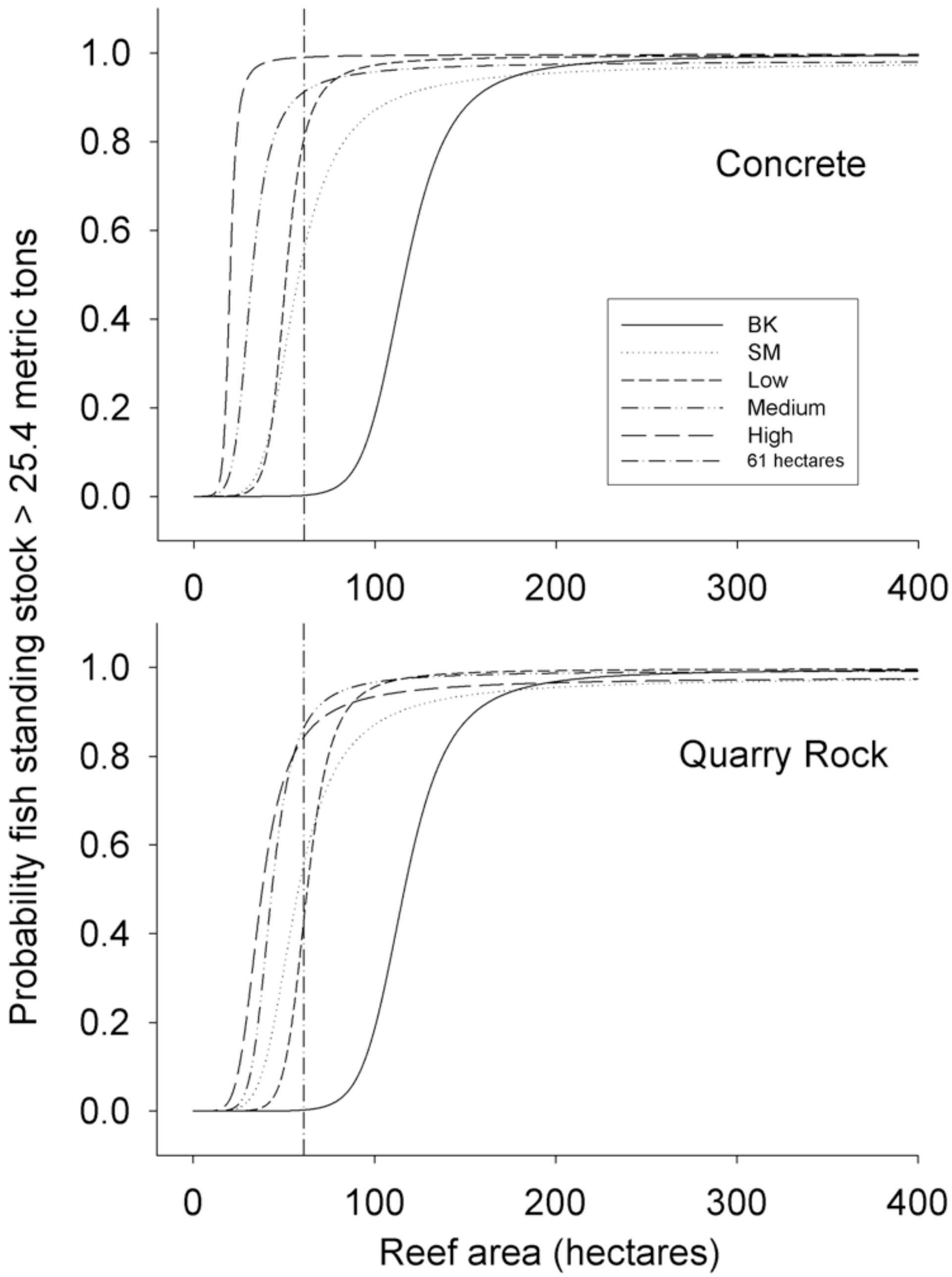


Figure III.C.17. Evaluation of the SONGS relative performance standards pertaining to the density and species richness of resident and YOY kelp forest fishes for the different reef designs using the Universe and Sample approaches (see text for details on these approaches). Solid circles indicate the means of the artificial reef designs in 2004 averaged over blocks (N = 7 modules per design). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different artificial reef designs and the natural reference reefs Barn (B) and San Mateo (SM). Means of artificial reef designs that were within the critical range were considered similar to the reference reefs. The ranges for the Universe approach were set by the mean values of SM and B. The ranges for the Sample approach were set by the 95% confidence limits of the mean of SM and B (N = 14 stations). Data were transformed ($\log_{10}$ [x+1]) for analysis and back transformed for plotting. Abbreviations for the artificial reef designs are as follows: LR = low-coverage rock, MR = medium-coverage rock, HR = high-coverage rock, LC = low-coverage concrete, MC = medium-coverage concrete, HC = high-coverage concrete.

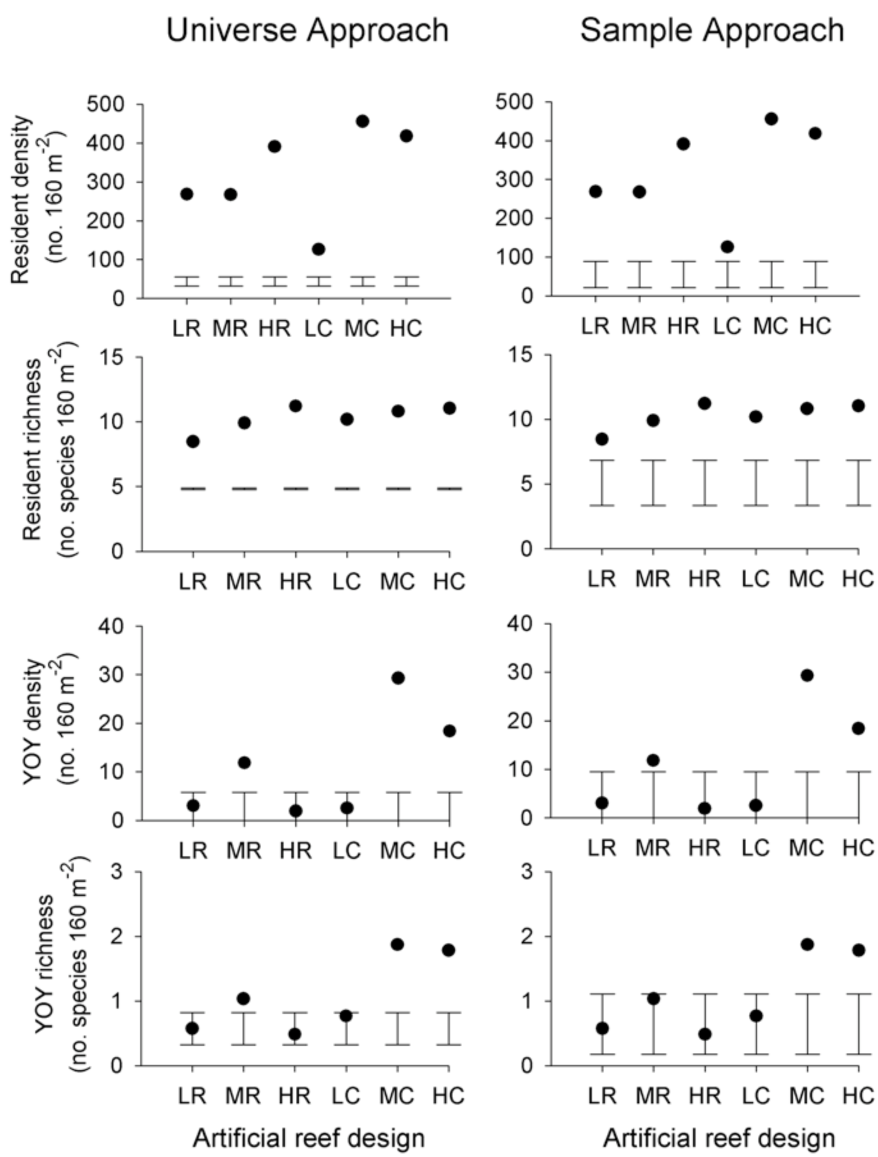
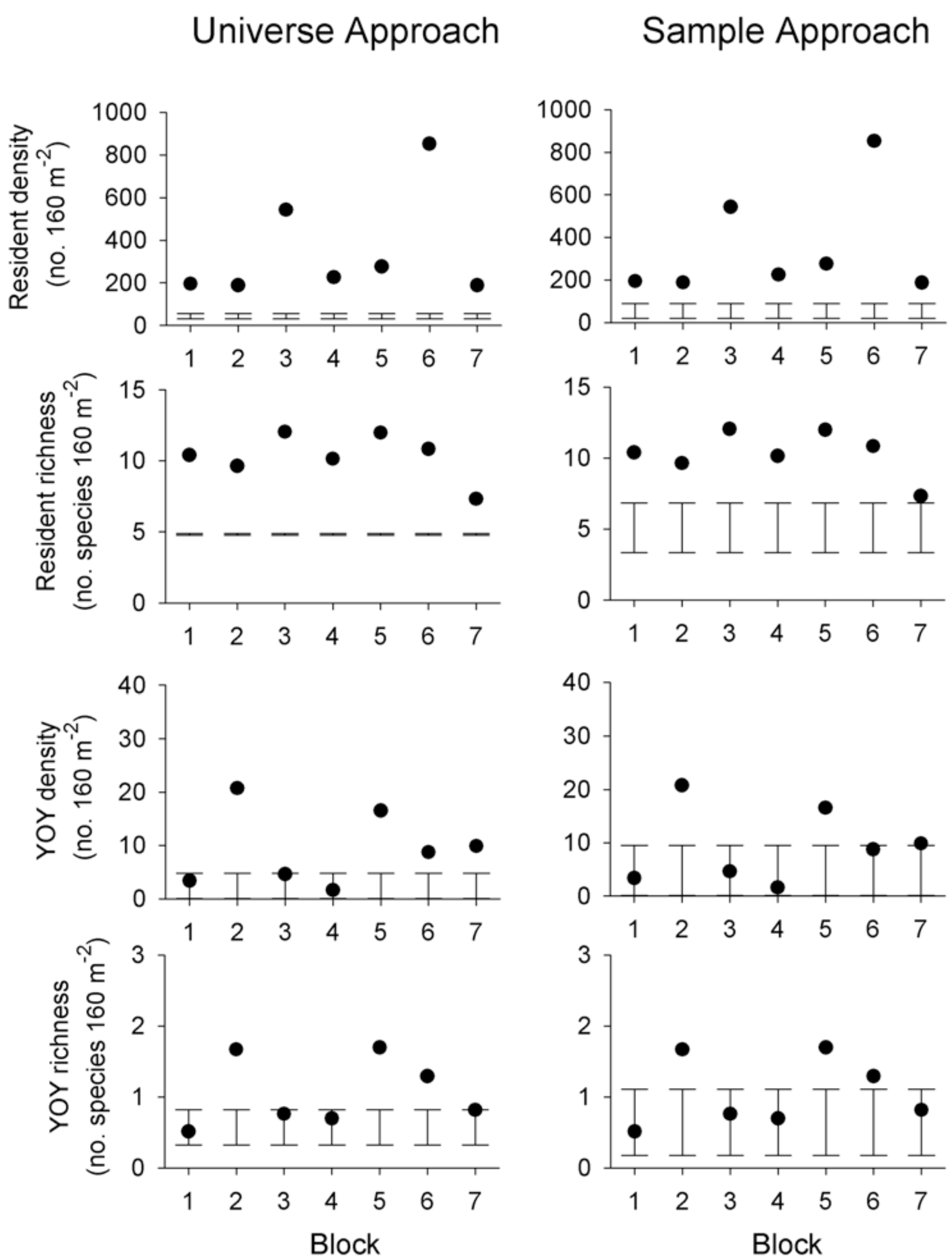


Figure III.C.18. Evaluation of the SONGS relative performance standards pertaining to the density and species richness of resident and YOY fishes for the different locations (i.e., blocks) on SCAR using the Universe and Sample approaches (see text for details on these approaches). Solid circles indicate the means of blocks in 2004 averaged over the different designs within a block (N = 6 modules per block). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different blocks and the natural reference reefs Barn (B) and San Mateo (SM). Means of blocks that were within the critical range were considered similar to the reference reefs. The ranges for the Universe approach were set by the mean values of SM and B. The ranges for the Sample approach were set by the 95% confidence limits of the mean of SM and B (N = 14 stations). Data were transformed ($\log_{10}$ [x+1]) for analysis and back transformed for plotting.



## *D. BENTHIC COMMUNITY*

**Mitigation requirement**

The SONGS permit specifies three performance standards for the kelp forest benthic community (invertebrates and understory algae) on the mitigation reef. These are: 1) the benthic community shall have a coverage (i.e,. percent cover) or density and number of species similar to natural reefs within the region, 2) the benthic community shall provide food-chain support for fish similar to natural reefs within the region, and 3) the important functions of the reef shall not be impaired by undesirable or invasive benthic species. Information as to whether the different artificial reef designs are likely to meet these performance standards was obtained by monitoring the abundance and species composition of benthic algae and invertebrates at SCAR, San Mateo and Barn.

**Methods**

The benthic communities at SCAR, Barn and San Mateo were sampled annually in the summer during 2000–2004 in the same permanent transects used to sample kelp (see *III. B. Giant Kelp*). Several different sampling methods were used to determine density and percent cover of benthic invertebrates, understory algae, and early life stages of *Macrocystis pyrifera*. Abundances of sessile invertebrates and understory algae that were either difficult to distinguish as individuals (e.g., foliose red or brown algae) or laid flat on the bottom (the brown algae *Desmarestia ligulata* and *Laminaria farlowii*) were measured as percent cover. Percent cover was estimated in six replicate 1-$m^2$ quadrats uniformly arranged at fixed locations on each transect using a uniform point contact method. The method consisted of noting the identity and vertical position of all organisms under 20 uniformly placed points within each quadrat, giving a total of 120 points per transect. Using this method the total percent cover of all species can exceed 100%; however, the maximum percent cover possible for any single species cannot exceed 100%. Large solitary invertebrates (e.g., sea stars, sea urchins, and lobsters) and algae (e.g., palm kelp, *Pterygophora californica*, subadult *Macrocystis*) were counted in replicate 40-m x 2-m areas centered along each transect on the artificial reef modules of SCAR and at Barn and San Mateo. Smaller solitary invertebrates (nudibranchs, bivalves, etc.) were counted in a 0.5 $m^2$-area created by dividing the 1-$m^2$ quadrats in half using an elastic cord stretched parallel to the permanent transect line.

Both count data and percent cover data were used to estimate species richness. Species richness at Barn and San Mateo was determined by the mean number of species of algae and invertebrates encountered in the 40 m x 2 m fixed transects at the seven sampling locations of Barn and San Mateo. Because estimates of species richness are highly dependent on sampling effort, the mean number of species encountered in the two replicated transects of each artificial reef module was used as the estimate of species richness for each module. In this way species richness of benthic invertebrates and understory algae was estimated as the mean number of species per 80 $m^2$ for both artificial and natural reefs (N = 7 artificial reef modules or reference reef locations).

**Results – Understory algae**

Temporal and spatial patterns of abundance of understory algae

Understory algae quickly colonized the artificial reef modules and in the first summer following construction (i.e., 2000) their percent cover on all artificial reef designs was within the range of that observed at the more established reference reefs (Figure III.D.1a). By contrast, densities of solitary algae at this time were much greater on the artificial reef modules compared to the reference reefs (Figure III.D.1b). The kelp *Laminaria farlowii* and numerous species of foliose red algae were among the most abundant colonists. The colonization of algae tended to be positively correlated to the amount of artificial reef substrate and largely unrelated to substrate type. Solitary algae on rock modules was the lone exception to this pattern as their mean density in the summer of 2000 was nearly identical on modules with low, medium and high cover of rock (Figure III.D.1b). A variety of red and brown understory algae quickly colonized the artificial reef modules. Foliose and filamentous red algae formed the dominant cover. Their abundance was not uniformly distributed in space and their percent cover in the summer of 2000 was significantly lower in the two northern most blocks (i.e., Blocks 6 and 7); whereas in subsequent years, their abundance was higher in the two northern blocks (Figure III.D.2a). Solitary algae counted on the modules consisted primarily of small recruits of giant kelp (*Macrocystis*) and the perennial understory kelp *Laminaria farlowii*. *Macrocystis* recruits were most abundant in the southern blocks while *Laminaria* recruits were more abundant in the northern blocks. As a consequence of these opposite patterns of abundance, solitary algae as a group did not show a trend with distance from San Mateo (Figure III.D.2). Over time as *Macrocystis* grew out of the understory, spatial patterns of algal density shifted such that the density of understory algae (dominated primarily by *Laminaria*) was greater in the more northern blocks.

The overall abundance of understory algae (as estimated by percent cover and density) steadily declined following the initial colonization and by 2003 was very sparse on all artificial reef designs (Figure III.D.1) and at all blocks (Figure III.D.2). The decline in understory algae was greater and occurred more rapidly on modules that were closest to San Mateo (Blocks 1 through 4; Figure III.D.2). The reason for this spatial difference was due to the higher percent cover and density of *Laminaria farlowii*, whose recruitment and survival was much greater in the more northern locations (i.e., Blocks 5 through 7).

The steady decline in algae observed at SCAR from 2000–2003 was not observed at Barn and San Mateo (Figure III.D.1). Although 2003 marked the time of lowest algal abundance at the reference reefs, algae were still much more abundant at Barn and San Mateo than they were on the artificial reef modules of SCAR. Importantly, the percent cover and density of understory algae at Barn and San Mateo showed a marked increase in 2004, which did not occur on SCAR.

Species richness of understory algae

Patterns of species richness in understory algae on SCAR followed the same temporal decline as those observed for percent cover and density (Figures III.D.3 and III.D.4 vs. III.D.1 and III.D.2). As was the case for algal abundance, the reference sites showed no such decline in species richness. Algal species richness of the various artificial reef designs was very similar, indicating the type and bottom coverage of artificial hard substrate had little effect on the number of algal species that inhabited a module. The algal assemblages on the different reef designs were very similar to each other and appeared to be influenced little by the type and bottom cover of artificial substrate. By contrast, the species assemblage of understory algae on SCAR differed noticeably from that of the reference reefs throughout the five-year experiment (Figures III.D.3 vs. III.D.1). Percent similarity between SCAR and the reference sites was relatively low (15 to 20%) in 2000 following the initial colonization of SCAR, rapidly increased to 40 to 48% in 2001, and gradually declined to 30 to 40% in 2004 (Figure III.D.5). In the summer of 2004, five years after construction, the sparse understory algal assemblage on SCAR consisted primarily of small foliose and filamentous red algae and the kelp *Laminaria farlowii* (Figure III.D.6). Similar to SCAR, *L. farlowii* was the most numerically dominant solitary alga at the reference reefs (Figure III.D.6b). However, unlike SCAR, the contribution of *L. farlowii* to the total cover of understory algae on the reference reefs was quite low (Figure III.D.6a). Instead, the understory algal assemblage at the reference reefs was dominated by large ovate fleshy algae (e.g., *Cryptonemia* sp. or *Schizymenia* sp.) and the foliose red alga *Rhodymenia californica*.

<u>Evaluation of the performance standards for understory algae</u>
The critical ranges used to evaluate the performance standards for understory algae set by the Sample approach were considerably larger than those set by the Universe approach (Figure III.D.7). Nonetheless, the method of evaluation had no effect on determining the similarity between the artificial reef modules and the reference sites as all of the six artificial reef designs had mean values of understory algal percent cover, density or species richness that were below the critical ranges established for the reference reefs by both the Universe and Sample approaches.

Evaluations of compliance based on location (i.e., block) were similar to those based on artificial reef design (Figure III.D.8). Algal density was the only standard found to be in compliance and this was only the case for Block 7 using the Universe approach and Blocks 6 and 7 using the Sample approach. In all other cases, block means for algal percent cover, density and species richness were below the critical ranges set by both approaches.

<u>Summary of results for understory algae</u>

- Algae (such as small juvenile red algae, short filamentous red algae and the understory kelp, *Laminaria*) rapidly colonized SCAR soon after construction.
- The density and percent cover of algal colonists on SCAR was positively related to the bottom cover of artificial substrate, and unrelated to the type of hard substrate and the distance from San Mateo kelp forest, the nearest natural reef.
- Since 2001 the abundance and species richness of understory algae on SCAR has steadily declined and by 2003 was uncommon on all artificial reef designs.
- The percent similarity in species composition and relative abundance of understory algae between SCAR and the reference sites appears to have leveled off at around 35% from an initial value of about 17%.

- All six of the artificial reef designs tested failed to meet the performance standards for the percent cover, density and number of species of understory algae established for the mitigation reef.
- All seven locations (i.e., blocks) failed to meet the performance standards for percent cover and number of species of understory algae established for the mitigation reef. Block 7 was the only location to meet the performance standard for density of understory algae using the Universe approach (in which the two reference reefs, San Mateo and Barn, constitute the entire population of sites to which the artificial reef is compared), while Blocks 6 and 7 met the standard for algal density using the Sample approach (in which San Mateo and Barn constitute a sample from a larger population of possible reference reefs).

Figure III.D.1. Change in the mean (± SE) abundance of understory algae over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). N = 7 artificial reef modules or reference reef locations. (a) Algae that are either difficult to distinguish as individuals (e.g., foliose red or brown algae) or lie flat on the bottom, and (b) Large solitary algae that are easy to count as individuals.

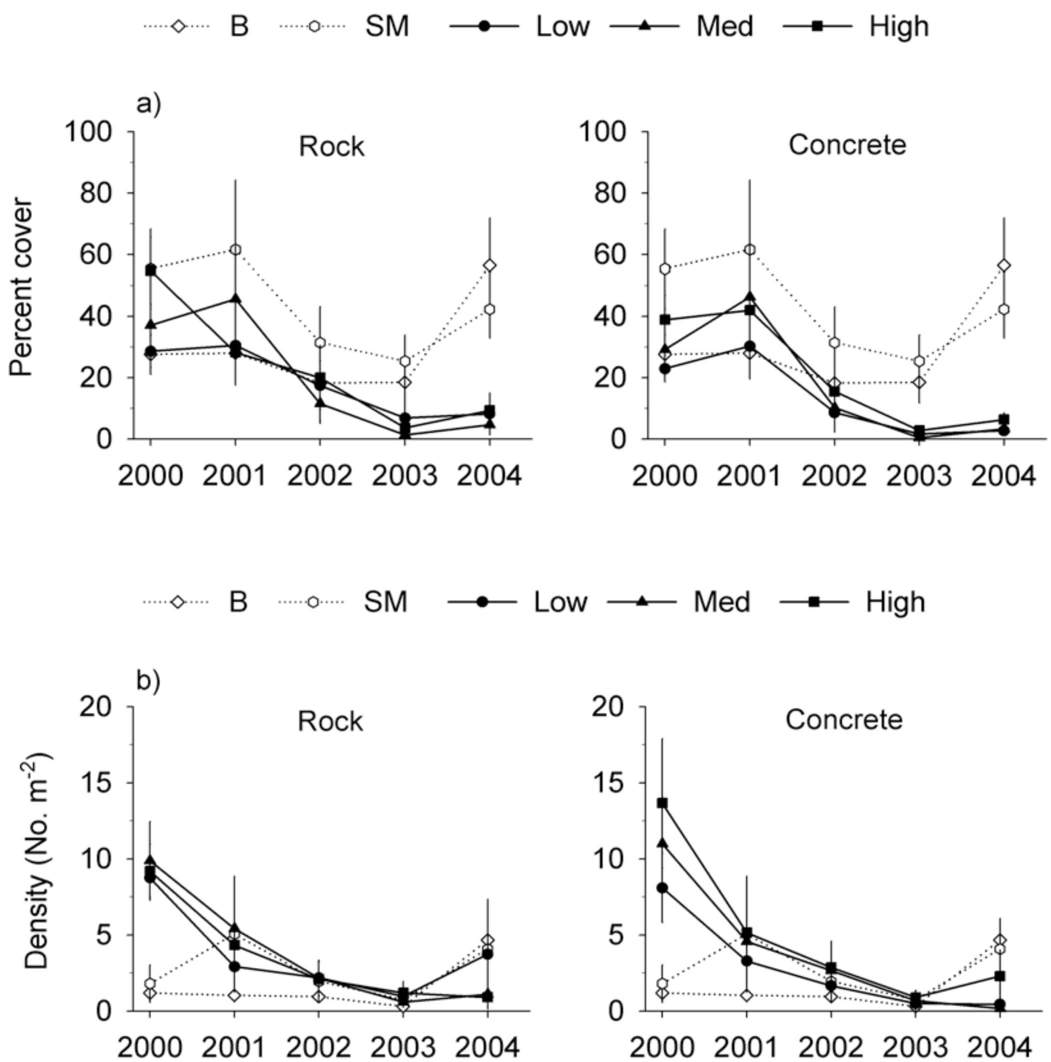
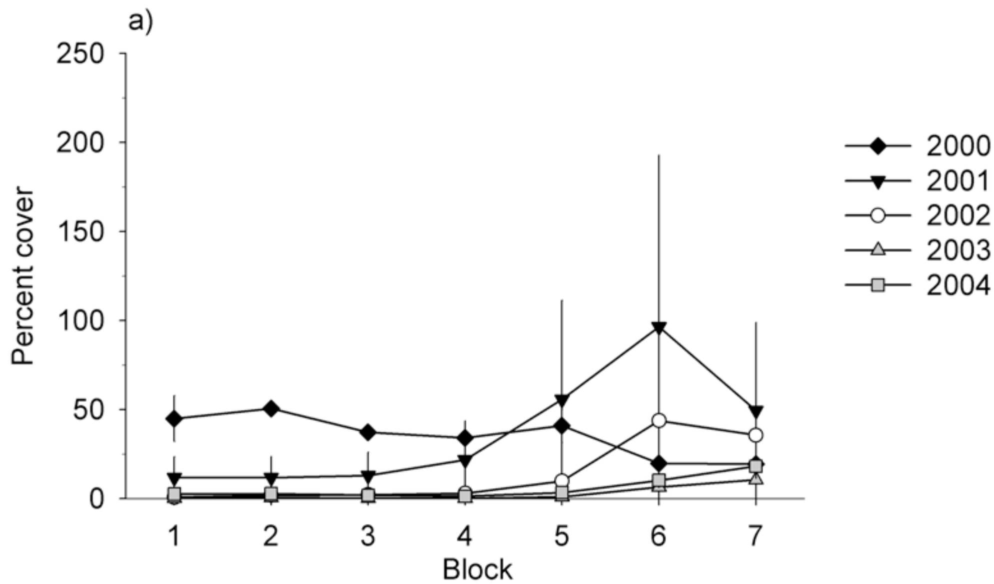


Figure III.D.2. Mean (± SE) abundance of understory algae on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. (a) Algae that are either difficult to distinguish as individuals (e.g., foliose red or brown algae) or lie flat on the bottom, and (b) Large solitary algae that are easy to count as individuals.



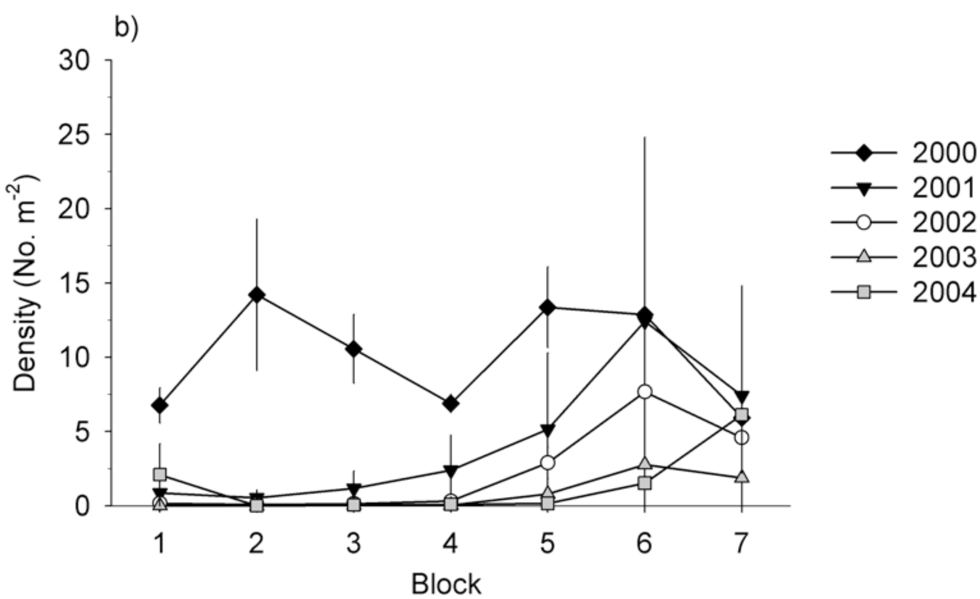



Figure III.D.3. Change in the mean (± SE) number of species of understory algae over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

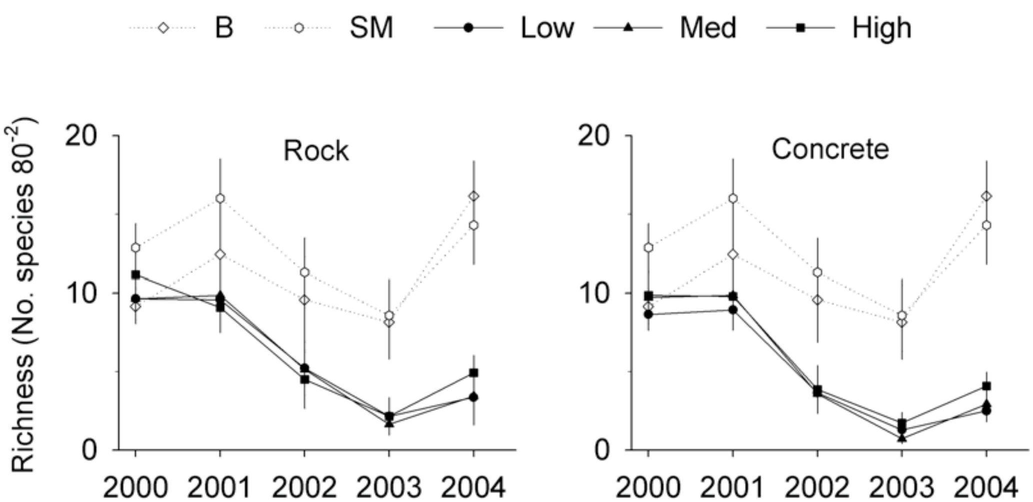



Figure III.D.4. Mean (± SE) number of species of understory algae on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef.

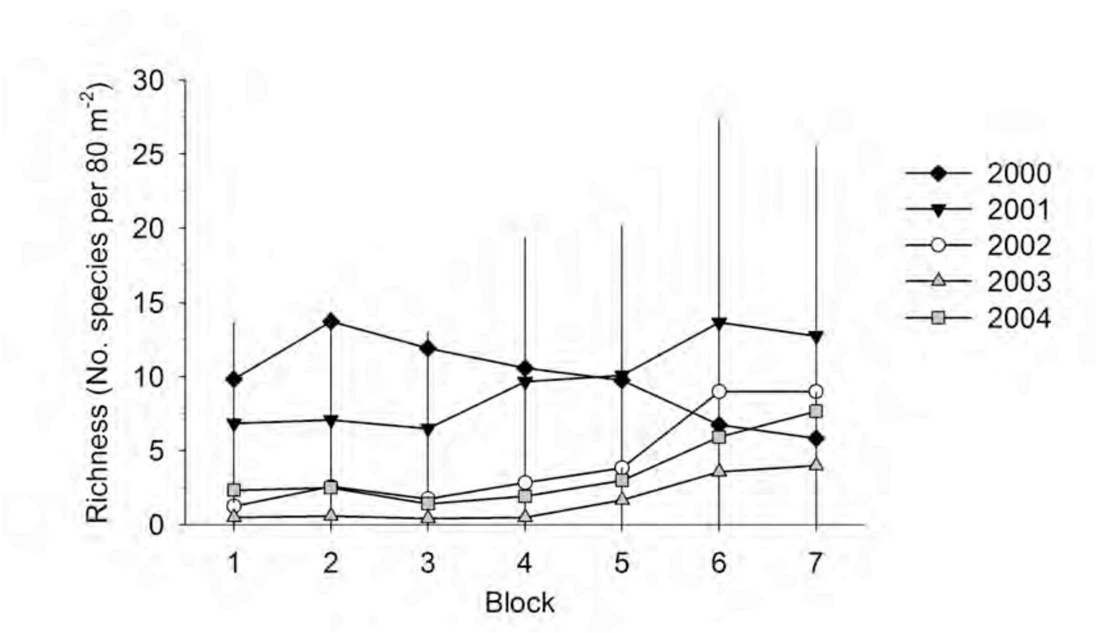


Figure III.D.5. Percent similarity in the assemblages of understory algae between the mean of the reference reefs (Barn and San Mateo) and artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high). (a) Algae that are either difficult to distinguish or count as individuals (e.g., foliose red or brown algae), and (b) Large solitary algae that are easy to count as individuals.

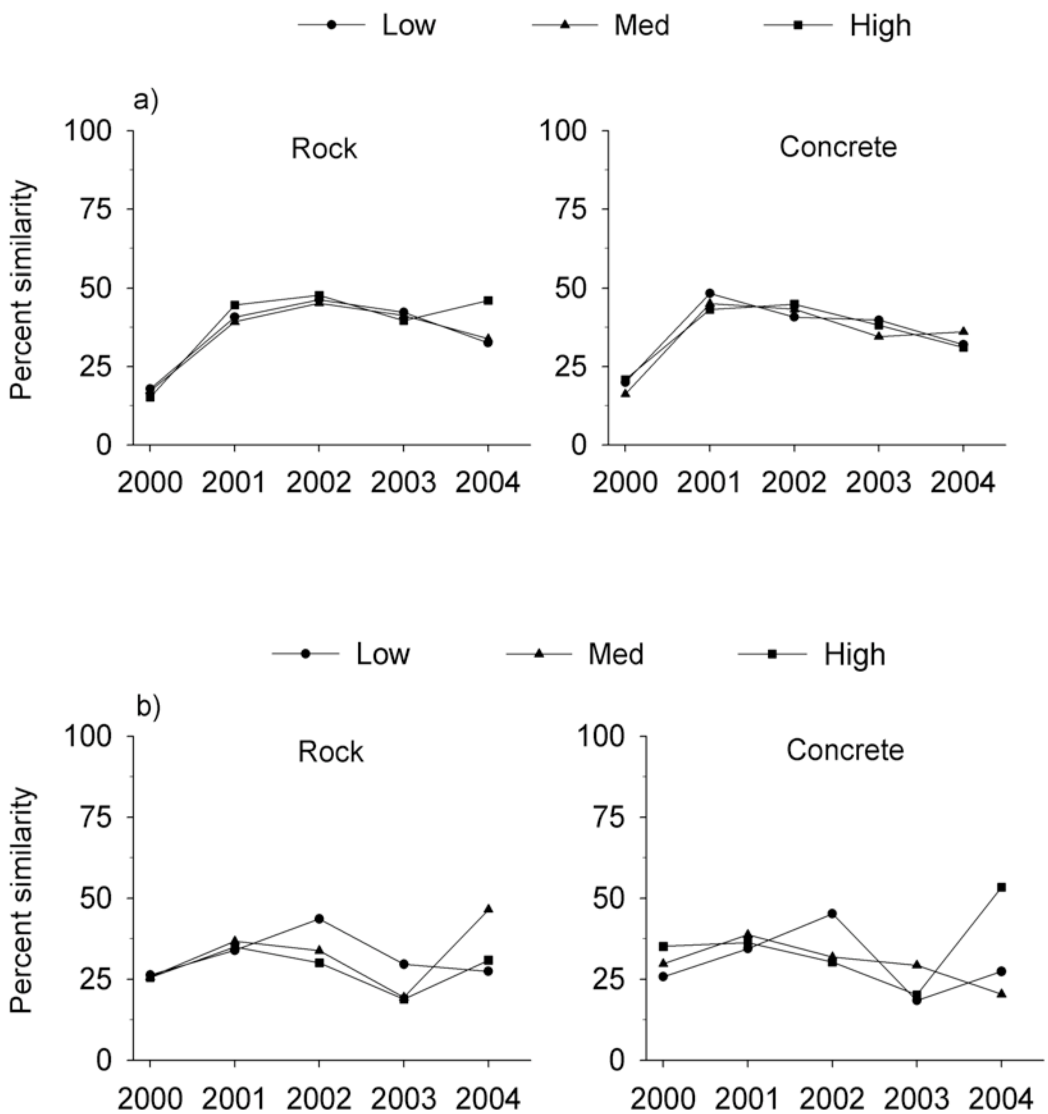


Figure III.D.6. Relative abundance of the most common understory algae at the artificial reef (SCAR) and the reference reefs, Barn and San Mateo (REF) in the summer of 2004. (a) Algae that are either difficult to distinguish or count as individuals (e.g., foliose red or brown algae) and (b) Large solitary algae that are easy to count as individuals.

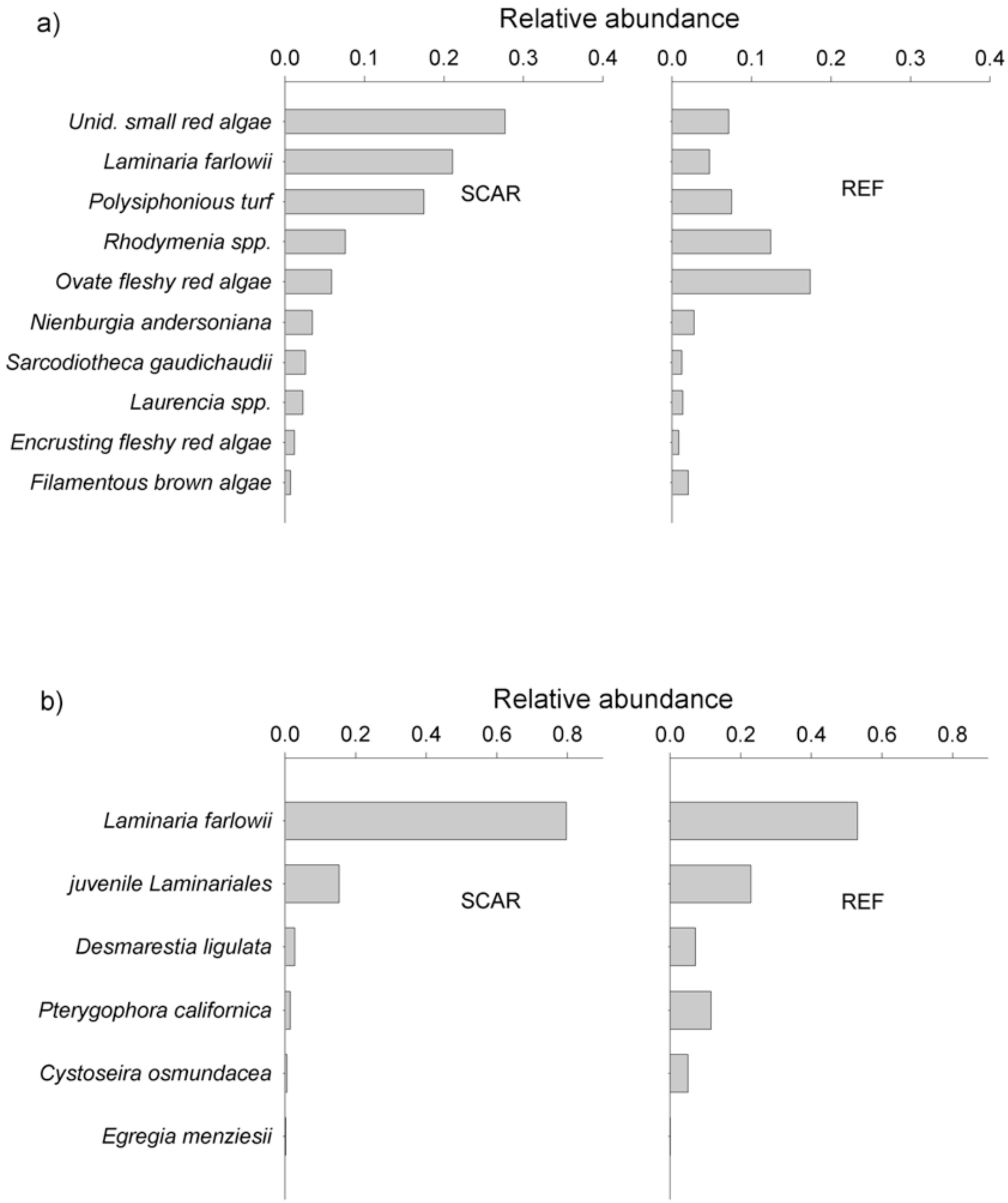


Figure III.D.7. Evaluation of the SONGS relative performance standards pertaining to the abundance and species richness of understory algae for the different artificial reef designs using the Universe and Sample approaches (see text for details on these approaches). Solid circles indicate the means of the artificial reef designs in 2004 averaged over blocks (N = 7 modules per design). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different artificial reef designs and the natural reference reefs Barn (B) and San Mateo (SM). Means of artificial reef designs that were within the critical range were considered similar to the reference reefs. The ranges for the Universe approach were set by the mean values of B and SM. The ranges for the Sample approach were set by the 95% confidence limits of the mean of B and SM (N = 14 stations). Data were transformed ($\log_{10}$ [x+1]) for analysis and back transformed for plotting. Abbreviations for the artificial reef designs are as follows: LR = low-coverage rock, MR = medium-coverage rock, HR = high-coverage rock, LC = low-coverage concrete, MC = medium-coverage concrete, HC = high-coverage concrete.

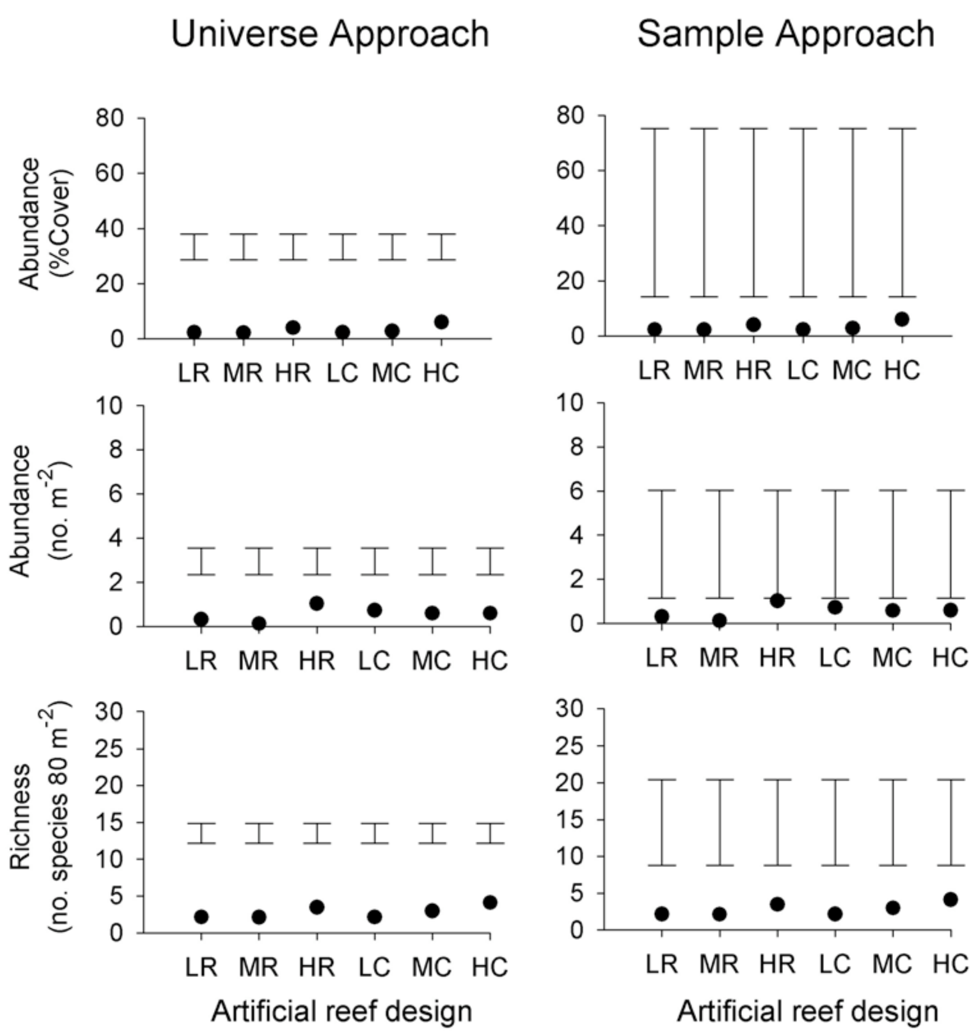
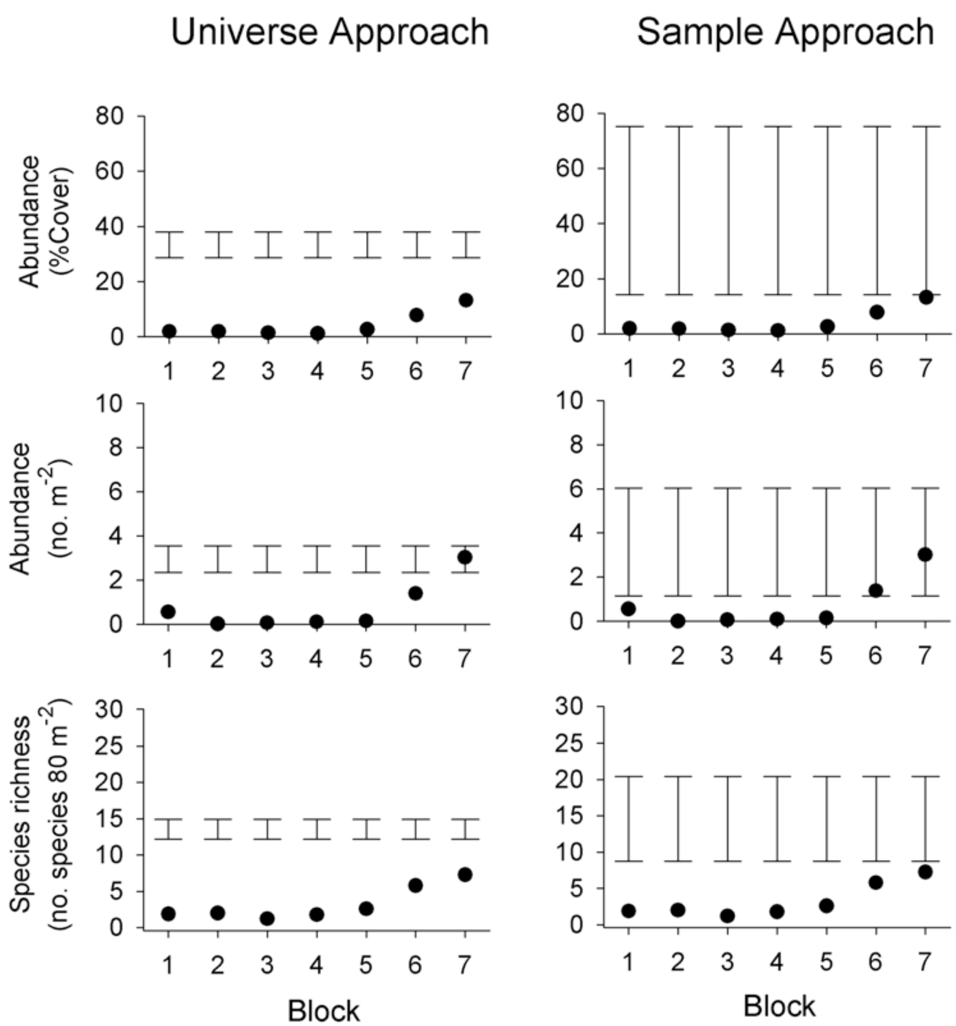


Figure III.D.8. Evaluation of the SONGS relative performance standards pertaining to the density and species richness of understory algae for the different locations (i.e., blocks) on SCAR using the Universe and Sample approaches (see text for details on these approaches). Solid circles indicate the means of the blocks in 2004 averaged over the different designs within a block (N = 6 modules per block). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different blocks and the natural reference reefs Barn (B) and San Mateo (SM). Means of blocks that were within the critical range were considered similar to the reference reefs. The ranges for the Universe approach were set by the mean values of SM and B. The ranges for the Sample approach were set by the 95% confidence limits of the mean of SM and B (N = 14 stations). Data were transformed ($log_{10}$ [x+1]) for analysis and back transformed for plotting.



**Results—Benthic invertebrates**

Temporal and spatial patterns of abundance of benthic invertebrates

Tunicates, bryozoans and sponges rapidly colonized the artificial reef modules and in the first summer following construction (i.e., 2000) the percent cover of sessile invertebrates on all the artificial reef designs exceeded that observed on the more established reference reefs (Figure III.D.9a). The compound tunicate *Cheylosoma productum* accounted for ~ 30% of the invertebrate cover on SCAR at this time. The percent of the bottom occupied by sessile invertebrates at SCAR gradually increased over time, and in most cases, leveled off by the end of the five-year experiment. Benthic invertebrates consistently formed a relatively low cover (~20 to 30%) at Barn and San Mateo for the entire five-year experiment. Unlike encrusting colonial invertebrates, relatively few solitary invertebrates colonized SCAR during the first two years. The first major pulse in recruitment of solitary invertebrates was observed during the summer of 2002 and by 2004 the densities of solitary invertebrates on all the different artificial reef designs of SCAR exceeded those on the reference reef (Figure III.D.9b).

Like understory algae, the colonization and subsequent establishment of benthic invertebrates on SCAR tended to be positively related to the amount of artificial reef substrate and largely unrelated to the type of artificial reef substrate (Figure III.D.9). The abundance (percent cover and density) of benthic invertebrates was largely unrelated to distance from San Mateo, the nearest natural reef to SCAR, throughout the five–year experiment (Figure III.D.10). The lone exception to this pattern was the trend of decreasing invertebrate density with increasing distance from San Mateo in 2002 (Figure III.D.10b). This pattern reflects the sudden appearance of the sea fan *Muricea californica*, whose recruitment density in 2002 declined with distance from San Mateo (see III.D. **Results—Undesirable and invasive species**).

Species richness of benthic invertebrates

The species richness of benthic invertebrates on SCAR increased over time much like the percent cover and density of benthic invertebrates (Figures III.D.11 and III.D.12). Similar increasing trends in the number of species of benthic invertebrates were observed at the reference reefs, even though the percent cover and density of benthic invertebrates at these sites showed relatively minor increases in abundance over time (Figures III.D.11 and III.D.12 vs. III.D.9. and III.D.10). This overall increasing trend at SCAR and the reference reefs may in part reflect a learning curve in the project staff's ability to recognize and identify uncommon species, however the comparatively higher rates of increase at SCAR relative to the reference reefs would not have been caused by such a "learning curve" effect. The effects of artificial substrate type and bottom cover on the number of species of benthic invertebrates were less pronounced than the effects on percent cover and density of benthic invertebrates. The assemblages of benthic invertebrates on the different artificial reef designs were similar to each other and were relatively unaffected by the type and bottom cover of artificial substrate.

The percent similarity between the assemblages of benthic invertebrates on SCAR and the reference reefs steadily increased during the first three years before leveling off in the summer of 2002 at approximately 50% (Figure III.D.13). The similarity in the invertebrate assemblages on SCAR and the reference reefs was largely unaffected by the type and bottom cover of artificial substrate on SCAR. As a group the benthic invertebrate assemblages on SCAR and the reference reefs were slightly more similar than were the algal assemblages, but substantially less similar than were the fish assemblages. In the summer of 2004, the compound tunicate *Chelyosoma productum* was still the most abundant invertebrate on SCAR accounting for 23% of the primary space occupied by benthic invertebrates (Figure III.D.14a). In contrast, the relative abundance of benthic invertebrates at Barn and San Mateo displayed a more uniform distribution as no single species accounted for more than 10% of the total assemblage of the colonial invertebrates. The brittle star *Ophiothrix spiculata* was by far the most abundant solitary invertebrate on both SCAR and the reference reefs (Figure III.D.14b).

<u>Evaluation of the performance standards for benthic invertebrates</u>
As with kelp forest fishes and understory algae the critical ranges for evaluating the performance standards for benthic invertebrates were consistently larger for the Sample approach compared to the Universe approach. These differences between the two approaches, however, had no effect on evaluations of the performance standard involving the abundance of benthic invertebrates, as the mean values of percent cover and density of invertebrates for all six artificial reef designs were greater than the critical ranges set by Barn and San Mateo, irrespective of the analytical approach used to set the range (Figure III.D.15). In the case of species richness, two of six artificial reef designs were within the critical range set by the Universe approach (low-cover concrete, and low-cover rock), and three were within the range set by the Sample (low- and high-cover rock and low-cover concrete). Importantly, none of the six artificial reef designs had mean values of invertebrate percent cover, density, or species richness that were below the critical ranges set by either the Universe or Sample approaches.

Similarly, none of the seven blocks had mean values of invertebrate percent cover, density, or species richness that were below the critical ranges set by either the Universe or Sample approaches (Figure III.D.16). All blocks had values of invertebrate percent cover and density that were above the critical ranges. Species richness in Block 7 was within the range using the Universe approach while all locations except Block 3 had mean values of species richness that were within the range using the Sample approach.

<u>Summary of results for benthic invertebrates</u>

- The abundance percent cover, density, and number of species of benthic invertebrates on all artificial reef designs increased throughout the five-year experiment.
- Invertebrate percent cover and density was positively related to the cover of artificial substrate and unrelated to the type of hard substrate and to distance from San Mateo.
- The percent similarity in the invertebrate assemblages on SCAR and the reference reefs displayed an asymptotic increase over time to ~ 50% and was largely unaffected by the bottom cover and type of artificial substrate.

- The most abundant invertebrate taxa on SCAR after five years were the compound tunicate *Chelyosoma productum* and the brittle star *Ophiothrix spiculata.*
- All six artificial reef designs met the performance standards for percent cover, density, and species richness of benthic invertebrates, and in all cases exceeded the range of values at the reference reefs established by the Universe and Sample approaches.
- All seven blocks met the performance standards for percent cover, density, and species richness of benthic invertebrates, and in all cases exceeded the range of values at the reference reefs established by the Universe and Sample approaches.

Figure III.D.9. Change in the mean (± SE) abundance of benthic invertebrates over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). N = 7 artificial reef modules or reference reef locations. (a) Sessile invertebrates that are difficult to distinguish and count as individuals (e.g., colonial tunicates, bryozoans, sponges) and (b) Solitary or colonial invertebrates that are easy to count as individuals (e.g., echinoderms, molluscs, crustaceans) or as individual colonies (e.g., sea fans).

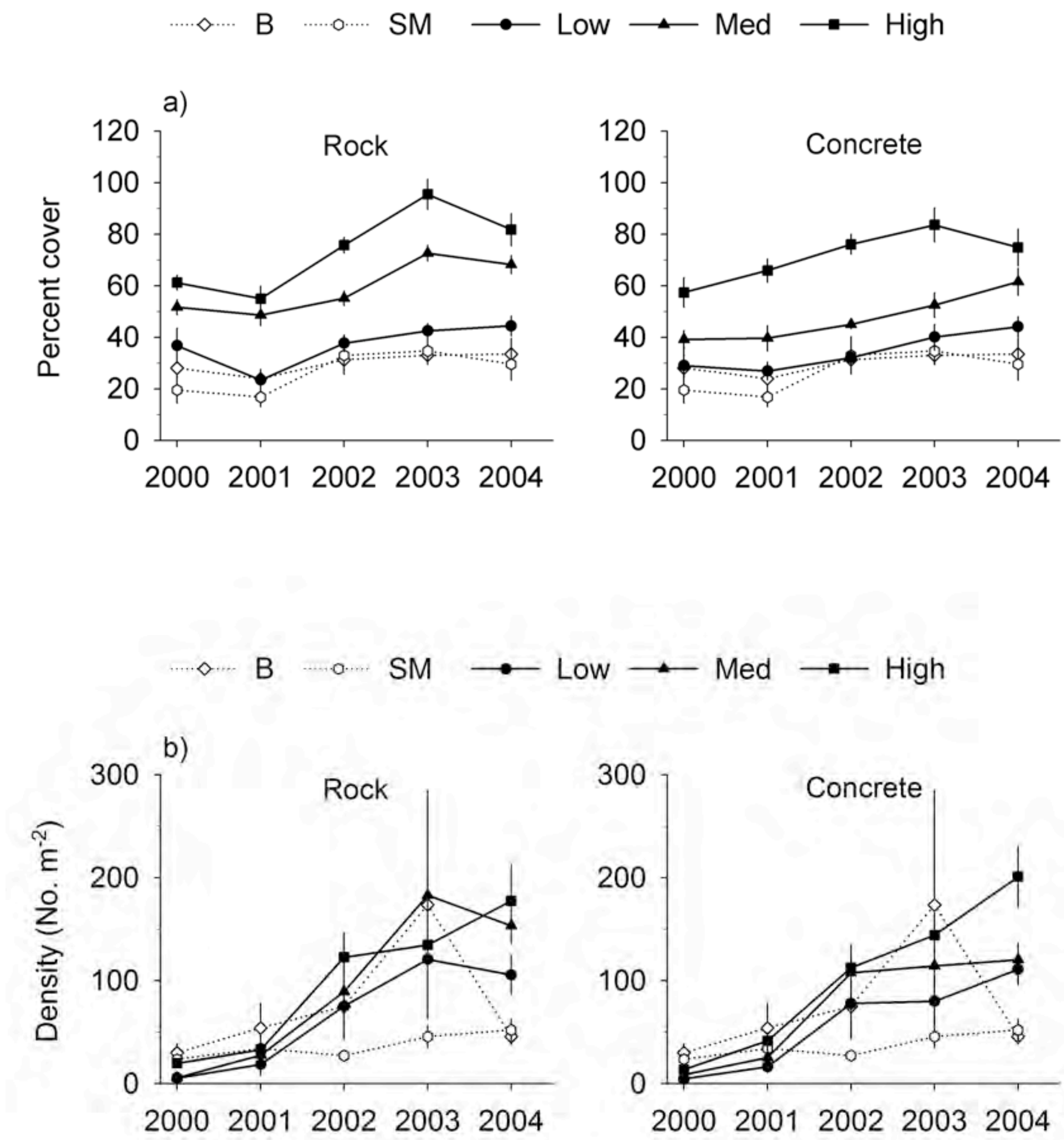
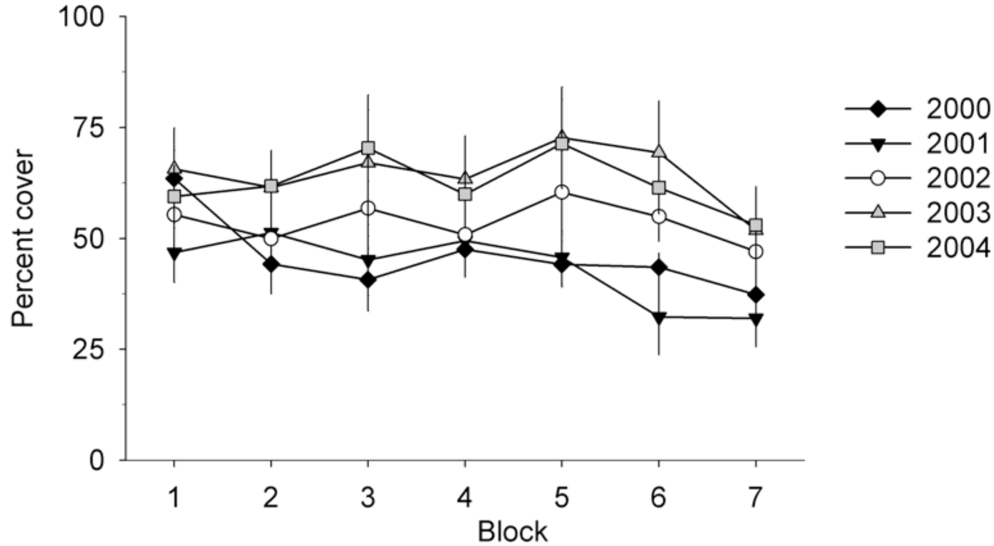


Figure III.D.10. Mean (± SE) abundance of benthic invertebrates on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef. (a) Sessile invertebrates that are difficult to distinguish and count as individuals (e.g., colonial tunicates, bryozoans, sponges), and (b) Solitary or colonial invertebrates that are easy to count as individuals (e.g., echinoderms, molluscs, crustaceans) or as individual (colonies (e.g., sea fans).

a)




b)

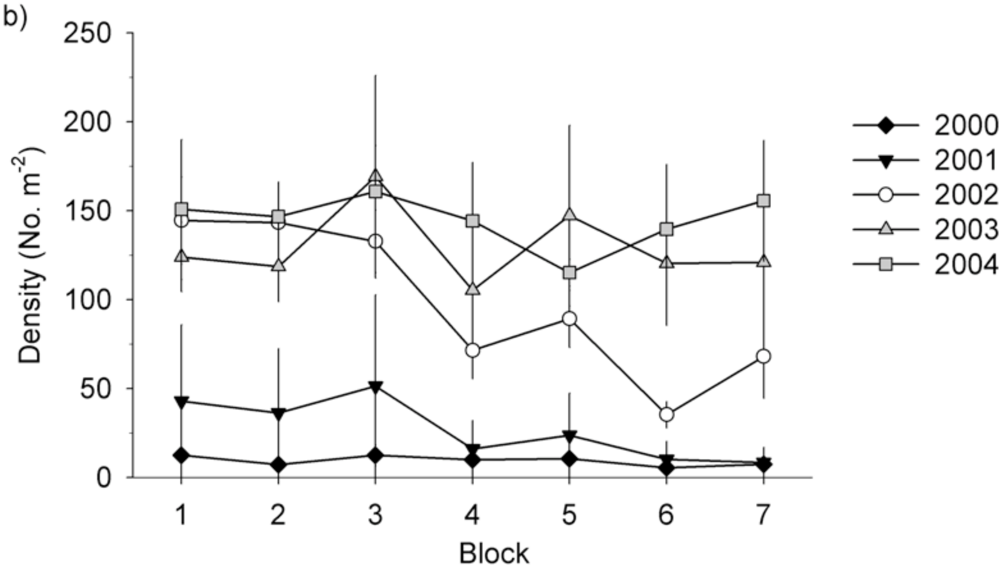


Figure III.D.11. Change in the mean (± SE) number of species of benthic invertebrates over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

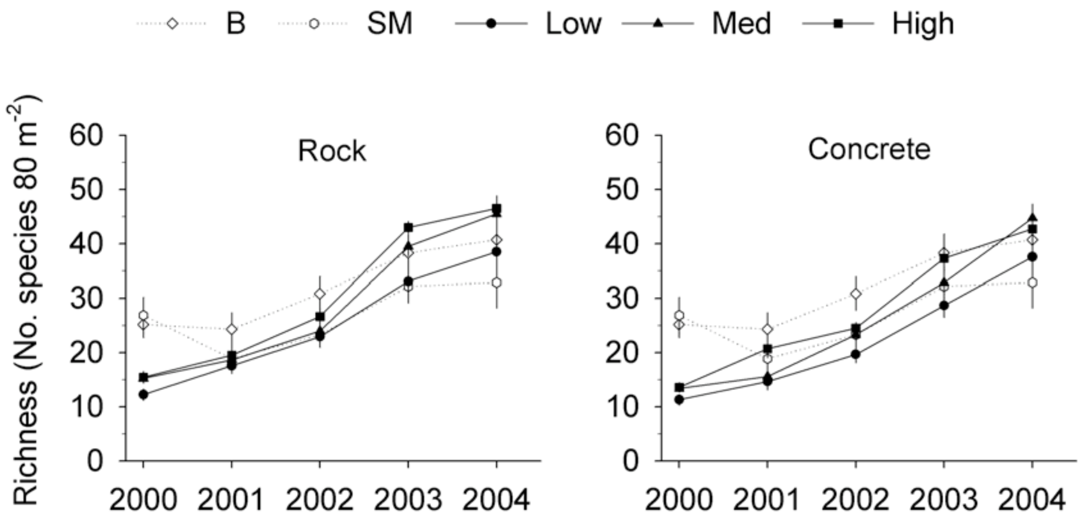



Figure III.D.12. Mean (± SE) number of species of benthic invertebrates on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north.

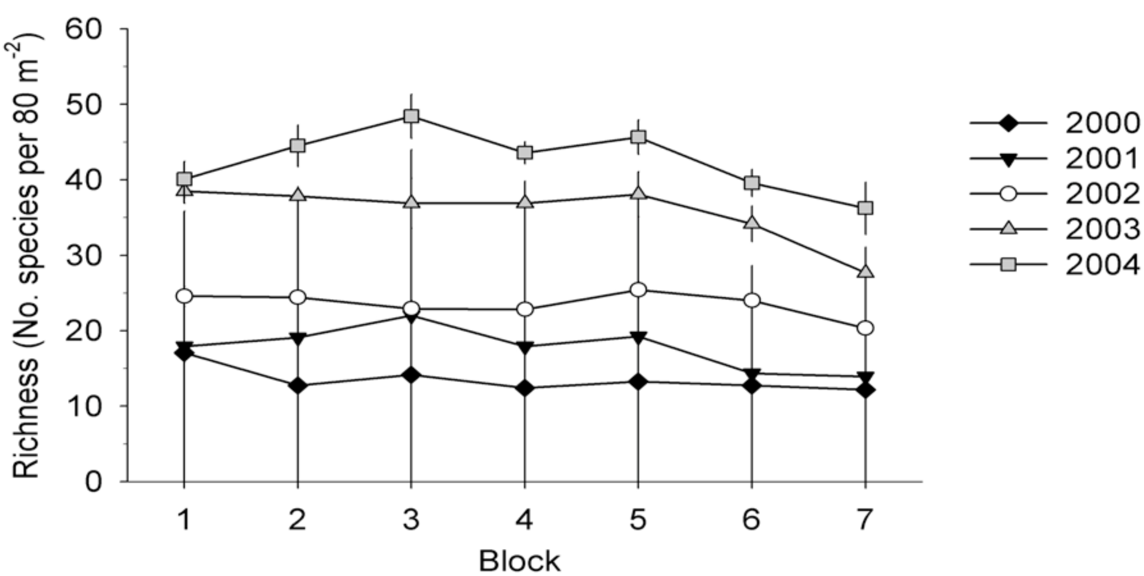


Figure III.D.13. Percent similarity in the assemblages of benthic invertebrates between the mean of the reference reefs (Barn and San Mateo) and the mean of the different artificial reef designs of SCAR having different substrate types (rock and concrete) and bottom coverages (low, medium and high). (a) Sessile invertebrates that are difficult to distinguish as individuals, and (b) Solitary invertebrates that are easy to count as individuals.

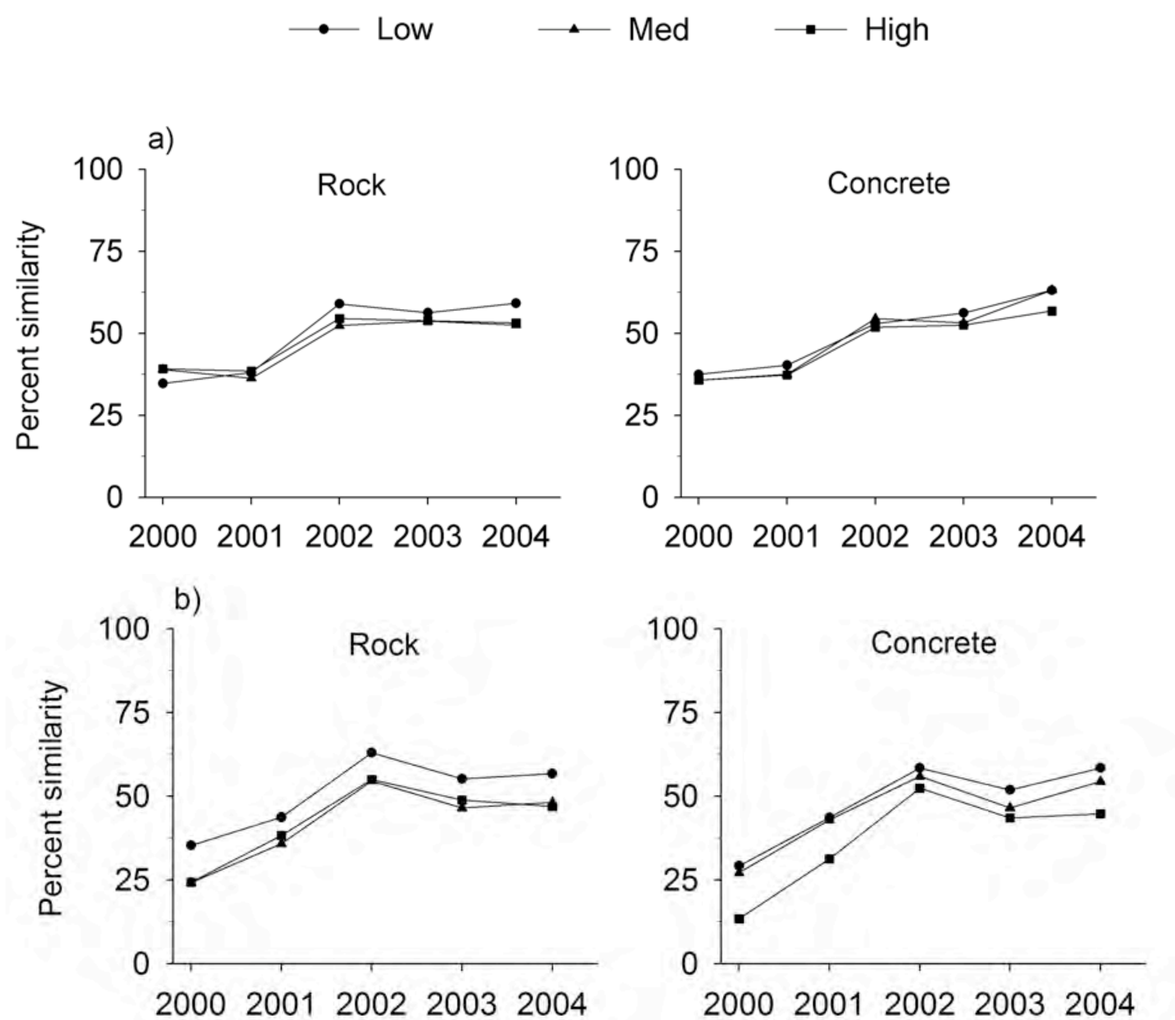
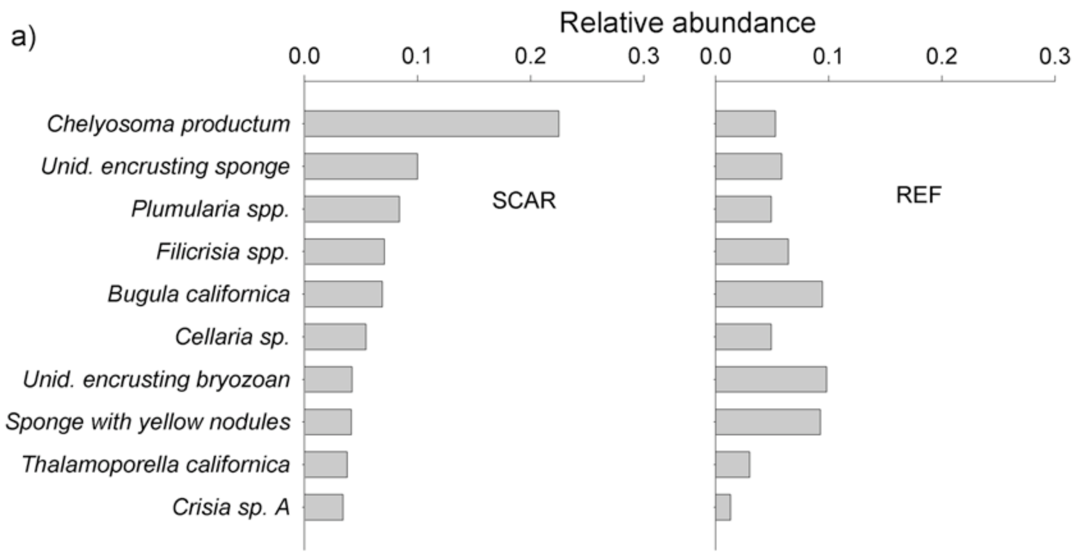


Figure III.D.14. Relative abundance of the most common benthic invertebrates at the artificial reef (SCAR) and the reference reefs Barn and San Mateo (REF) in summer 2004. (a) Sessile invertebrates that are difficult to distinguish as individuals, and (b) Solitary invertebrates that are easy to count as individuals.



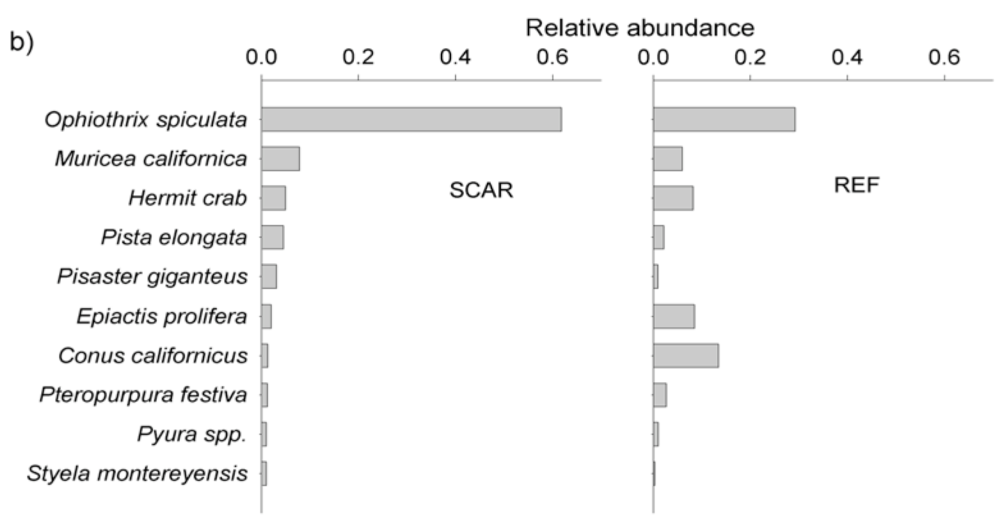



Figure III.D.15. Evaluation of the SONGS relative performance standards pertaining to the abundance and species richness of benthic invertebrates for the different artificial reef designs using the Universe and Sample approaches. Solid circles indicate the means of the artificial reef designs in 2004 averaged over blocks (N = 7 modules per design). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different artificial reef designs and the natural reference reefs Barn (B) and San Mateo (SM). Means of artificial reef designs that were within the critical range were considered similar to the reference reefs. The ranges for the Universe approach were set by the mean values of B and SM. The ranges for the Sample approach were set by the 95% confidence limits of the mean of B and SM (N = 14 stations). Data were transformed ($\log_{10}$ [x+1]) for analysis and back transformed for plotting. Abbreviations for the artificial reef designs are as follows: LR = low-coverage rock, MR = medium-coverage rock, HR = high- coverage rock, LC = low-coverage concrete, MC = medium-coverage concrete, HC = high-coverage concrete.

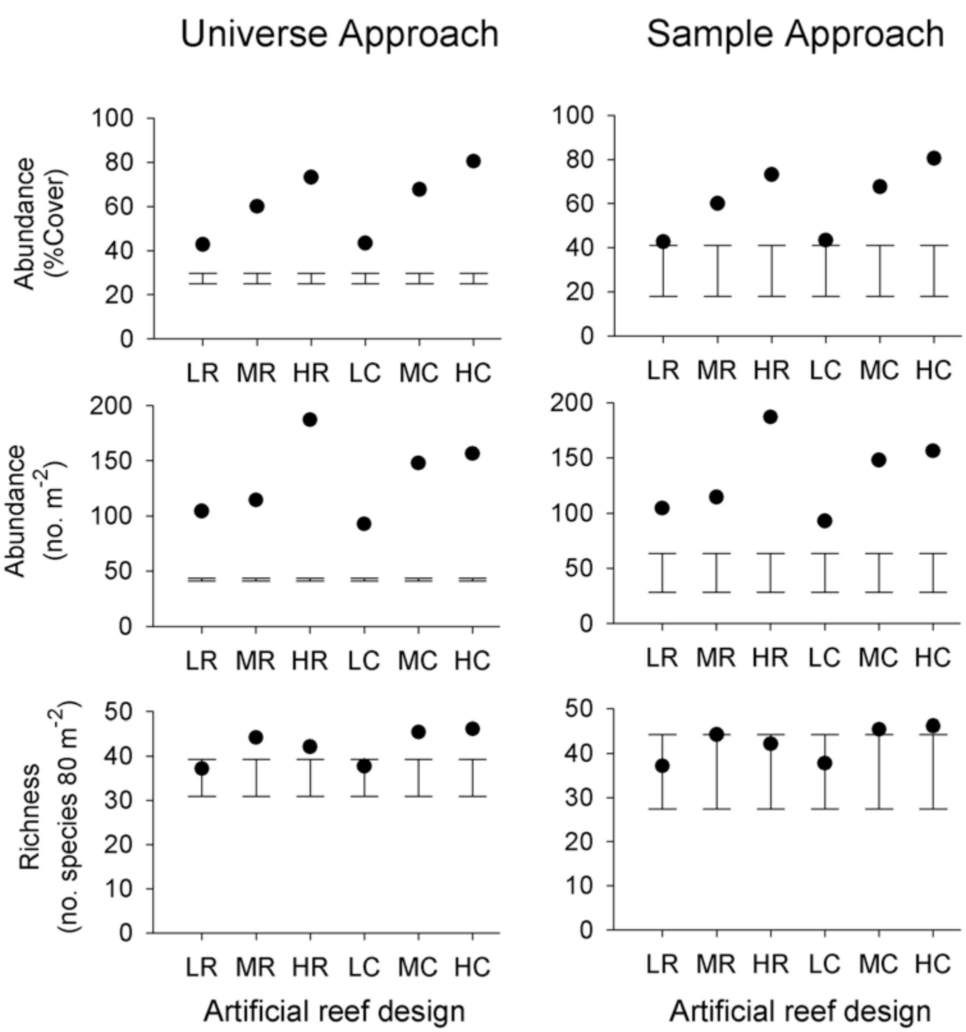
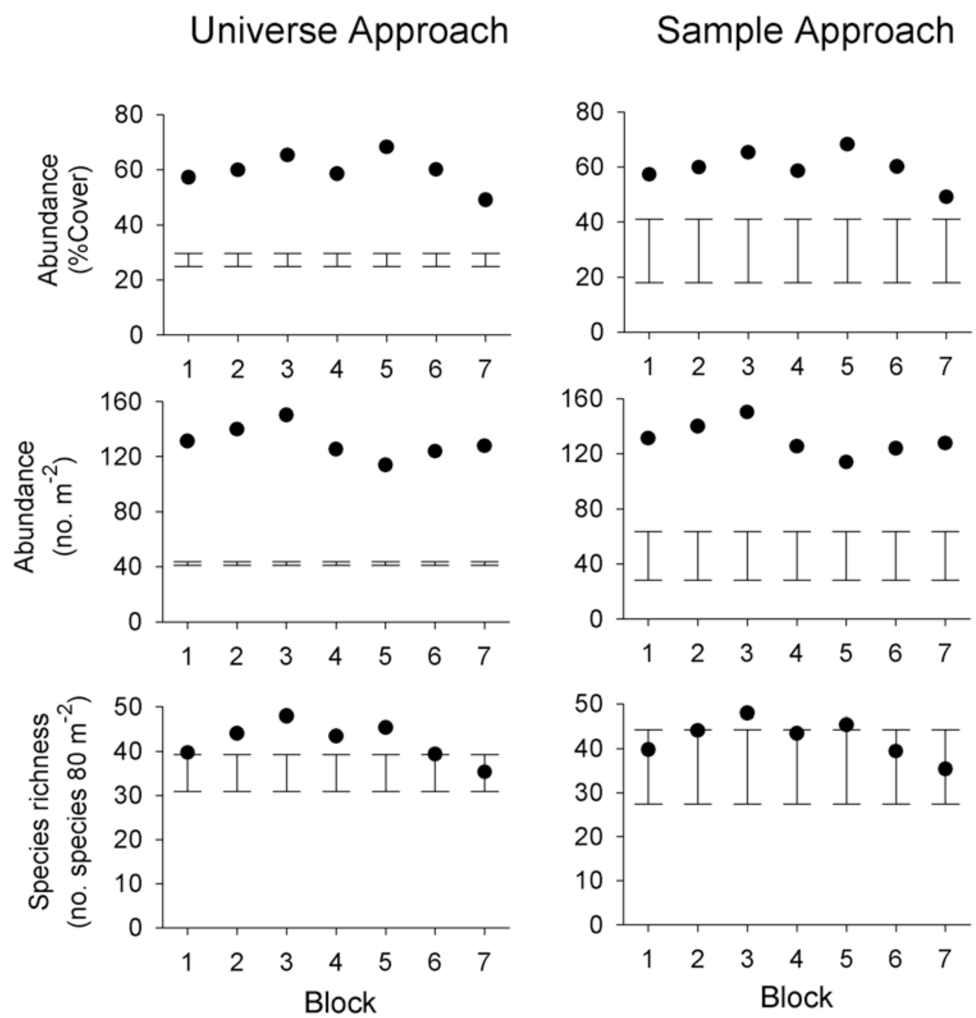


Figure III.D.16. Evaluation of the SONGS relative performance standards pertaining to the density and species richness of benthic invertebrates for the different locations (i.e., blocks) on SCAR using the Universe and Sample approaches (see text for details on these approaches). Solid circles indicate the means of the artificial reef blocks in 2004 averaged over the different artificial reef designs within a block (N = 6 modules per block). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different blocks and the natural reference reefs Barn (B) and San Mateo (SM). Means of blocks that were within the critical range were considered similar to the reference reefs. The ranges for the Universe approach were set by the mean values of SM and B. The ranges for the Sample approach were set by the 95% confidence limits of the mean of SM and B (N = 14 stations). Data were transformed ($\log_{10}$ [x+1]) for analysis and back transformed for plotting.



**Results—Unoccupied hard substrate**

Physical and biological disturbance generally create bare space on shallow reefs by removing or killing sessile organisms (Sousa 1984, Foster and Schiel 1985). Consequently the amount of bare or unoccupied space on the artificial reef modules could be viewed as a proxy for the intensity and/or frequency of disturbance. The amount of unoccupied hard substrate on the artificial reef modules during the period 2000 to 2004 was nearly constant for all artificial reef designs, averaging between 10 to 20% for all years suggesting that there was little temporal variation in disturbance during this period (Figure III.D. 17a). As expected, the percent of the total bottom substrate (i.e., artificial hard, natural hard and soft substrates combined) that was unoccupied by reef biota varied among modules with different coverages of hard substrate, but not among modules with different types of hard substrate (Figure III.D.17b). The percentage of free space on the two reference reefs was intermediate between that of artificial reef designs with low- and medium-substrate coverage.

There was a strong negative relationship between the percent of unoccupied space on the bottom and the bottom coverage of artificial substrate (Figure III.D.18a, slope = -0.79), and a very weak negative relationship between the percent of artificial substrate that was unoccupied and the bottom coverage of artificial substrate (Figure III.D.18b, slope = -0.08). Our interpretation of these patterns is that the coverage of understory algae and sessile invertebrates on the bottom was determined by the percent of the bottom covered by artificial substrate. In addition, the amount of artificial substrate covered by understory algae and sessile invertebrates varied independently of the bottom coverage of artificial substrate. These results suggest that sessile organisms living on modules with different coverages of artificial substrate experienced similar rates of disturbance.

Smaller-sized substrates have a higher probability of being moved by wave action than larger-sized substrates, and thus are likely to be more frequently disturbed. However, we found that substrate size had little effect on the percent cover of unoccupied space, sessile invertebrates and understory algae on quarry rock substrates (Figure III.D.19). In contrast, there was a trend on concrete modules for the percent cover of unoccupied space to decrease and the percent cover of sessile invertebrates to increase with substrate size (Figure III.D.19). The observations on concrete modules are consistent with the hypothesis that larger-sized substrates are less frequently disturbed and suggest that substrate size may be important in determining benthic community structure on artificial reefs constructed of rubble concrete, but not of quarry rock.

Figure III.D.17. The percent cover of (a) artificial substrate and (b) total bottom substrate (artificial hard, natural hard and soft substrates combined) that was unoccupied by understory algae and sessile benthic invertebrates. Data are annual means (± SE) for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM).

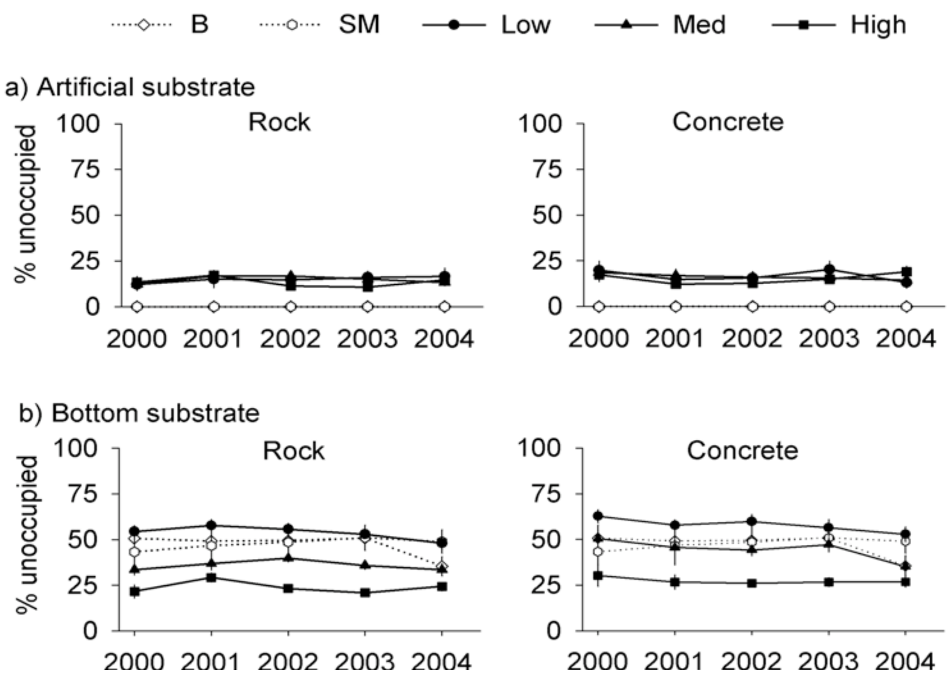



Figure III.D.18. Relationship between the percent cover of artificial substrate and the percent of unoccupied space on (a) the bottom (soft and hard substrates combined) and (b) artificial substrate. Data are annual means of the artificial reef modules of all six artificial reef designs for the period 2000–2004. N = 42 modules per year.

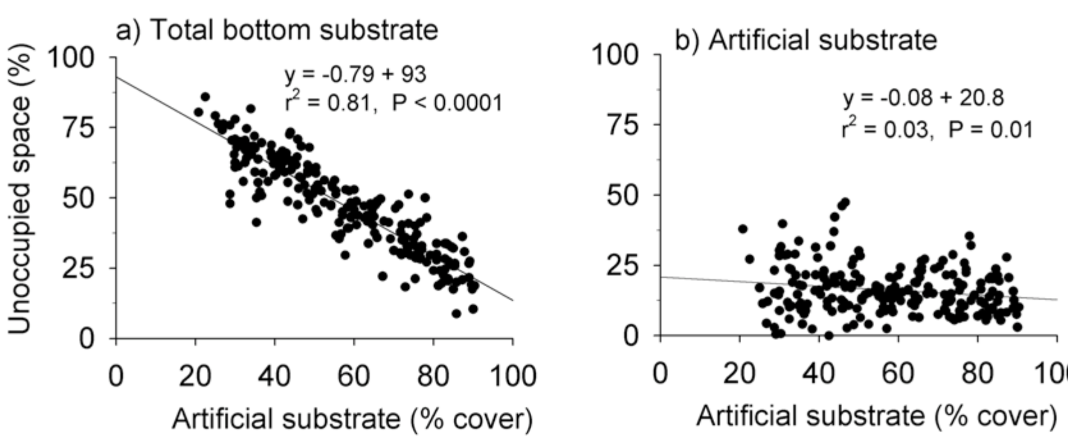
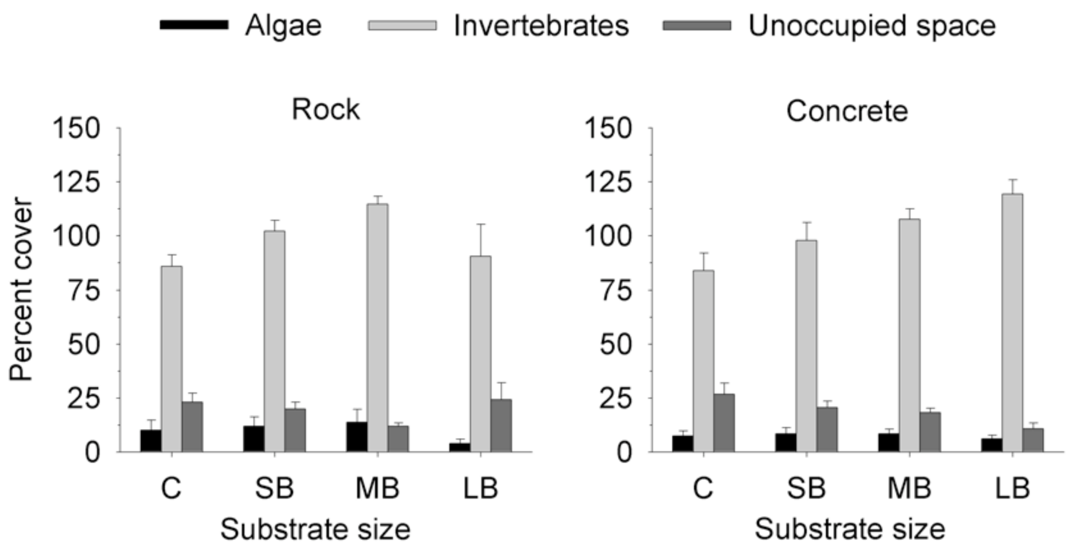


Figure III.D.19. Mean (± SE) percent cover of understory algae, sessile invertebrates and unoccupied space on different sized rock and concrete substrates in the summer of 2004. Substrate sizes (i.e., lengths) are as follows C = cobble (7–25 cm), SB = small boulder (26–49 cm), MB = medium boulder (50–99 cm), and LB = large boulder ( $\geq$ 100 cm).



**Results—Undesirable and invasive species**

Colonization by the sea fan *Muricea* spp.

One of the more notable undesirable or invasive species on shallow artificial reefs in Southern California is the sea fan *Muricea* spp. It is known to occur at high densities and exclude kelp, understory algae and other sessile invertebrates. Of particular concern to the SONGS artificial reef mitigation project is the ability of *Muricea* to withstand disturbance and ultimately displace giant kelp, which appears to have happened at nearby Pendleton and Torrey Pines artificial reefs (Patton et al., 1996; Deysher et al., 2002).

The concern about the potential for *Muricea* domination on SCAR was heightened in the winter of 2002 when large numbers of small recruits (i.e., ~1 cm tall) of *Muricea californica* (and fewer numbers of *M. fruticosa* recruits) were observed on the artificial reef modules. By the summer of 2002, the mean density of *Muricea* recruits was near or above 10 $m^{-2}$ on all artificial reef designs (Figure III.D.20). In contrast, relatively low recruitment of *Muricea* was observed on the nearby reference reefs at Barn and San Mateo. The recruitment of sea fans was greatest in Block 1 (i.e., the southern-most location closest to San Mateo) and declined with increasing distance to the north (Figure III.D.21). Substantial recruitment of *Muricea* was also observed in 2003 with lesser amounts in 2004 indicating that sea fan recruitment in the region of SCAR may occur regularly.

Growth and survivorship of Muricea

By the summer of 2003 the *Muricea* recruits on SCAR had grown to five to ten cm in height and consisted of multiple branches. In June 2003, 116 *Muricea* colonies were marked with uniquely numbered tags (Floy Tag and Manufacturing, Inc. Model FD-94) and their growth and survivorship were followed over time. Tagged sea fans were located in permanent quadrats of the low-, medium- and high-cover rock modules of Block 1 and included colonies from both the 2002 and 2003 year class. All marked colonies were photographed in the summers of 2003 and 2004, and the images were digitized in the laboratory to estimate colony height, width and surface area. There was a tendency for sea fan growth to decline as the bottom cover of rock increased (Figure III.D.22). The mean increase in the total amount of surface area of a colony was two to three times greater in the 2002 cohort compared to the 2003 cohort indicating that absolute growth was greater in older larger colonies (Figure III.D.22a). The rate of growth was faster in younger smaller colonies, however, as the relative increase in surface area of a colony was 25 to 50% greater in the 2003 cohort compared to the 2002 cohort (Figure III.D.22b). Despite the trend for density to be higher and growth to be lower on modules with higher rock cover (Figures III.D.20, and III.D.22), growth was unrelated to the local density of sea fans (Figure III.D.23). This finding suggests that the physical characteristics associated with a lower coverage of rock provided more favorable conditions for *Muricea* growth.

By the summer of 2004 the size structure of *Muricea* was similar and relatively uniform on all six artificial reef designs (Figure III.D.24) indicating that any differences in growth related to the cover of artificial substrate did not alter the subsequent size structure of sea fan populations. It is important to note that the size structure data are likely to be much more robust than the growth data given the large discrepancy in the sample size between these two measures ($N_{size\ structure}$ > 800 colonies per reef design vs. $N_{growth}$ = 10 to 32 colonies per reef design). In the summer of 2004, 2 ½ years after the initial colonization of sea fans, 40% of *Muricea* colonies on the artificial reef modules were > 6 cm tall, and 10% were > 15 cm tall. Sea fans were considerably larger (and older) at Barn and San Mateo where 70% of *Muricea* colonies were > 6 cm tall and 40% were > 15 cm tall.

*Muricea* experienced relatively high survivorship on the artificial reef modules. The percent of tagged colonies surviving from 2003 to 2004 typically averaged 80% or more for the 2002 cohort and slightly less for the 2003 cohort (Figure III.D.25). Survivorship was largely independent of the bottom cover of rock, rock size, substrate slope and sea fan density (Figures III.D.25, III.D.26, and III.D.27). The one exception to this pattern was the 2003 cohort on high-cover rock modules, which had a much lower survival rate of 40% (Figure III.D.25). That the 2002 and 2003 cohort had similar survival rates from 2003 to 2004 for two of the three reef designs suggests that little mortality occurred after the first year in the 2002 cohort and, in the case of low- and medium-cover rock modules, conditions for sea fan survival did not vary much between years. It should be noted that the survivorship data presented here are based on relatively small sample sizes and should be viewed with caution.

Patterns of abundance

Continuous recruitment of *Muricea* coupled with relatively high survivorship enabled it to persist at relatively high densities on SCAR since 2002. By 2004 *Muricea* density averaged 10 or more colonies $m^{-2}$ of bottom for all artificial reef designs (Figure III.D.28). Sea fan density at this time was unrelated to the type and cover of artificial substrate ($F_{1,35}$ = 3.37, P = 0.075 for type, and $F_{2,35}$ = 1.80, P = 0.181 for cover; Figure III.D.28), inversely related to distance from San Mateo ($F_{1,35}$ = 113.8, P <<0.0001, Figure III.D.29), and unrelated to module depth (Figure III.D.30). Although the densities of *Muricea* on the artificial reef modules at the end of the five-year experiment were quite high, most individuals were still relatively small and collectively covered less than 2% of the bottom on all artificial reef designs (Figure III.D.31). In 2004 the percent cover of *Muricea* on five of the six artificial reef designs (low-coverage concrete being the exception) was within the range observed at the two reference reefs. Even in Block 1 where sea fan densities exceeded 30 $m^{-2}$ (Figure III.D.29), the percent cover of *Muricea* was only slightly greater than 3%. (Figure III.D.32).

Potential for dominance by *Muricea*

As mentioned above, a genuine concern to the SONGS artificial reef mitigation project is the ability of *Muricea* to withstand disturbance and ultimately displace giant kelp and other reef biota. It has been hypothesized that higher rates of disturbance favor giant kelp because it removes longer-lived and slower-growing competitors like *Muricea* (Patton et al. 1996). Moreover, it has been argued that *Muricea* is susceptible to damage from sand scour, and low-relief reefs having a low coverage of hard substrate may increase rates of disturbance from sand scour and thus be more likely to prevent dominance by *Muricea*. We found little evidence to support this hypothesis. The percent of unoccupied space on hard substrate (our best indicator of disturbance intensity) was very weakly related to the coverage of hard substrate (Figure III.D.18b), while the density of *Muricea* was strongly **positively** related to the percent of unoccupied hard substrate (Figure III.D.33). Furthermore, we found no difference in the density of *Muricea* in quadrats located in the middle of the module vs. those closer to the perimeter where disturbance from sand scour is expected to be higher (Figure III.D.34). It is important to note that our results were obtained during a period of relatively calm conditions that lacked extraordinarily large wave events. Consequently, disturbance to *Muricea* and other reef biota was likely less severe than during periods characterized by much greater wave activity (e.g., 1983), and the extent to which substrate coverage interacts with sand scour to adversely affect *Muricea* in more severe disturbance regimes remains unknown.

Ambrose (1987), working under the auspices of the CCC's Marine Review Committee, surveyed the abundance of *Muricea* and *Macrocystis* on 26 artificial and natural reefs in Southern California and found that giant kelp was sparse or absent on reefs having sea fan densities > 10 $m^{-2}$, suggesting that there may be a threshold density of *Muricea* above which *Macrocystis* is excluded (Figure III.D.35). Although the densities of *Muricea* on the artificial reef modules in 2004 were at or above 10 $m^{-2}$, the colonies were still too small (Figure III.D.24) and occupied too little space on the bottom (Figures III.D.31, III.D.32) to exclude algae and other invertebrates. More data are needed to determine the threshold density and cover of *Muricea* above which kelp and other biota are excluded. It remains to be seen whether or not high densities of large sea fan colonies develop on the artificial reef modules. Our observations of frequent episodes of dense sea fan recruitment coupled with patterns of density independent growth and survivorship raise the distinct possibility that high densities of large *Muricea* may eventually dominate SCAR.

Summary of results for undesirable or invasive species

- High densities of the sea fan, *Muricea* recruited to SCAR in 2002 and 2003; lower densities recruited in 2004.
- The recruitment density of *Muricea* was not affected by the type of bottom cover of artificial substrate and was inversely related to distance from San Mateo, the nearest reference reef.
- Tagged sea fan colonies grew faster on modules with low bottom cover of rock than on modules where bottom cover was high. In addition, growth rates were unrelated to local sea fan density.
- The distribution of sizes of *Muricea* was very similar on modules of the different artificial reef designs, and sizes tended to be much smaller on the artificial reef compared to the reference reefs.
- The percent of tagged sea fan colonies surviving from 2003–2004 typically averaged 80% or more for the 2002 cohort and slightly less for the 2003 cohort. The one exception to this pattern was the 2003 cohort on high-cover rock, which had a much lower survival rate of 40%.
- *Muricea* survivorship was largely independent of the bottom cover of rock, rock size, substrate slope, and sea fan density.

- *Muricea* density (but not percent cover) on the artificial reef modules in 2004 was at or above densities known to exclude algae and other benthic invertebrates. Density was unrelated to substrate, type, cover and depth, and negatively related to distance from San Mateo.
- The data collected on sea fan recruitment, growth, and survivorship indicate that it is reasonable to expect that high densities of large *Muricea* will eventually invade the mitigation reef.

Figure III.D.20. Change in the mean (± SE) density of *Muricea* recruits over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). N = 7 artificial reef modules or reference reef locations.

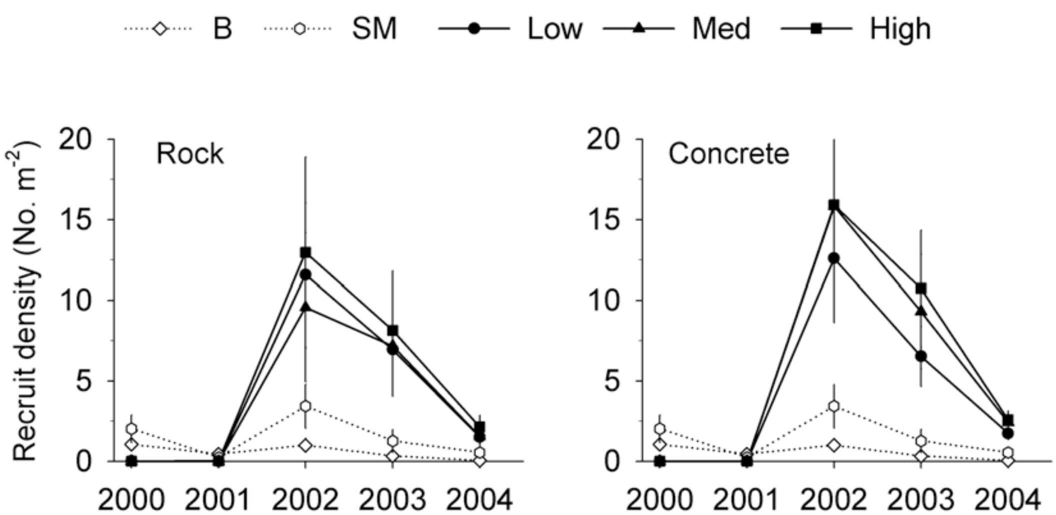



Figure III.D.21. Mean (± SE) density of *Muricea* recruits on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef.

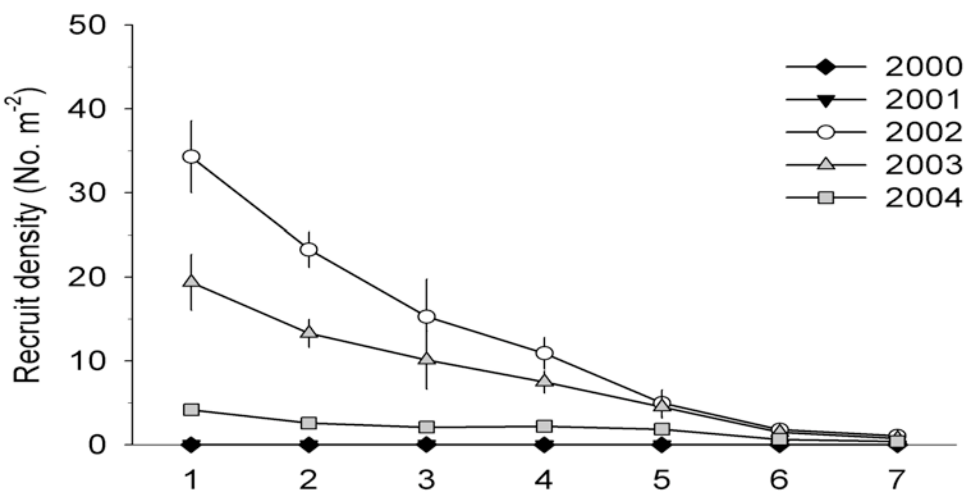


Figure III.D.22. Mean (± SE) increase in per capita colony area for tagged *Muricea* that recruited to SCAR in 2002 and 2003. (a) Absolute growth measured in $cm^2$, (b) Relative growth measured as a percent increase in colony area. Data are from tagged colonies in permanent quadrats of modules in Block 1 with low, medium and high cover rock. Sample sizes for the different reef designs were 18, 12, and 10 colonies for the 2002 and 22, 34, and 20 colonies for the 2003 cohort for low, medium and high cover rock modules, respectively.

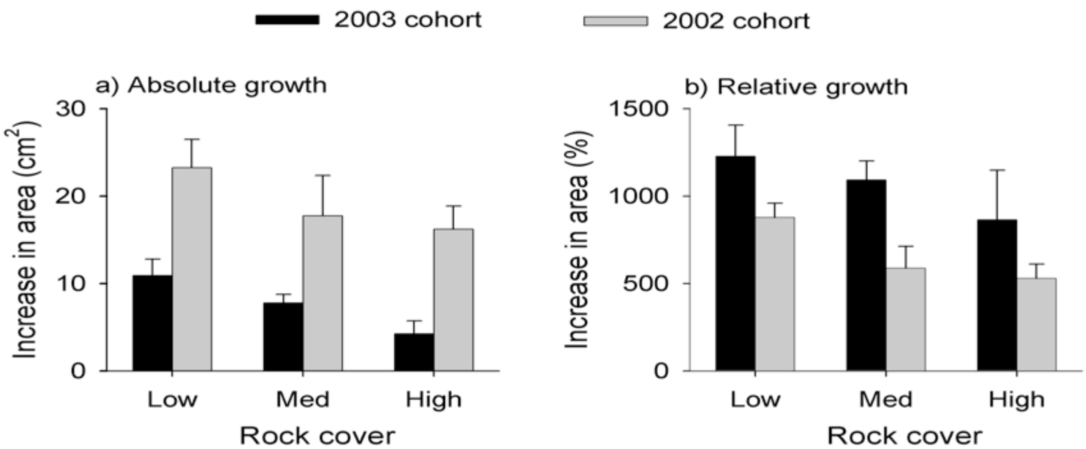



Figure III.D.23. Relationship between *Muricea* density and the absolute and relative increase in per capita colony area. Growth data are from tagged *Muricea* in fixed quadrats and density data are from all *Muricea* (tagged and untagged) in the same fixed quadrats.

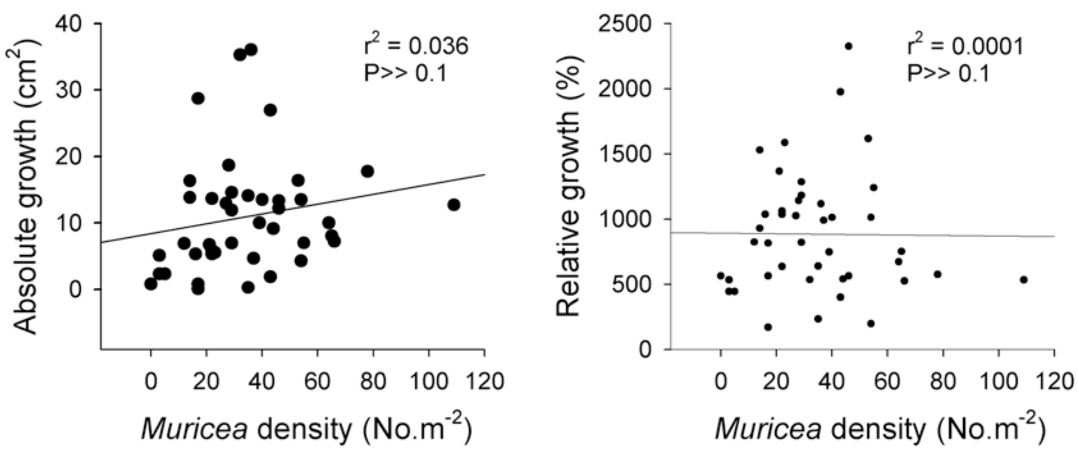


Figure III.D.24. Size structure of *Muricea* in the summer of 2004. Data are heights (cm) of colonies sampled in permanent quadrats on artificial reef modules of the six reef designs and at the reference reefs Barn (B) and San Mateo (SM). Sample sizes (i.e., number of colonies) for the different reef designs are as follows: 863 low rock, 807 medium rock, 973 high rock, 796 low concrete, 1123 medium concrete, 1380 high concrete, 74 B, and 178 SM.

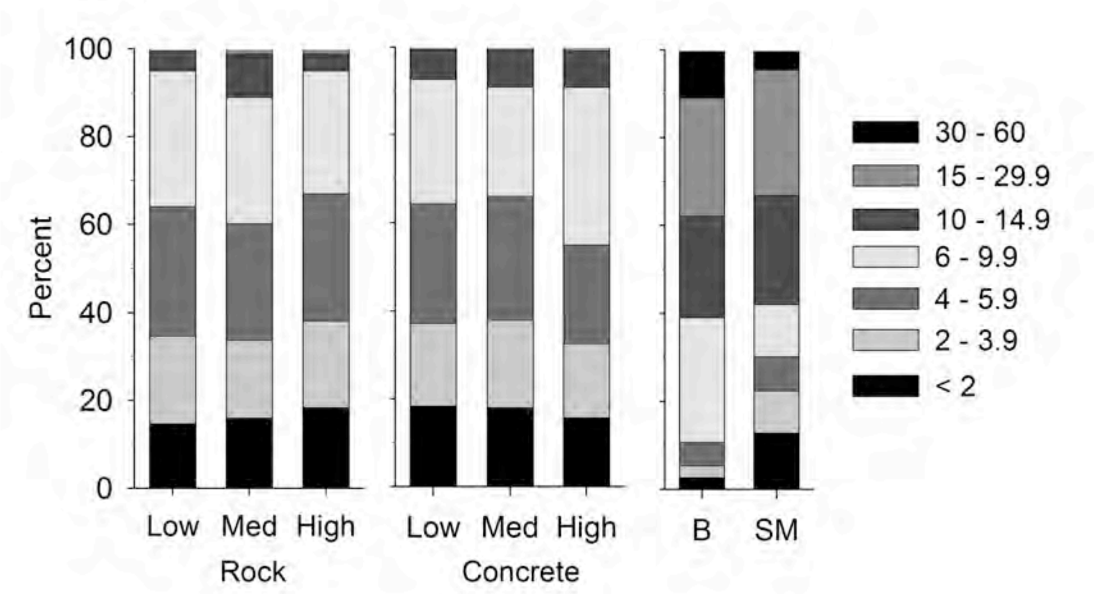



Figure III.D.25. Percent of *Muricea* surviving to the summer of 2004 for artificial reef designs with different rock coverages (low, medium and high). Sample sizes (number of colonies initially tagged) are shown at the top of each bar.

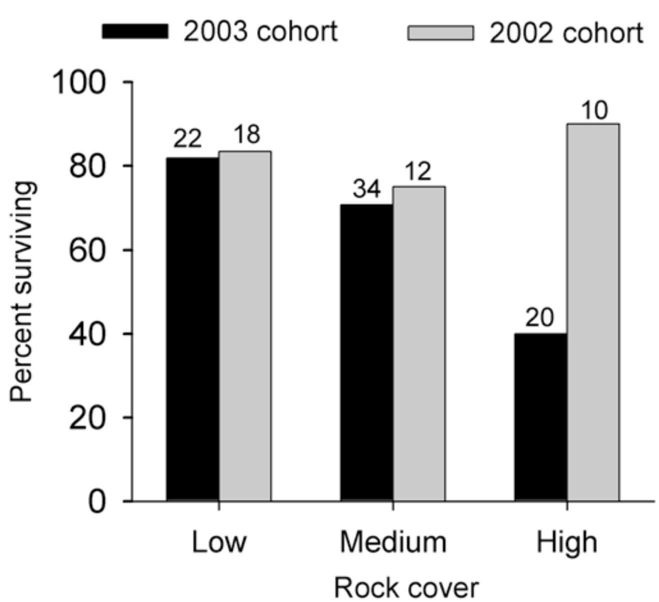


Figure III.D.26. Percent of tagged *Muricea* surviving to 2004 as a function of (a) substrate size and (b) substrate slope for the 2002 and 2003 cohorts. Sample sizes (i.e., number of colonies) are given above each bar. Abbreviations for substrate size are as follows: C = cobble, SB = small boulder, MB = medium boulder, LB = large boulder.

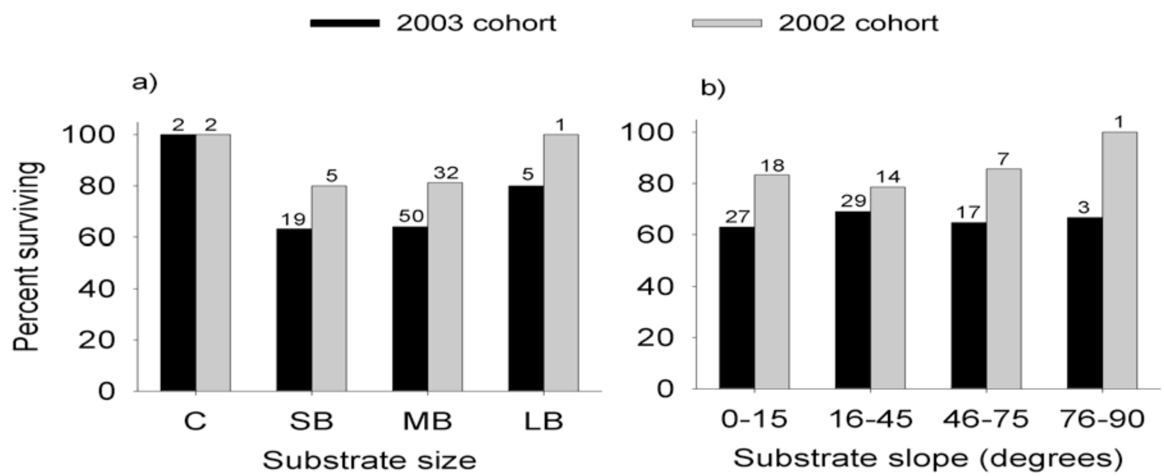



Figure III.D.27. Relationship between *Muricea* density and survivorship. Survivorship data are from tagged *Muricea* in fixed quadrats and density data are from all *Muricea* (tagged and untagged) in the same fixed quadrats.

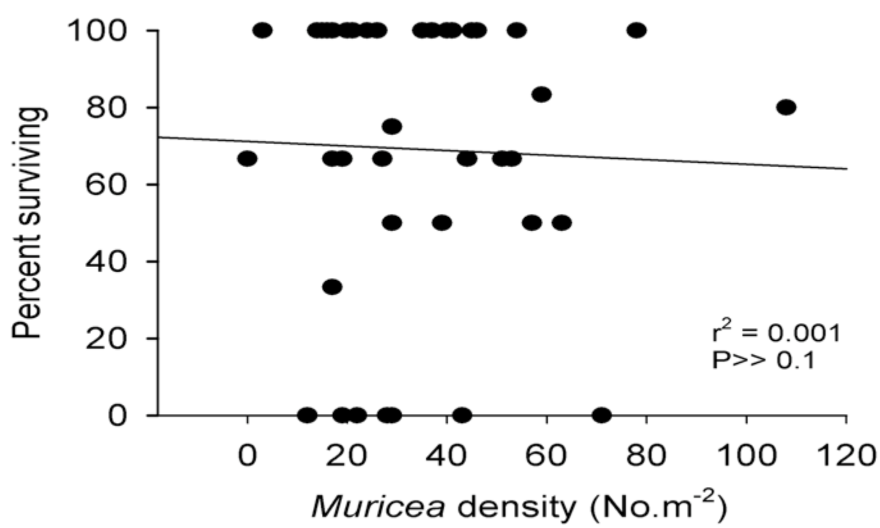


Figure III.D.28. Change in the mean (± SE) number of *Muricea* (all year classes combined) per $m^2$ of bottom over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). N = 7 artificial reef modules or reference reef locations.

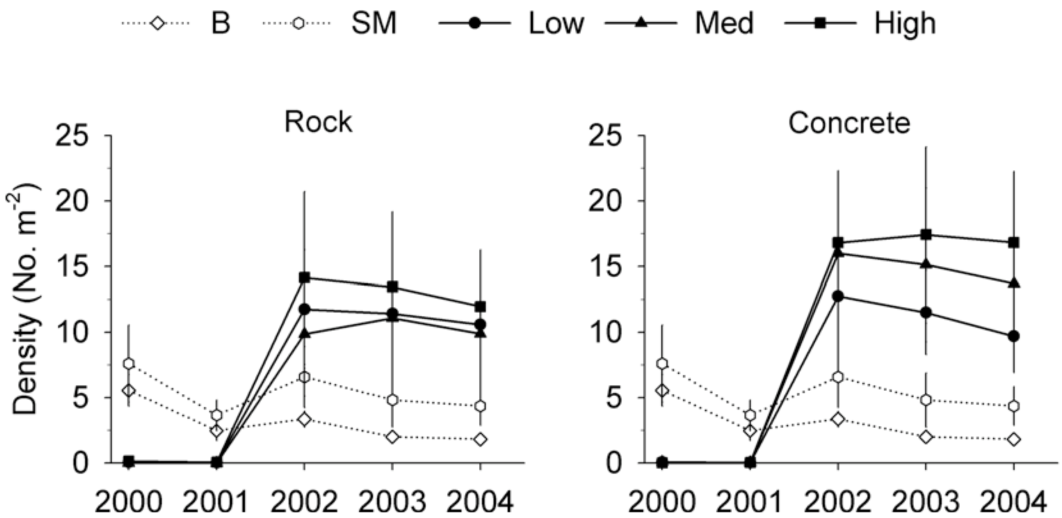



Figure III.D.29. Mean (± SE) density of *Muricea* (all year classes combined) per $m^2$ of bottom on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from the San Mateo, the nearest reference reef.

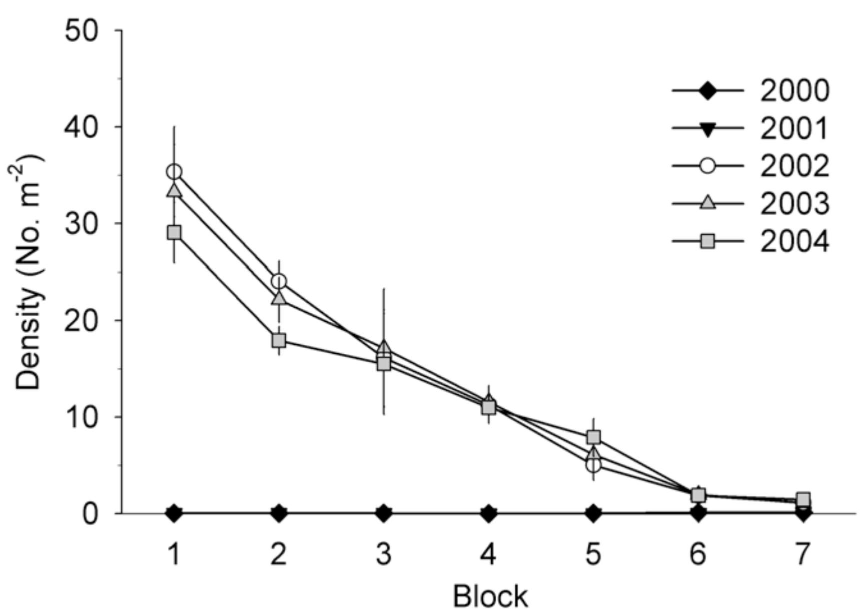


Figure III.D.30. Relationship between *Muricea* density and depth of module. Data are means of modules in 2004 averaged across quadrats (n = 12 quadrats per module).

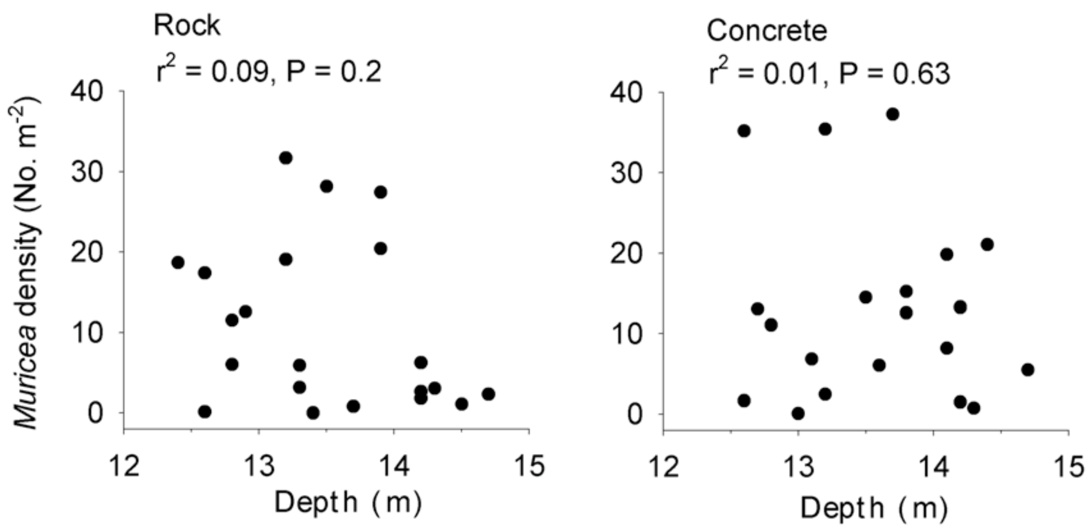



Figure III.D.31. Change in the mean (± SE) percent cover of *Muricea* over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium and high) and for the reference reefs Barn (B) and San Mateo (SM). N = 7 artificial reef modules or reference reef locations.

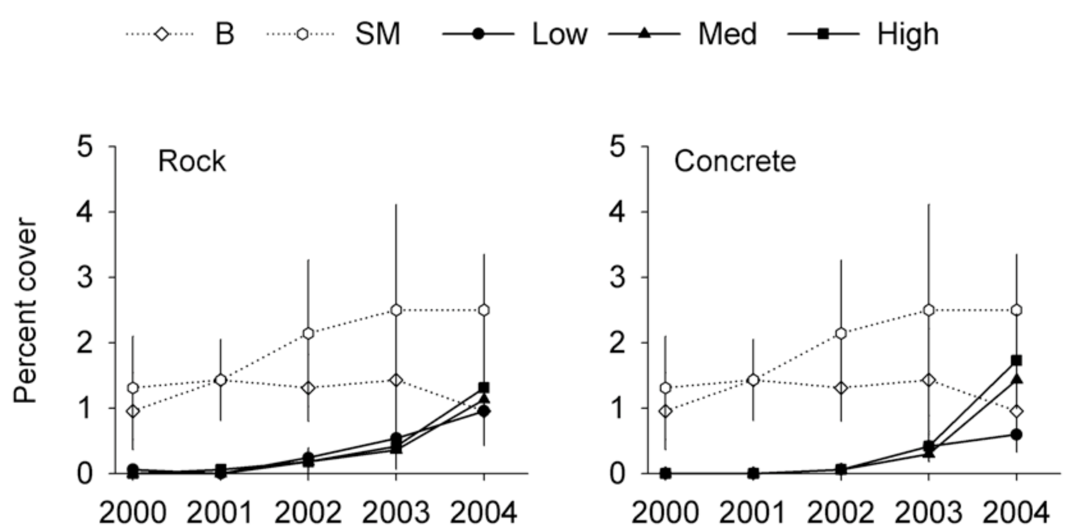


Figure III.D.32. Mean (± SE) percent cover of *Muricea* on the different blocks of artificial reef modules for the years 2000–2004. Blocks are numbered 1 to 7 from south to north and vary linearly with distance from San Mateo, the nearest reference reef.

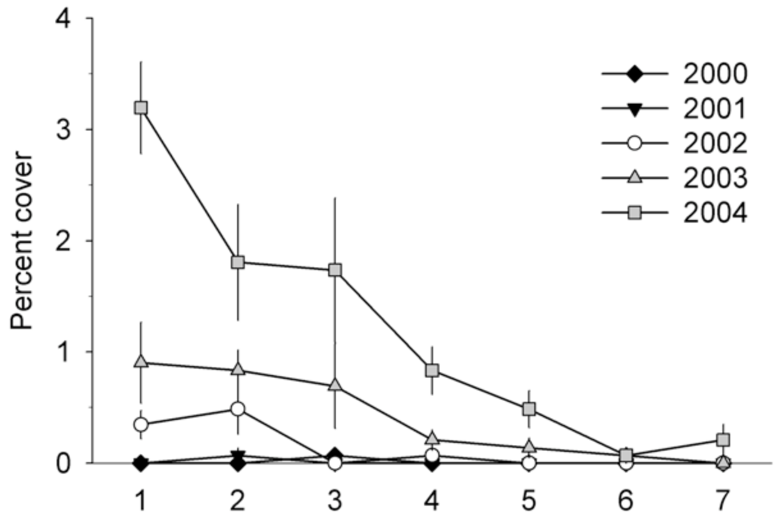



Figure III.D.33. Relationship between the density of *Muricea* and the percent cover of unoccupied hard substrate. Data are from 2004 and represent means of the 42 artificial reef modules.

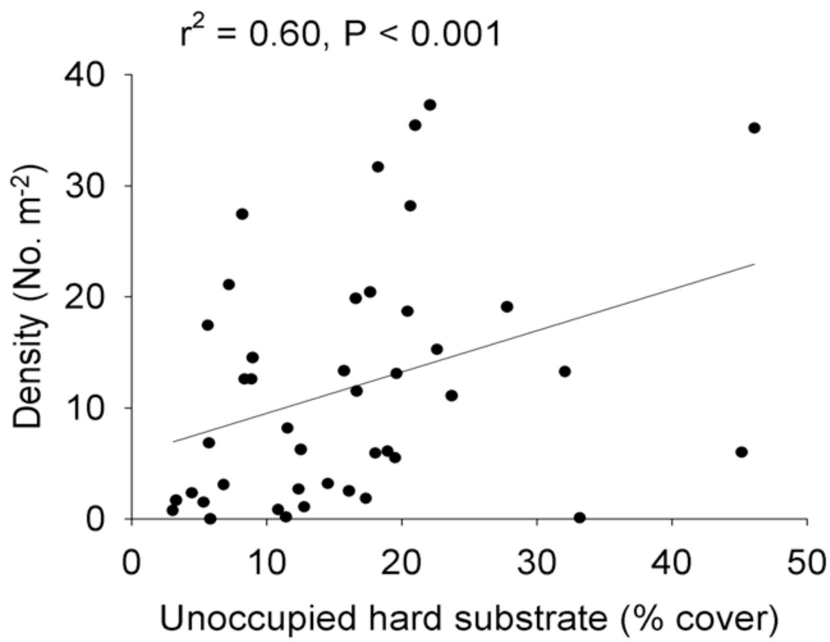


Figure III.D.34. Mean (± SE) density of *Muricea* on hard substrate in 1-$m^2$ quadrats located near the outer edge and in the middle of the artificial reef modules. Edge quadrats were located four to six meters from the module perimeter and middle quadrats were located 17 m from the perimeter. N = 168 quadrats for edge and middle.

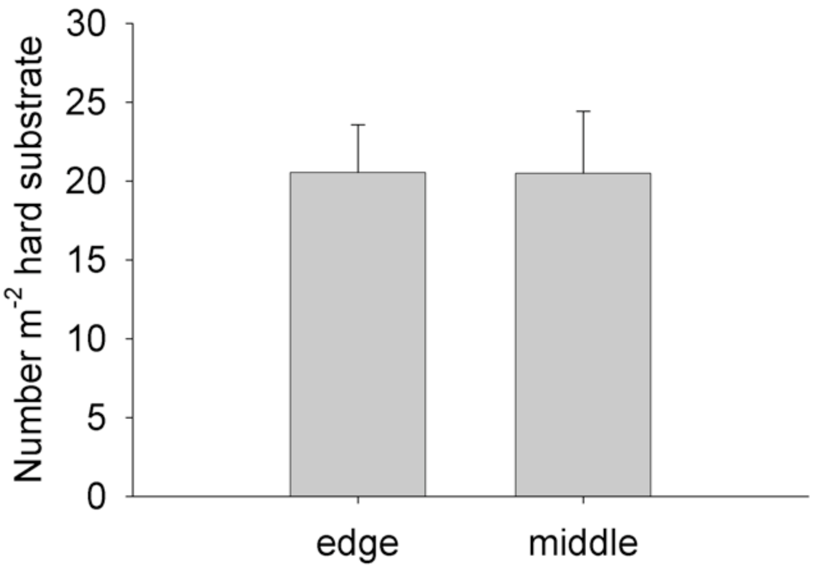
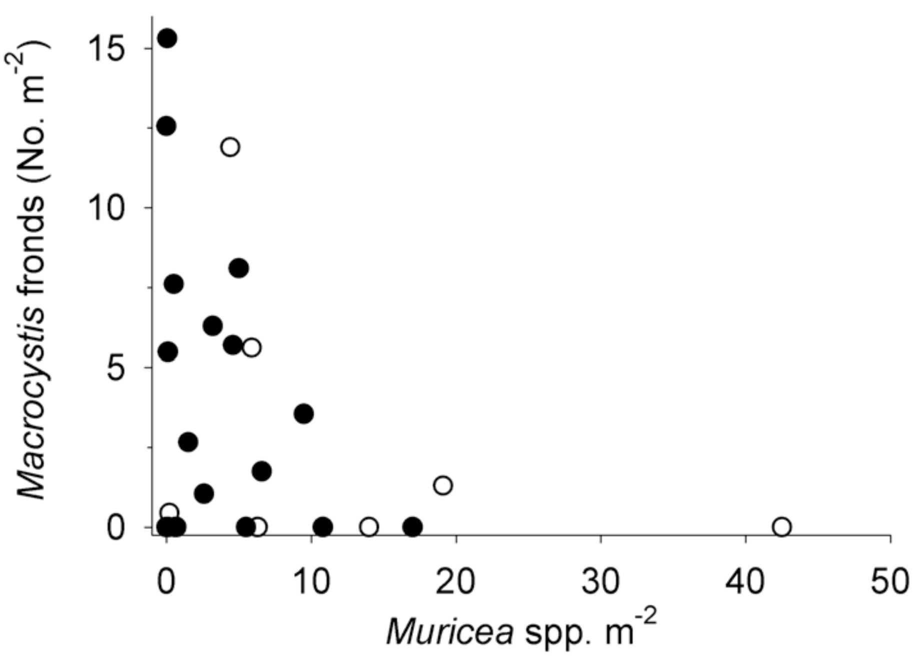



Figure III.D.35. The relationship between the mean density of *Muricea* and the mean density of giant kelp fronds. Data are from 26 artificial and natural reefs in Southern California (Ambrose, 1987). Solid circles represent natural reefs, open circles represent artificial reefs.



## *E. LONG-TERM SUSTAINABILITY OF GIANT KELP AND UNDERSTORY ALGAE.*

In order for the mitigation reef to be successful it must "sustain" 150 acres of medium- to high-density giant kelp. For populations to be sustainable, the recruitment of new individuals must balance the loss incurred by the death of established individuals. A large cohort of giant kelp recruited to SCAR during the first year following construction. Individuals from this cohort grew to adulthood by the summer of 2001 and have gradually declined in abundance since then (Figure III.B.4). Importantly, there has been little recruitment of new plants in many areas of the reef since the initial colonization event in 2000 (Figures III.B 10 and II.B.11). It is difficult to evaluate the potential for the different reef designs to support sustainable populations of giant kelp in the absence of disturbances that led to substantial adult mortality and subsequent recruitment during the five-year experimental phase.

The SONGS coastal development permit also requires the mitigation reef to support an understory algal assemblage that is similar in abundance and species number to natural reefs in the region. Like giant kelp, understory algae also rapidly colonized SCAR and their abundance and species number on all artificial reef designs and locations rapidly reached levels that were within the ranges of those observed on San Mateo and Barn (Figures III.D.1 and III.D.2). The abundance and species richness of understory algae drastically declined since 2001, and by 2004 they were uncommon on SCAR and well below the values observed on the reference reefs (Figures III.D.7 and III.D.8). Meanwhile, benthic sessile invertebrates (the other prime occupier of primary space on the reef) increased in abundance over time on SCAR (Figures III.D.9, III.D.10), and in the case of the medium and high substrate cover designs, were consistently well above the levels observed on the reference reefs (Figures III.D.15 and III.D.16).

Two of the more likely reasons for sparse kelp recruitment and the decline in understory algae on SCAR are increased competition for space with sessile invertebrates, and increased competition for light due to excessive shading by dense kelp canopies. The expectations for these two mechanisms would be different if they were responsible for producing the observed patterns on SCAR. For example, if low kelp recruitment and understory algal abundance resulted from sessile invertebrates out-competing algae for space, then one would expect: (1) an inverse relationship between the percent cover of sessile invertebrates and understory algae, (2) an inverse relationship between the percent cover of sessile invertebrates and density of kelp recruits, and (3) little hard substrate available for colonization by giant kelp and understory algae. On the other hand, if shading by dense kelp canopies were responsible for the sparse kelp recruitment and the decline in understory algae on SCAR, then one would expect the density of kelp recruits and the percent cover of understory algae to be inversely related to the density of giant kelp fronds.

To avoid costly errors when designing the mitigation reef, it is important to understand which mechanisms are most responsible for causing the decline of understory algae and the lack of continued kelp recruitment on SCAR. In the absence of large, natural disturbances during the five-year experiment, this understanding can only come about by experimental manipulations that isolate the effects of competition with sessile invertebrates from the effects of shading by giant kelp.

Experimental design

In the spring of 2004 we initiated a 2 x 2 factorial experiment using the kelp transplant modules constructed with a medium cover of quarry rock (Figure III.E.1). Annual sampling of these modules was discontinued in 2001 after kelp transplant techniques were developed and tested (see II.E. *MONITORING*). Thus the use of these artificial reef modules in this experiment did not affect our ability to evaluate the five-year time series for the six combinations of substrate type and cover that were tested in the experimental phase of the artificial reef mitigation project. The surface canopy of kelp was manipulated on six of the seven kelp transplant modules by cutting off all kelp fronds 1 meter above the holdfast (one of the kelp transplant modules was used in a different experiment that investigated the timing of colonization on community development (see *F. FACTORS INFLUENCING BENTHIC SPECIES COMPOSITION*). The benthic assemblage of invertebrates and algae was removed with scrapers in six 1-m$^2$ quadrats on each of the six kelp transplant modules. Another six 1-m$^2$ quadrats on each module were left undisturbed. The six nonkelp transplant modules of medium cover of quarry rock (i.e., the modules used to test the suitability of medium cover of rock in the mitigation phase) were used as kelp canopy control plots for this experiment. Six scraped and six undisturbed 1-m$^2$ quadrats were followed on each on these modules as well. The scraped quadrats on the nonkelp transplant modules were located on transects that were no longer used in the routine monitoring of the experimental reef, which again was designed to preserve the five-year time series of the six reef designs tested in the experimental phase. Kelp removal and quadrat scraping were completed in March 2004. The cover and density of algae and invertebrates in all quadrats and the density of giant kelp fronds along all transects used in the experiment were sampled in July and November 2004. Increases in the cover of understory algae and density of kelp recruits on modules where kelp was removed would indicate a canopy shading effect, whereas greater abundances of algae in scraped vs. un-scraped quadrats would indicate that competition for space with invertebrates contributed to the declining abundance of algae on SCAR.

Results

The abundances and species richness of understory algae in July 2004 was uniformly low on quarry rock modules and significantly less than that observed on the reference reefs (Figures III.E.2a). By contrast, algal cover at this time had increased to 44% in plots in which the kelp canopy had been cleared and the bottom had been scraped (Cleared / Scraped in Figure III.E.2a). Removal of only kelp (Cleared / Un-scraped) or the benthic assemblage (Uncleared / Scraped) resulted in substantially lower cover of understory algae (10% and 7% respectively) at this time. Algal abundance was lower still in un-manipulated quadrats (Uncleared / Un-scraped). It remained low and similar to that on the un-manipulated rock modules through November 2004.

Unlike understory algae, the percent cover of benthic invertebrates in July 2004 was relatively high on quarry rock modules and substantially greater than that observed on the reference reefs (Figures III.E.2b). The removal of invertebrates in scraped quadrats in

March 2004 coupled with relatively slow rates of re-colonization resulted in significantly higher percent cover of invertebrates in un-scraped quadrats in July 2004 relative to scraped quadrats, which is the opposite pattern of that observed for understory algae. The recovery of sessile invertebrates in scraped quadrats was faster on modules that had not been cleared of kelp indicating that the kelp canopy has a negative effect on the colonization of sessile invertebrates (this may have been an indirect effect of removing kelp that led to increased competition with understory algae). Clearing kelp had little effect on the percent cover of invertebrates in un-scraped quadrats.

Patterns of species richness of algae and invertebrates followed those observed for abundance. Scraping the bottom and clearing kelp had additive effects on species richness of algae with the greatest number of species observed in the Cleared / Scraped quadrats and the least number in the Uncleared / Un-scraped quadrats (Figure III.E.3a). Clearing kelp tended to have a larger effect on algal diversity than scraping the substrate. Both scraping the bottom and clearing kelp had negative effects on invertebrate species richness (Figure III.E.3b). Interestingly, the abundance and species richness of invertebrates recovered more rapidly in Uncleared / Scraped quadrats than in Cleared / Scraped quadrats, which is the opposite pattern observed for algae.

Low densities of *Macrocystis* recruits (i.e., $< 2\ m^{-2}$) were observed on all unmanipulated quarry rock modules in July 2004, while high densities of kelp recruits were observed at the reference sites (Figure III.E.4). Clearing kelp and scraping the bottom had large positive effects on giant kelp recruitment. The response of giant kelp recruitment to the experimental manipulations was similar to those observed for understory algae; Cleared /Scraped > Cleared / Un-scraped > Uncleared / Scraped > Uncleared / Un-scraped. The positive response of kelp recruitment to clearing the canopy undoubtedly resulted from more than a two-fold increase in the amount of light reaching the bottom (Figure III.E.5). Importantly, bottom irradiance on the cleared modules increased above the critical level of 1% surface light, which is minimum level needed for kelp recruitment to occur (Luning 1981).

Collectively these results indicate that shading by the kelp canopy and competition for space with sessile invertebrates has adverse effects on understory algal development and giant kelp recruitment and likely played an important role in contributing to the steady decline in the abundance and species richness of understory algae and the sparse recruitment of giant kelp observed on SCAR during the period 2001–2004.

Summary of experimental results for sustainability

- The removal of kelp increased bottom irradiance to levels known to promote kelp recruitment.
- Clearing kelp and scraping the bottom had positive additive effects on understory algal abundance and species richness, and on the density of giant kelp recruitment.
- Clearing kelp and scraping the bottom had negative effects on the abundance and species richness of benthic invertebrates.

- Shading by the kelp canopy and competition for space with sessile invertebrates has likely played an important role in contributing to the steady decline in the abundance and species richness of understory algae and the sparse recruitment of giant kelp observed on SCAR during the period 2001–2004.
- Results from this short-term experiment when coupled with data from the longer term five-year artificial reef experiment indicate that populations of giant kelp, understory algae and benthic invertebrates will likely be sustainable over the long term, but will undoubtedly undergo large fluctuations in absolute and relative abundance depending on the size and frequency of physical disturbance.

Figure III.E.1. Experimental design used to test the effects of the giant kelp canopy and percent cover of sessile invertebrates on the abundance and species richness of the understory alga and the density of giant kelp recruits at SCAR using the six kelp transplant modules constructed of a medium cover of quarry rock.

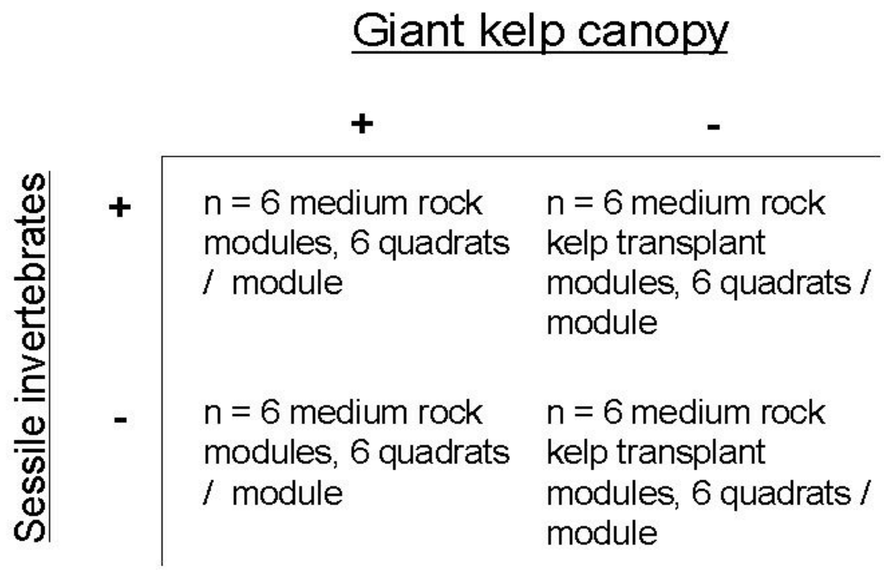



Figure III.E.2. Mean (± SE) percent cover of (a) understory algae and (b) benthic sessile invertebrates on unmanipulated quarry rock modules with low (L), medium (M) and high (H) cover of rock, the reference reefs Barn (B) and San Mateo (SM) and in quadrats of the four experimental kelp-clearing and bottom-scraping treatments.

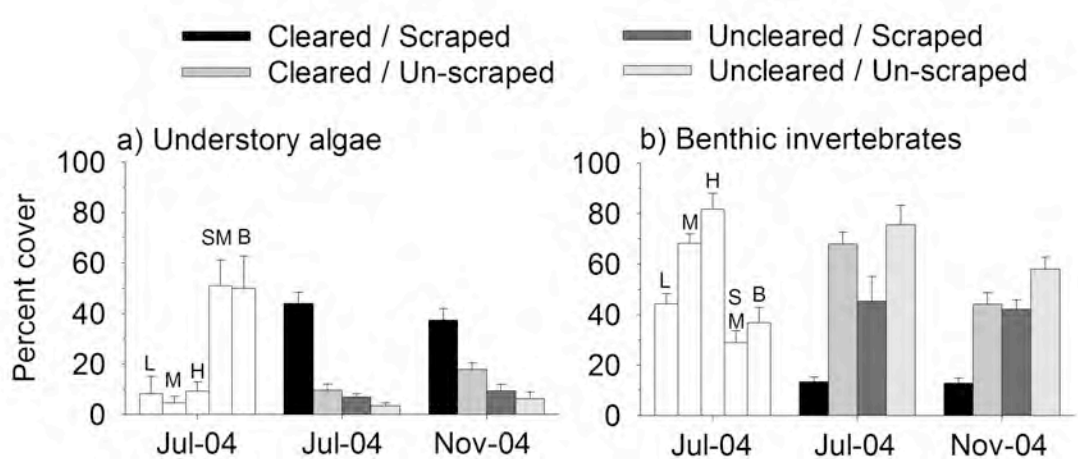


Figure III.E.3. Mean (± SE) species richness of understory algae and benthic sessile invertebrates at SCAR on unmanipulated quarry rock modules with low (L), medium (M) and high (H) cover of rock, the reference reefs Barn (B) and San Mateo (SM) and in quadrats of the four experimental kelp-clearing and bottom-scraping treatments.

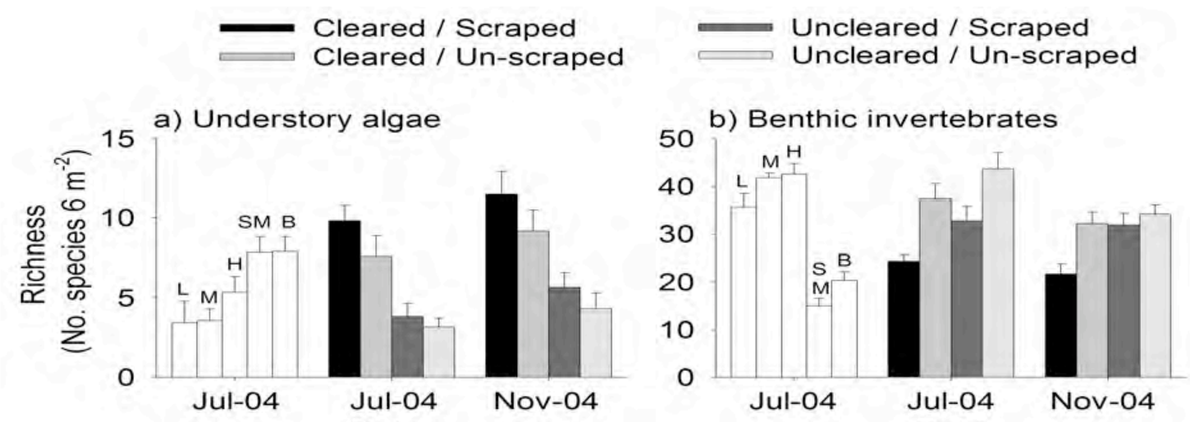



Figure III.E.4. Mean (± SE) density of giant kelp recruits at SCAR on unmanipulated quarry rock modules with low (L), medium (M) and high (H) cover of rock, at the reference reefs Barn (B) and San Mateo (SM) and in quadrats of the four experimental kelp-clearing and bottom-scraping treatments in July and November 2004.

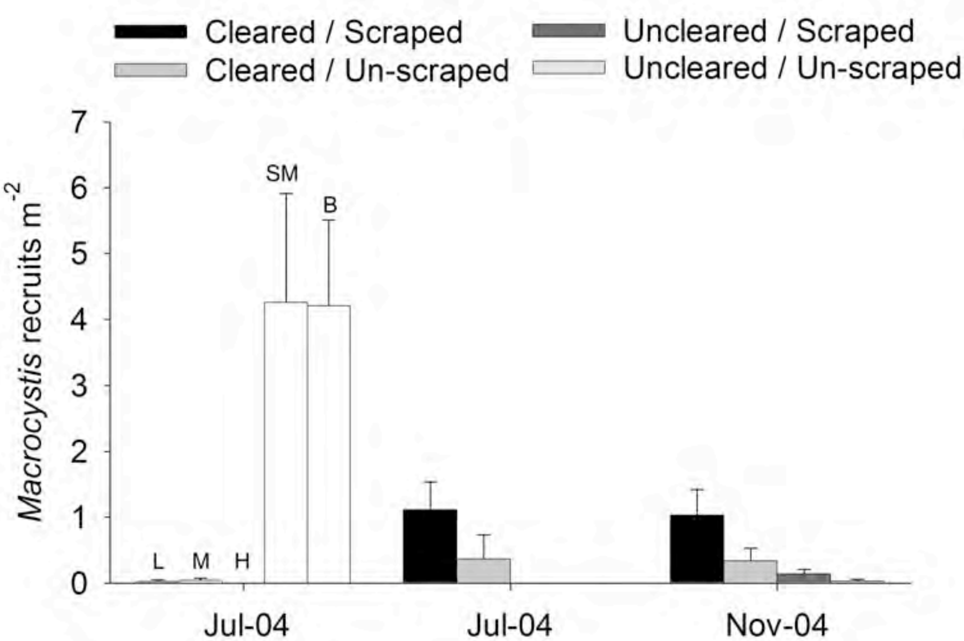
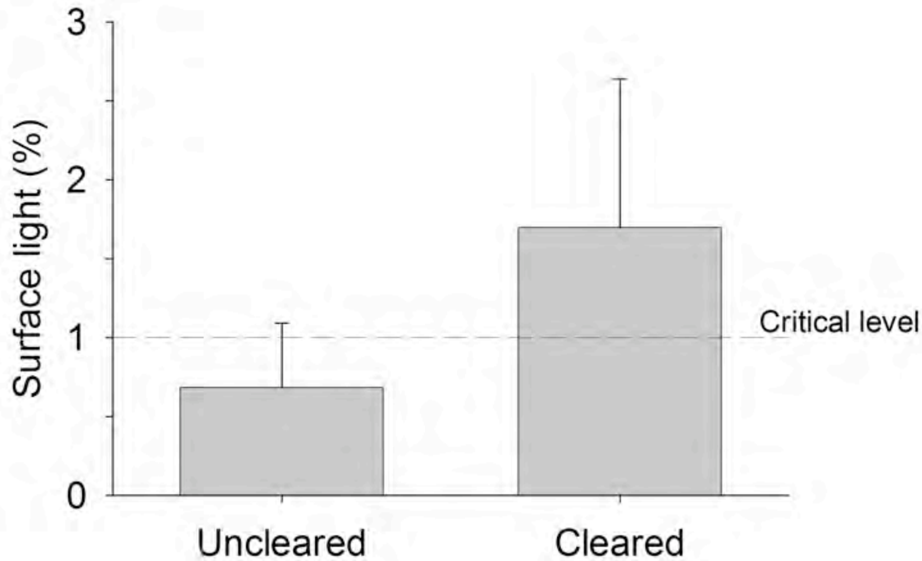


Figure III.E.5. Mean (± SE) percent of surface irradiance reaching the bottom on artificial reef modules cleared of giant kelp and on modules with natural densities of kelp (uncleared). Critical level represents the minimum level needed for kelp recruitment.



## *F. FACTORS INFLUENCING SPECIES COMPOSITION OF THE BENTHOS*

Unlike kelp forest fishes whose species composition on SCAR quickly resembled that of nearby natural reefs (Figure III.C.7), the species composition of understory algae and sessile invertebrates on SCAR and the reference reefs remained relatively dissimilar throughout the five-year experiment (Figures III.D.5, III.D.6, III.D.13, and III.D.14). In 2002 we proposed several mechanisms that could have led to differences in species composition of understory algae and benthic invertebrates observed between SCAR and the reference reefs (Reed et al. 2002), including:

1. Differences in successional stage between the recently constructed reef and established reference reefs
2. Seasonal and/or interannual differences in the pool of species available to settle when the artificial and natural reefs were colonized
3. Effects of location
4. Differences in substrate characteristics (e.g., artificial vs. natural substrates)

An experiment was initiated in March 2002 to determine whether substrate type (boulders of natural rock or quarry rock) or location (reference site vs. artificial reef) might account for the observed differences in relative species composition between SCAR and the reference reef at San Mateo.

**Methods**

In March 2002, ten three-boulder clusters were established at a location in the San Mateo kelp bed (SM), and on a module on the San Clemente Artificial Reef (SCAR). Each set was composed of three boulders of similar size, but of different origin and substrate type. They consisted of one transplanted scraped boulder (from SM to SCAR or vice versa), one scraped and one un-scraped local boulder (i.e., quarry rock on SCAR and natural rock on SM). These clusters were placed along the 5- and 15-meter transects at the kelp transplant module in Block 4, and along a location in SM. Community development and species composition were compared on undisturbed boulders at SCAR and SM to natural and artificial substrates from which all plants and animals were removed. These scraped substrates were either returned to their place of origin (transplant controls) or were transplanted to the other site (e.g., scraped quarry rock boulders were moved from SCAR to SM, and scraped natural boulders were moved from SM to SCAR).

Benthic invertebrates and algae on each rock were sampled approximately three times per year (March, July, and September). Solitary algae and invertebrates found on the surface of each boulder were counted, and the percent cover of sessile organisms was determined using a point contact grid that conformed to the contours of the rock. All solitary organisms, (e.g., juvenile understory kelps, urchins, and larger sessile invertebrates) on any part of a boulder's surface were counted. Often, mobile invertebrates and epiphytes were found above the sea floor on upright portions of algae. These were counted only if found at a height less than or equal to 25 cm above the rock's surface.

The percent cover of sessile invertebrates and algae was determined using a three-sided PVC frame. The frame was oriented on the bottom with the open face directed due east. The sides of the quadrat were equal in length and enclosed an area of 1 m x 1 m. Small link chain of indeterminate length was run from north to south over the surface of the boulder. Multiple parallel lengths of chain (separated by 10 cm) were sampled every 10 cm creating a nonplanar uniform grid of points over each boulder. Planar estimates of percent cover were estimated by noting the identity of points at each grid intersection. The angle of the substrate at each point was determined using an underwater level consisting of a graduated arc and a small piece of line attached to a float. These angles were categorized as vertical (90° ± 15°), approaching vertical (45° – 75°), approaching horizontal (15° – 45°), horizontal (0° ± 15°), and overhanging (angle less than vertical, facing the ground). The category of the substrate orientation, substrate, and all colonial invertebrates and algae were recorded at each grid point. The investigator also recorded 'rare' sessile species (i.e., those occurring in the quadrat but not in contact with the grid of points) on a separate datasheet. Sessile invertebrates and algae were considered rare if they were present on the rock, but were not intercepted by a point contact on the chain.

The effects of location of transplant destination (SCAR or SM) and substrate type (quarry rock or natural rock) on algal and invertebrate communities were assessed with data on percent cover in two ways. First, the similarity of algae and invertebrate communities in five treatments (SCAR Natural Scraped, SCAR Artificial Scraped, SCAR Artificial Un-scraped, SM Natural Scraped, and SM Artificial Scraped) were compared to un-scraped natural boulders at SM (SM Natural Un-scraped, = Control). Percent similarity (S) in species composition of algae and invertebrates was calculated using Czekanowski index of similarity (Pielou 1984) in which:

$$S = \sum_{i=1}^{n} \min (P_{Ci}, P_{Yi})$$

where $P_{Ci}$ is the relative abundance of species $i$ in the Control treatment and $P_{Yi}$ is the relative abundance of species $I$ in treatment $_Y$. Second, the relative abundances of the 10 most abundant species as well as the relative abundance of all remaining species combined (designated as "Other") were calculated for all treatments and the Control on the final survey. These were ranked from most to least abundant at the Controls and this ranking was used in the other treatments. These data were plotted as bar graphs and the treatments and Controls were compared graphically.

**Results**

Effects of substrate type and location on similarity of algal communities

The location to which the boulders were transplanted had a greater effect on the percent cover of understory algae than the type of boulder. Colonization of algae was equally low on scraped natural and quarry rock boulders (Figure III.F.1). Twenty-seven months after the start of the experiment, the percent cover of algae averaged less than 2% on scraped boulders placed at SCAR and about 5% on scraped boulders placed at SM. The cover of understory algae on un-scraped natural boulders placed at SCAR declined continuously over time from approximately 20% to 3%, while algal cover on un-scraped boulders placed at SM declined for the first 19 months from 20% to 10% before increasing abruptly to 30% at month 27.

Patterns of similarity for understory algae were similar to those observed for benthic invertebrates in that the location to which boulders were transplanted was the most important factor influencing relative species composition and abundance (Figure III.F.2). The algal assemblages on scraped boulders (artificial and natural) placed at SM became more similar to un-scraped natural boulders at SM over time. After 27 months the percent similarity between the algal assemblages on un-scraped natural boulders at SM and scraped artificial and natural boulders at SM ranged between 70% and 80%. In contrast, the percent similarity between the algal assemblages on scraped boulders (artificial and natural) placed at SCAR remained relatively low (i.e., below 33%) for the entire 27-month experiment. The relative species composition of algae differed greatly between boulders placed at SM and SCAR (Figure III.F.3). Interestingly, ovate fleshy red algae were the most abundant taxon on boulders placed at SM, but were conspicuously absent on boulders placed at SCAR. Scraped boulders at SCAR had the fewest algal species of any of the treatments.

<u>Effects of substrate type and location on similarity of invertebrate communities</u>
As observed for understory algae, rock type had little effect on the percent cover and species composition of benthic invertebrates. Benthic invertebrates rapidly colonized all scraped boulders, and within six months attained a cover of approximately 90% at both SCAR and San Mateo (Figure III.F.4). Invertebrates on un-scraped natural boulders remained relatively constant over time at SCAR at approximately 80%. In contrast, invertebrates on un-scraped natural boulders at SM increased from 60% to 90% before declining to 70% on the last sample date.

The percent similarity between the benthic invertebrate assemblages on the un-manipulated control (un-scraped natural boulders at SM) and all other experimental treatments increased for the first 13 months of the experiment before leveling off or declining. The largest decline was observed on un-scraped quarry rock boulders placed at SCAR, which in the later half of the experiment dropped from being 80% similar to the control to ~ 50% similar (Figure III.F.5). As was the case for the algal assemblage, the most important factor affecting the percent similarity between the various experimental treatments and the control was the location to which the boulders were transplanted. The benthic invertebrate assemblages on boulders transplanted to SM were most similar to natural un-scraped boulders at SM (i.e., control boulders) regardless of boulder type (artificial vs. natural) or successional state (scraped vs. un-scraped). Invertebrates on scraped boulders placed at SCAR were the least similar to the control regardless of boulder type (artificial vs. natural). The bryozoan *Bugula californica* accounted for 30% to 50% of the invertebrate cover on boulders placed at SM, but less than 20% of boulders placed at SCAR (Figure III.F.6). The cup coral *Balanophyllia elegans* was common on the control boulders and rare or completely absent in the experimental treatments. More than 50% of the cover on boulders at SCAR consisted of species that were uncommon on the control, whereas only 10–20% of the cover on experimental boulders at SM consisted of species that were uncommon on the control. *Didemnum* spp., an invasive compound tunicate tended to be more abundant on all the experimental treatments compared to the control (Figure III.F.6).

<u>Summary of boulder transplant experiment</u>

- The location to which boulders were transplanted affected the species composition and abundance of understory algae and benthic invertebrates and understory algae, while the type of boulder (natural vs. quarry rock) did not. Benthic assemblages on boulders placed at SM were most similar to natural un-scraped boulders at SM (i.e., control boulders) regardless of boulder type (artificial vs. natural) or successional state (scraped vs. un-scraped).
- Scraped boulders placed at SCAR were the least similar in species composition to natural un-scraped boulders at SM (i.e., control boulders), regardless of boulder type (artificial vs. natural).
- The algal assemblages on scraped boulders (artificial and natural) placed at SM became more similar to un-scraped natural boulders at SM over time. After 27 months the percent similarity between un-scraped natural boulders at SM and scraped artificial and natural boulders at SM ranged between 70% and 80%.
- Percent similarity in the species composition of the benthos between boulders placed at SCAR and the natural un-scraped boulders at SM appeared to level off at relatively low levels (i.e., < 50%) after 6 to 13 months.
- These results suggest that the relatively low percent similarity observed between the benthic communities on the natural reefs at SM and B and those on artificial reef modules of SCAR will likely be maintained over the long term due to inherent site-specific differences between SCAR, SM and B.

Figure III.F.1. Mean (± S.E.) percent cover of understory algae vs. month since start of experiment. Data are from scraped natural and quarry rock (i.e., artificial) boulders and on un-scraped natural boulders placed at SCAR and San Mateo (SM). N = 10 boulders.

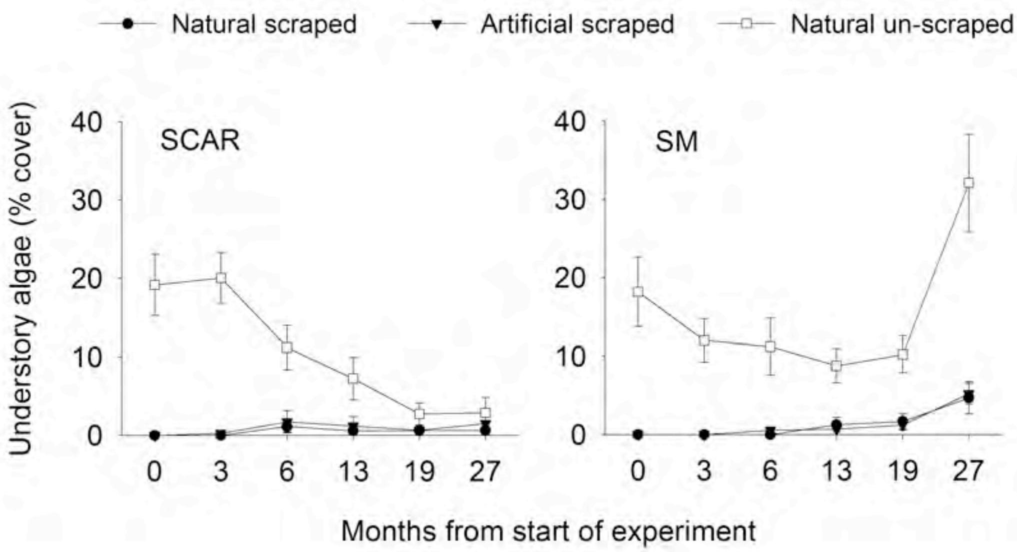



Figure III.F.2. Similarity between the algal assemblages on natural un-scraped boulders at San Mateo (SM_NAT_U) and other experimental treatments. SC_ART_U = un-scraped artificial substrate at SCAR, SC_ART_S = scraped artificial substrate at SCAR; SC_NAT_S = scraped natural substrate at SCAR; SM_ART_S = scraped artificial substrate at San Mateo; SM_NAT_S = scraped natural substrate at San Mateo.

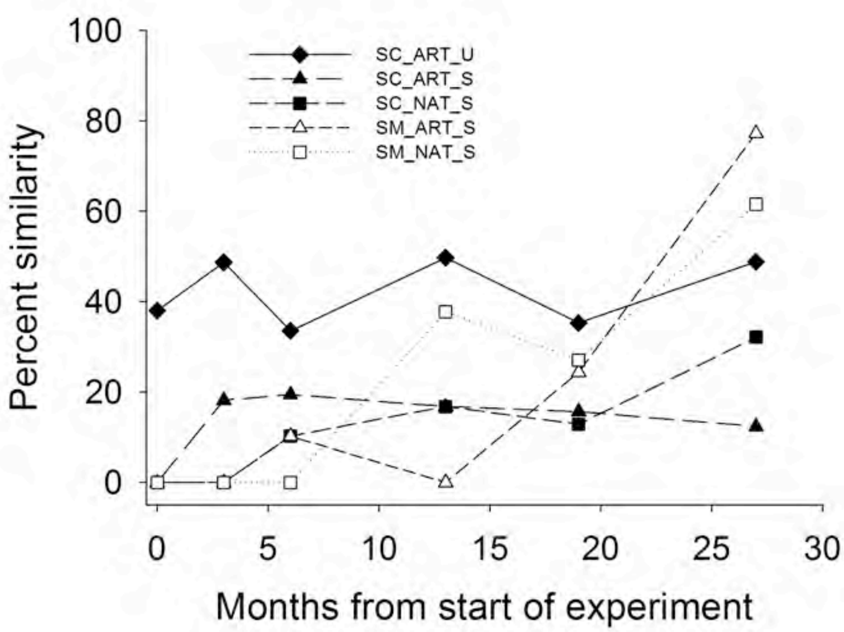


Figure III.F.3. Species composition of the algal assemblages on natural un-scraped boulders at San Mateo (SM_NAT_U) and other experimental treatments 27 months after the start of the experiment. SC_ART_U = un-scraped artificial substrate at SCAR, SC_ART_S = scraped artificial substrate at SCAR; SC_NAT_S = scraped natural substrate at SCAR; SM_ART_S = scraped artificial substrate at San Mateo; SM_NAT_S = scraped natural substrate at San Mateo.

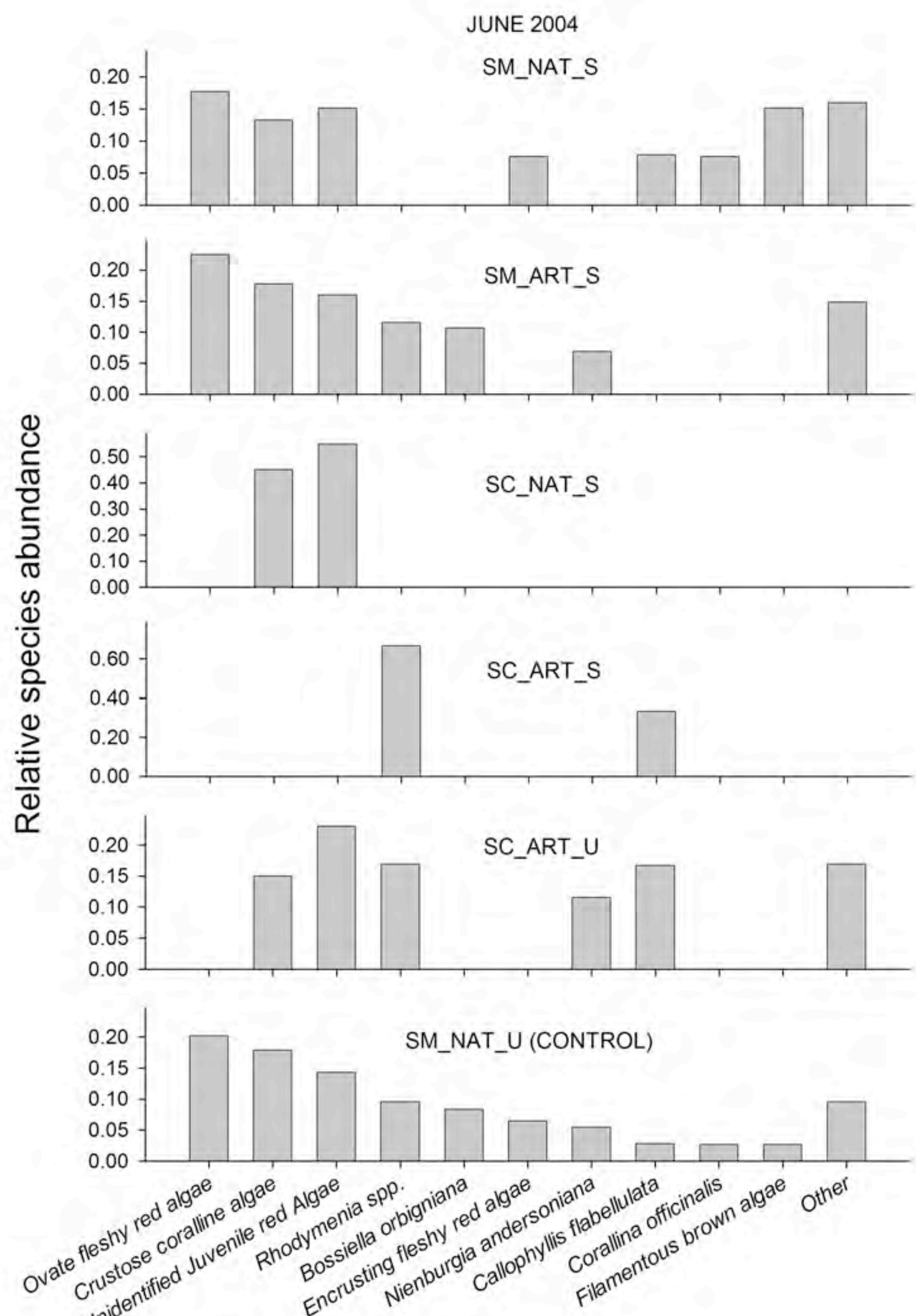


Figure III.F.4. Mean (± S.E.) percent cover of benthic invertebrates vs. month since start of experiment. Data are from scraped natural and quarry rock (i.e., artificial) boulders and on un-scraped natural boulders placed at SCAR and San Mateo (SM). N = 10 boulders.

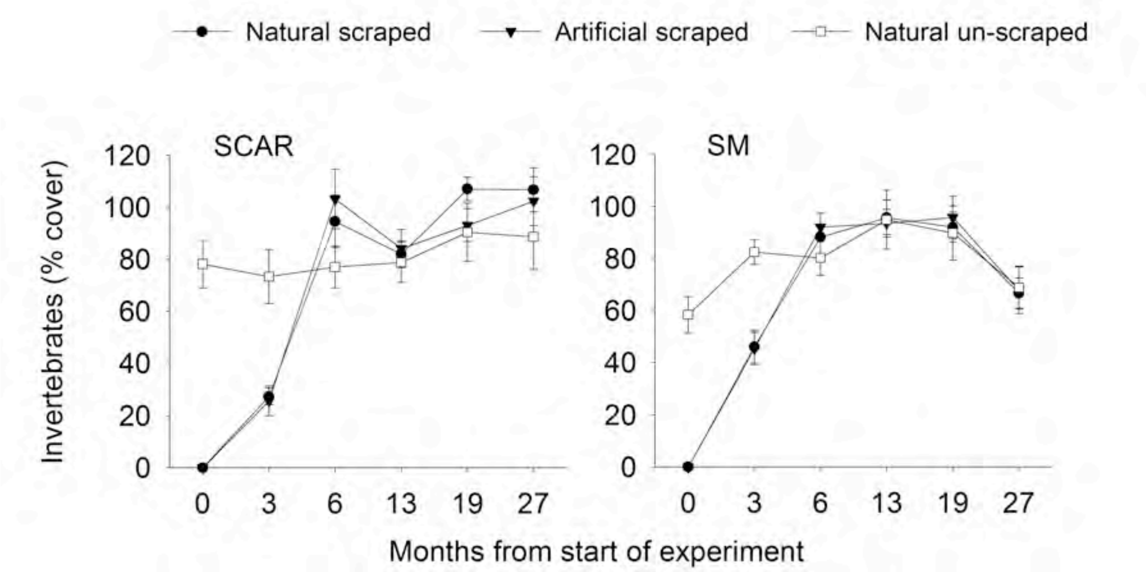



Figure III.F.5. Similarity between the benthic invertebrate assemblages on natural un-scraped boulders at San Mateo (SM_NAT_U) and the other experimental treatments. SC_ART_U = un-scraped artificial substrate at SCAR, SC_ART_S = scraped artificial substrate at SCAR; SC_NAT_S = scraped natural substrate at SCAR; SM_ART_S = scraped artificial substrate at San Mateo; SM_NAT_S = scraped natural substrate at San Mateo.

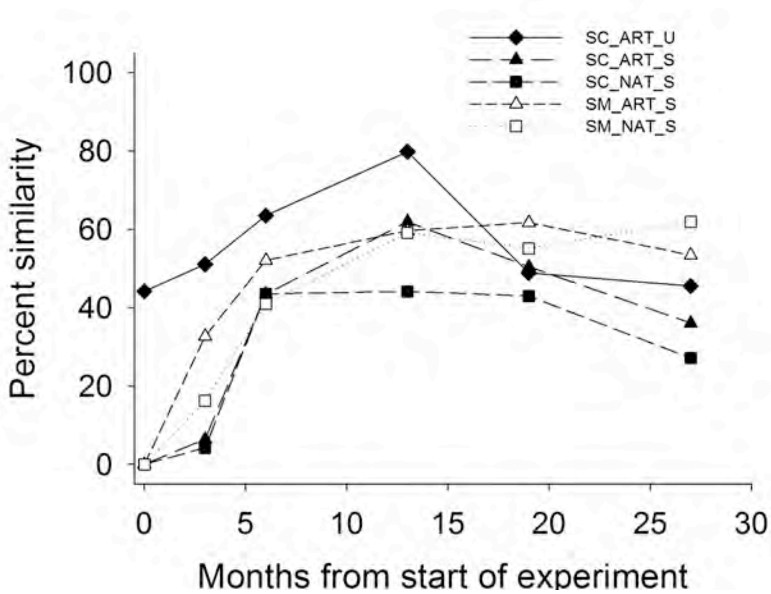
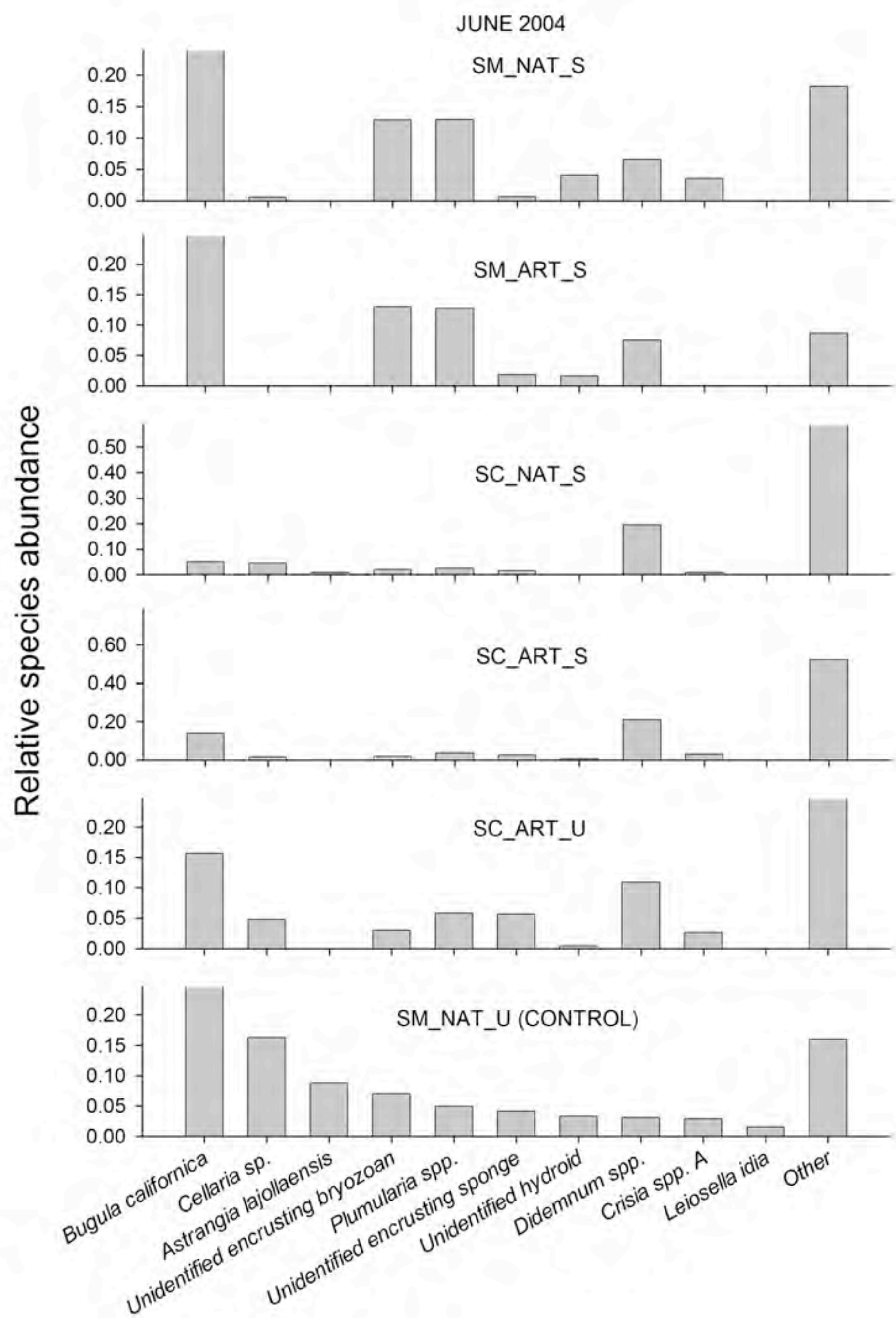


Figure III.F.6. Species composition of the benthic invertebrate assemblages on natural un-scraped boulders at San Mateo (SM_NAT_U) and the other experimental treatments 27 months after the start of the experiment. SC_ART_U = un-scraped artificial substrate at SCAR, SC_ART_S = scraped artificial substrate at SCAR; SC_NAT_S = scraped natural substrate at SCAR; SM_ART_S = scraped artificial substrate at San Mateo; SM_NAT_S = scraped natural substrate at San Mateo.



## G. KELP TRANSPLANTATION

Concerns were raised in the environmental review process for the SONGS experimental artificial reef that giant kelp may not colonize the artificial reef modules during the five-year experiment due to limitations on spore dispersal or poor environmental conditions for kelp recruitment. Additional concerns were raised during the review process about the need to develop means for augmenting kelp abundance (as an alternative to augmenting reef material) in the event that the mitigation reef failed to support 61 ha of medium- to high-density kelp forest. To address these concerns, the design of the experimental phase was altered during the environmental review process to include 14 additional modules to be used as a safeguard in the event natural recruitment to SCAR failed and to assess the feasibility of transplanting juvenile *Macrocystis* as a means of augmenting giant kelp abundance on the mitigation reef should the need ever arise.

### Methods

Coastal Research Associates transplanted laboratory-reared giant kelp to 14 of the 56 modules in June/July 2000 (one medium-cover rock module and one medium concrete module in each of the seven blocks) to assess the feasibility of transplanting as an effective means of augmenting kelp density in the event that remediation is required. Thirty transplant units were uniformly placed approximately 2 m from two of the four transect lines on each of the 14 transplant modules (N = 60 transplant units per transplant module). A transplant unit consisted of a small length of braided nylon rope containing many young laboratory-reared giant kelp. The braided rope with transplanted kelp was fastened to a plastic plate bolted to the artificial reef substrate. Each transplant unit was sampled in August 2000 and August 2001 for presence/absence of the transplant plate, presence/absence of giant kelp on the transplant plate, and size category of kelp on the transplant plate (i.e., recruit, juvenile, sub-adult, adult).

### Results

More than 80% of the plastic transplant plates bolted to the rock and concrete modules remained after one year at all seven experimental blocks (Figure III.G.1). Transplanted kelp survived reasonably well on plates that remained in place. On average, more than 70% of the surviving plates on rock and concrete modules supported living *Macrocystis* one year after transplantation (Figure III.G.2). Growth of kelp transplanted to concrete modules in the summer of 2000 (as estimated by size in the summer of 2001) was similar to that of kelp that recruited naturally to concrete modules, whereas the growth of kelp transplanted to rock modules was somewhat stunted compared to kelp that recruited naturally to rock modules (Figure III.G.3). The growth and survivorship of transplanted *Macrocystis* varied substantially among the different blocks. There was nearly 100% survival of transplanted *Macrocystis* on remaining plates in Block 5, but less than 30% survival on remaining plates in Block 2 (Figure III.G.4). The survival of transplanted *Macrocystis* (as measured by the percentage of plates with kelp in June 2001) was inversely related to the density of *Macrocystis* that naturally recruited in August 2000 (Figure III.G.5). Spatial variation in transplant growth mirrored that of transplant survivorship (Figure III.G.6). The vast majority of kelp transplanted to Blocks 1, 2 and 3 (where densities of naturally recruited plants were highest) remained less than

1-m tall after 1 year, which was substantially shorter than kelp that recruited naturally to these blocks. In contrast, the size structure of kelp transplanted to Blocks 4 through 7, where natural recruitment was lower, resembled that of kelp that recruited naturally to these blocks. These data suggest that the transplanting technique was successful, though very labor intensive, but that transplanted kelp was out competed by naturally recruited kelp on modules where natural recruitment of kelp was high. This asymmetrical competition that favored natural kelp over transplanted kelp may have been caused in part by the smaller size of transplanted kelp relative to naturally recruited kelp at the time of transplanting.

Summary of kelp transplantation

- On average, between 70% to 80% of the transplant substrates remained in place after one year.
- On average, more than 70% of the surviving plates on rock and concrete modules supported living *Macrocystis* 1 year after transplantation.
- Growth of transplanted kelp was similar to or slightly less than that of naturally recruited kelp.
- The method of transplanting juvenile kelp tested in the experiment may be a viable, but labor intensive, means of augmenting the density of naturally recruited kelp on the mitigation reef if remediation is determined necessary.

Figure III.G.1. Survivorship of the plastic plates used to transplant *Macrocystis.* Data are means (± SE) averaged over modules within blocks. N = 2 modules per block.

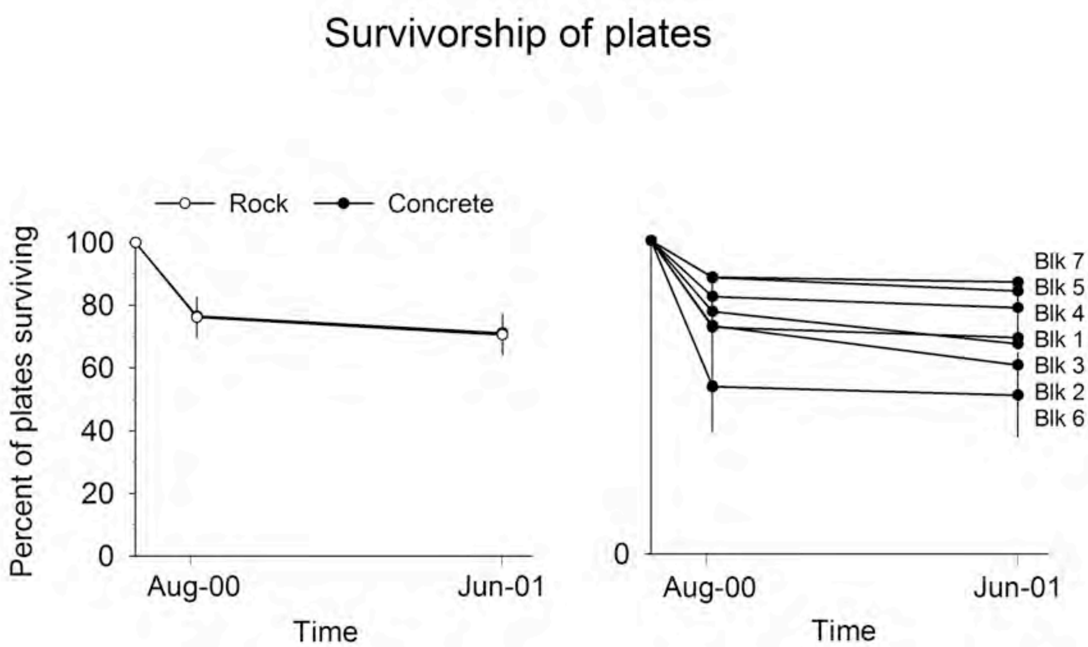



Figure III.G.2. Survivorship of *Macrocystis* transplanted to rock and concrete modules on SCAR. Data are means (± SE) averaged over modules within blocks. N = 2 modules per block.

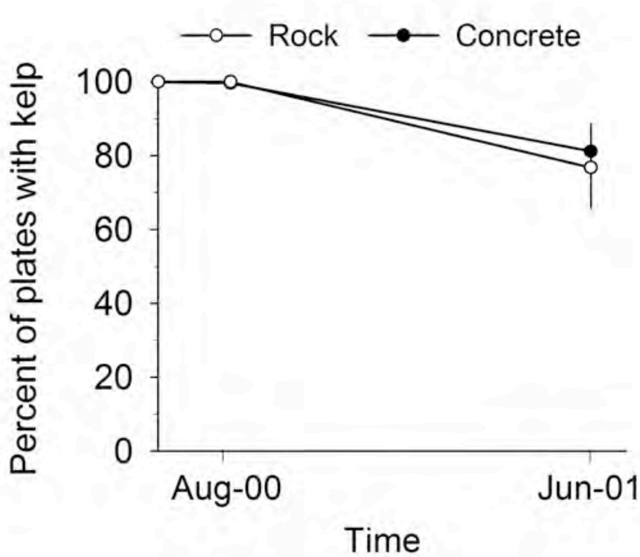


Figure III.G.3. Mean size distributions of transplanted *Macrocystis* and naturally recruited *Macrocystis* for rock and concrete modules on SCAR in June 2001.

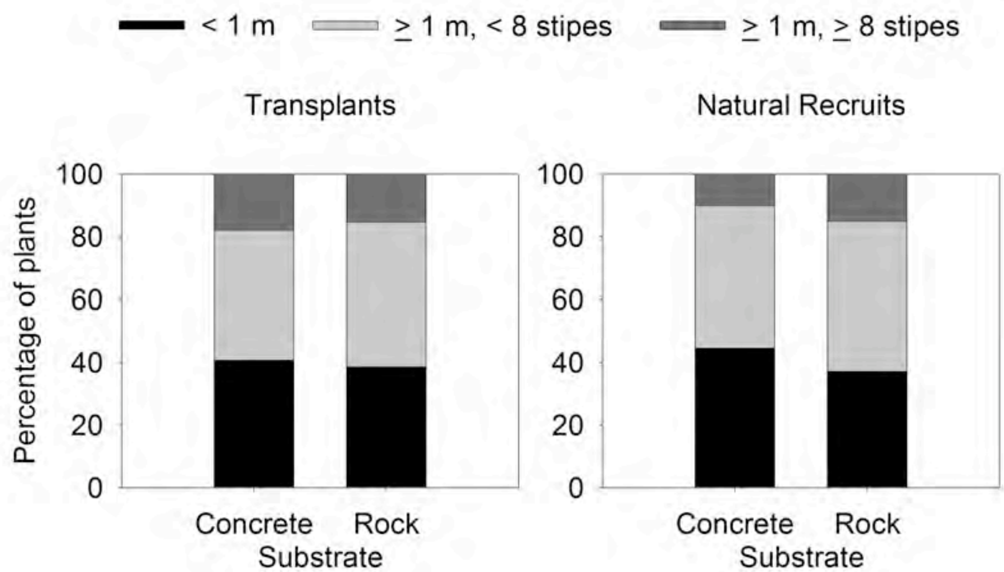



Figure G.4. Survivorship of *Macrocystis* transplanted to the seven locations (i.e., blocks) on SCAR. Data are means (± SE) averaged over modules within blocks. N = 2 modules per block.

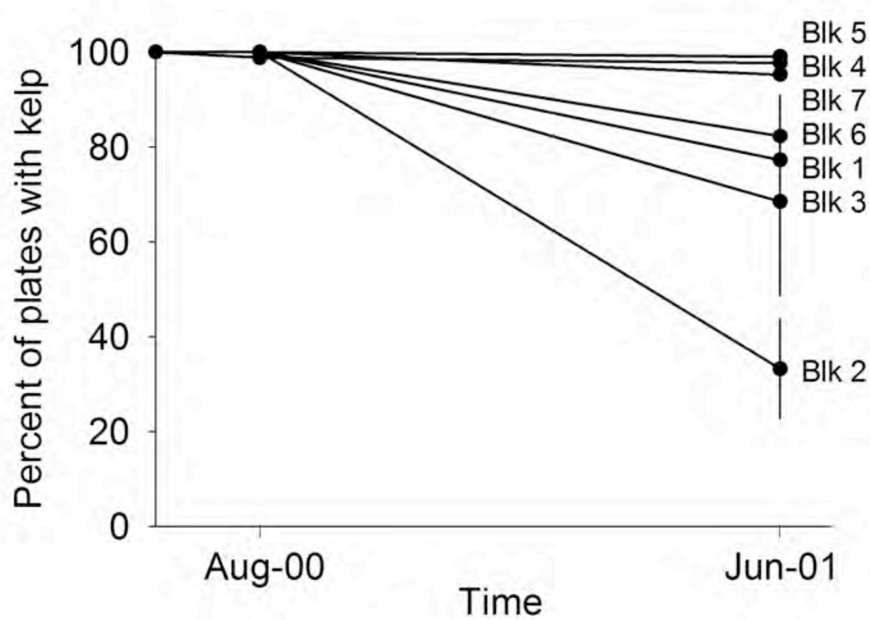


Figure III.G.5. Relationship between the percent of plates with transplanted kelp in June 2001 vs. the density of natural giant kelp recruits (i.e., plants < 1-m tall) in August 2000.

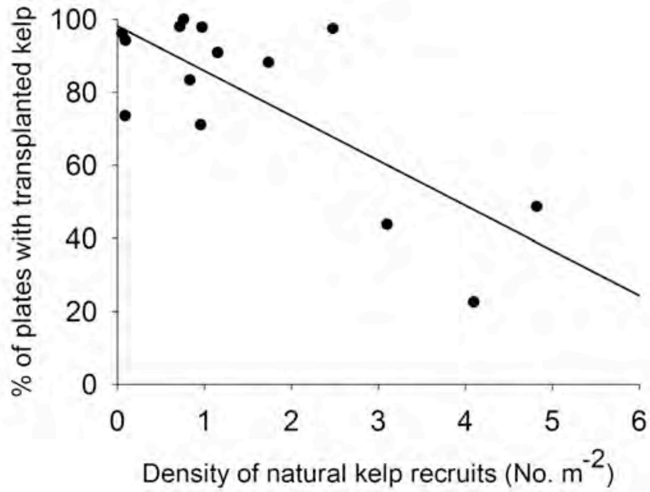
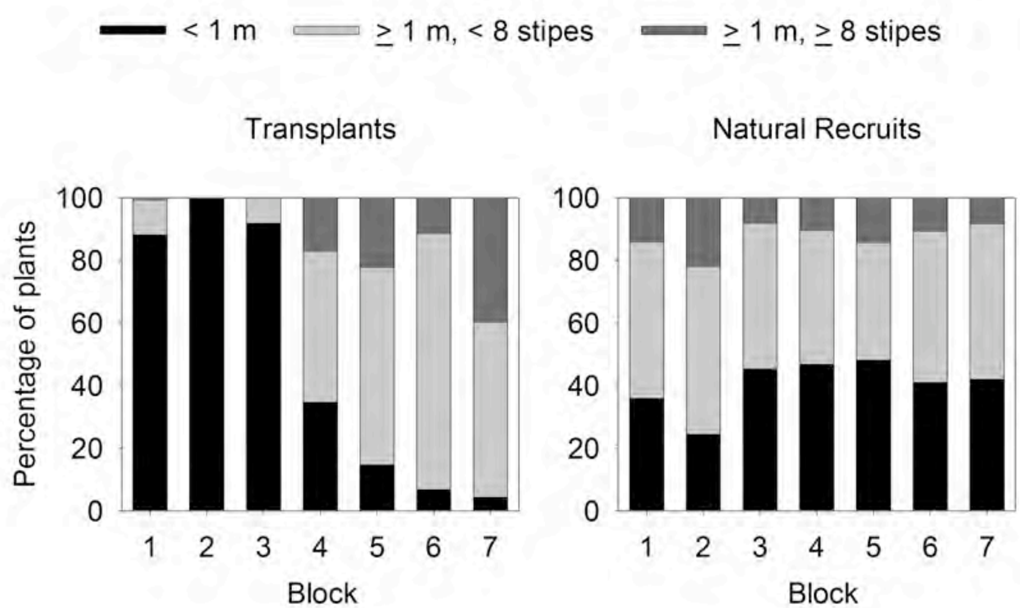



Figure III.G.6. Mean size distributions of transplanted *Macrocystis* and naturally recruited *Macrocystis* for the seven locations (i.e., blocks) on SCAR.



# IV. RECOMMENDATIONS FOR THE DESIGN OF THE MITIGATION PHASE OF THE SONGS ARTIFICIAL REEF MITIGATION PROJECT

## *A. GENERAL RECOMMENDATIONS*

The operation of SONGS Units 2 and 3 has been shown to adversely impact the San Onofre kelp forest community. Coastal Act Section 30230 states "[m]arine resources shall be maintained, enhanced, and where feasible, restored." Thus, the operation of SONGS Units 2 and 3 is consistent with the Coastal Act only if the significant adverse impacts to kelp bed resources identified by the Marine Review Committee (MRC) are fully mitigated. The MRC recommended and the CCC found that compensation for the kelp bed community losses, in the form of an artificial reef, was preferable to redesigning the SONGS cooling system to avoid the adverse impacts to the San Onofre kelp forest. Thus, the overall goal of the SONGS artificial reef project is to compensate for the loss of kelp bed resources including giant kelp, understory algae, invertebrates, and fishes.

The performance standards, monitoring, and remediation provisions set forth in Condition C of the SONGS coastal development permit (No. 6-81-330-A) were designed to ensure that the artificial reef will, to the fullest extent possible, replace the kelp forest community resources lost at San Onofre. Nonetheless, when the permit was amended in 1991 to include mitigation requirements, there was much uncertainty as whether an artificial reef could successfully compensate for these losses. The two-phase approach to artificial reef mitigation adopted by the CCC was designed to reduce this uncertainty and to determine whether artificial reefs could be used to compensate for the loss of kelp forest resources caused by SONGS operations.

Results from the five-year experimental phase of the artificial reef mitigation project were quite promising in that all six artificial reef designs and all seven locations (i.e., blocks) tested showed a near equally high tendency to meet the performance standards established for the mitigation reef (Tables IV.A.1 and IV.A.2). Specifically, at least 90% of the artificial reef material deployed remained available for colonization after five years, for all artificial reef designs and for five of the seven blocks on SCAR. Densities of giant kelp, fish, and benthic invertebrates on the artificial reef modules were similar to or greater than those on nearby reference reefs. Only the abundance and number of species of understory algae were lower on the artificial reefs compared to the natural reefs. Manipulative experiments demonstrated that this pattern of low algal abundance and diversity on the artificial reef modules is not likely to persist over the long term. Periodic disturbances that reduce the competitive advantages of giant kelp and benthic invertebrates will most likely allow understory algae to re-establish itself on the artificial reef and attain levels of abundance and diversity that are similar to natural reefs in the region. *We conclude from these findings that a low-relief concrete rubble or quarry rock reef constructed off the coast of San Clemente, California has a very good chance of* *providing adequate in-kind compensation for the loss of kelp forest biota caused by the operation of SONGS Units 2 and 3***.**

## *B. RECOMMENDATIONS ON SPECIFIC DESIGN FEATURES:*

### Substrate type

*The mitigation reef should be built of quarry rock or rubble concrete having dimensions, size structures, and specific gravities similar to those of the rock and concrete used to construct the SONGS experimental artificial reef.*

Artificial reef modules constructed of quarry rock and rubble concrete supported very similar biological communities. Importantly, we found no evidence that one type of material was consistently better than the other in terms of its ability to meet the performance standards established for the mitigation reef (Table IV.A.1). Different conclusions might be drawn if the sizes and shapes of the two substrate types were to change. For this reason we recommend that the dimensions, size structures, and specific gravities of the materials used to construct the mitigation reef be similar to those used in the experimental phase of the SONGS artificial reef mitigation project.

### Substrate coverage and bottom relief

*The percent of the bottom covered by quarry rock or rubble concrete on the mitigation reef should be at least 42% but no more than 86% (as determined by divers using the uniform point contact method employed in this study). The average vertical relief of the bottom should not exceed 1 m.*

A relatively low coverage of hard substrate may be sufficient for meeting some of the performance standards. For example, the standard for giant kelp of four adult plants per 100 $m^2$ could conceivably be achieved by placing as few as four boulders per 100 $m^2$ of bottom. When determining the minimum coverage of hard substrate for the mitigation reef, however, it is important to recognize that the goal of the artificial reef is to compensate for losses to an entire kelp forest community of giant kelp, understory algae, invertebrates and fishes.

Data collected during the experimental phase of the SONGS mitigation project indicate that the mitigation reef will have the greatest chance of meeting all the performance standards if it has an average coverage of hard substrate that is at least as high as that of the low-coverage artificial reef design tested in the five-year experiment. We found that the percent cover of benthic reef algae and invertebrates on the artificial reef modules exhibited a strong positive relationship to the percentage of the bottom covered by artificial substrate (Figure IV.B.1a). Importantly, we found no evidence that modules with lower coverage of artificial substrate supported a proportionally greater coverage of benthic biota; in fact there was a weak relationship that suggested the opposite was true (Figure IV.B.1b). Moreover, results from a boulder transplant experiment showed that natural rock and quarry rock supported similar abundances and species of algae and invertebrates (Figures III.F.1 and III.F.4), indicating that all else considered equal, an artificial reef will not inherently support more organisms than a similar natural reef. Collectively these data indicate that the more closely the substrate coverage of an artificial reef mimics that of a natural reef, the more likely the artificial reef will support a biota that is similar in abundance and diversity to that of the natural reef. The mean cover of hard substrate on the natural reefs at Barn and San Mateo during 2000–2004 was 49 and 52 %, respectively, which was intermediate between the low- and medium-coverage artificial reef designs.

The different levels of substrate coverage tested in the experiment differed little in their ability to meet the performance standards. However, the low coverage designs had the lowest probability (i.e., ~ 50%) of attaining the performance standard for fish standing stock (Figure III.C.16). Moreover, contrary to expectations, sea fan abundance was not any lower on modules with low substrate cover (Figures III.D.28 and III.D.31), whereas sea fan growth and survivorship tended to be higher (Figures III.D.22 and III.D.25). These results argue that an artificial reef design with a mean bottom coverage much less than the low coverage designs (i.e., 42%) would have a lower probability of meeting some of the performance standards.

Given the results described above and the overall goal of compensating for losses to all components of the kelp forest community, we recommend that artificial substrate cover an average of at least 42% of the bottom of the 61-ha mitigation reef. Because too much hard substrate could cause an artificial reef to produce a community that was substantially different from nearby natural reefs, we recommend limiting the bottom coverage of artificial substrate to 86%, which was the mean value of the high-bottom coverage designs tested in the experimental phase.

Dominance by reef associated fish and invertebrates that results in the reduced abundance of understory algae has been observed on artificial reefs with high bottom relief (Patton et al. 1994, Deysher et al. 2002). None of the artificial reef designs tested in the experimental phase of the SONGS artificial reef mitigation project averaged more than 1 m in vertical relief, and all were found to be relatively successful in meeting most of the performance standards. Thus, the mitigation reef should maintain the low-profile design tested in the experimental phase, and the average vertical relief of the 61-acre footprint should not exceed 1 m. The incorporation of a few high relief areas into the design of the mitigation reef may be useful for meeting certain performance standards (e.g., standing stock of kelp bed fish). If such high relief areas are included in the mitigation reef, then they should be included as acreage that is in addition to the minimum 61-ha footprint.

**Location**

*The mitigation reef should be built within or near the existing 144-ha project site located off the coast of San Clemente, California. The quarry rock or concrete rubble used to construct the mitigation reef should not be placed on any hard bottom areas known to support kelp forest biota and commercial and recreational fisheries. The most northern portion of the project site should be avoided if possible because sand inundation in this area may cause higher rates of burial of artificial reef material.*

No areas within the existing project site were found to be unsuitable for supporting kelp forest biota over the long term (Table IV.A.2). It should be noted however, that higher rates of sand burial were observed in the most northern location (Block 7), which could cause the amount of reef material deposited in this area to fall below the "90% of the initial" criteria required by the performance standard for hard substrate. These results argue for building the majority of the mitigation reef within the 144-ha project site, preferably away from the northern portion of the site where higher rates of sand burial were observed.

While the overall performance of the seven blocks in meeting the performance standards was similar, significant differences were observed among the blocks for several of the biological variables measured. Such "block effects" are believed to have resulted primarily from species characteristics or competitive interactions that were shaped by initial colonization patterns, rather than inherent differences in the suitability of different blocks to support kelp forest biota. For example, the greater cover of understory algae in Blocks 6 and 7 likely resulted from reduced shading by giant kelp, whose recruitment density declined with distance from San Mateo (most likely due to reduced spore dispersal to more distant locations). Similarly, the lower density of *Muricea* in Blocks 6 and 7 reflected lower initial rates of colonization, which were likely due to limitations on larval dispersal. Such founder effects on the artificial reef will likely diminish over time as new source populations become established and/or extent populations become diminished (i.e., via disturbance), thereby reordering spatial patterns of abundance and species richness of reef biota.

Aerial photographs, testimony from fishermen, and results from this study indicate that much of the natural hard substrate present in the project site serves as suitable habitat for a variety of kelp forest biota, some of which are economically valuable. As per the SONGS coastal development permit (6-81-330-A), reef construction should minimize the disruption of natural reef and cobble habitats within the project site and avoid placing artificial reef material in hard bottom areas known to support kelp forest biota and commercial and recreational fisheries. Additional diver and sonar surveys of the bottom that are capable of distinguishing different types of consolidated (e.g., mudstone, cobble/boulder, bedrock) and unconsolidated (e.g., sand, shell hash) substrates coupled with analyses of previously collected data (e.g., aerial imagery of kelp, fishing logs), should be done in the build-out site prior to constructing the mitigation reef to avoid placing artificial reef material in areas that are likely to support kelp forest biota and commercial and recreational fisheries.

## *C. OTHER CONSIDERATIONS*

### Timing and phasing of construction

*The timing and phasing of construction of the mitigation reef will probably not have any long-term effects on the biological communities that develop on the artificial reef.*

It is anticipated that construction of the mitigation reef will be done in phases over a period of more than one year to mitigate concerns over air quality that were raised in the environmental impact report. Furthermore, construction will likely be confined to spring and summer to avoid rough ocean conditions in the winter and adverse impacts to the commercial lobster fishery in the fall and winter. Such phasing could have lasting impacts on the biological development of the mitigation reef. For example, phasing construction over multiple years could minimize potential founder effects inherent in any given year, thereby promoting increased species diversity on the mitigation reef. Alternatively, providing newly created space at a time of year when it is not normally made available (i.e., spring and summer) could cause the species composition on the mitigation reef to differ substantially from that of the nearby natural reefs used to evaluate its performance. Our results, though limited, indicate that the timing and phasing of construction of the mitigation reef will probably not have any long-term effects on the assemblages of plants and animals that develop on the artificial reef. Results from a boulder transplant experiment (Section II.F) showed that the observed differences in the species assemblages on the artificial reef modules and the natural reefs during the five-year experiment were more likely caused by location effects than by differences in the type of reef material (i.e., artificial vs. natural) or the timing of colonization. Such differences in species composition are likely to persist through time on the mitigation reef and will most likely be unaffected by a plan involving phased construction. These conclusions support a plan in which the construction schedule is driven primarily by logistical constraints and mitigation requirements (i.e., air quality) rather than by a desire to optimize the biological performance of the mitigation reef.

## *D. OUTSTANDING ISSUES*

**Dominance by *Muricea***

*Data collected on sea fan recruitment, growth, and survivorship during the experimental phase of the SONGS artificial reef mitigation project indicate that it is reasonable to expect high densities of large* Muricea *will eventually invade the mitigation reef. None of the artificial reef designs tested appeared to substantially deter* Muricea *recruitment, growth or survivorship. Additional studies should be pursued during the interim period before the construction of the mitigation reef to determine the factors most important in controlling the distribution and abundance of* Muricea *and the most cost-effective means of managing it.*

Continuous recruitment of *Muricea* coupled with relatively high survivorship has enabled it to persist at relatively high densities on SCAR since 2002. Moreover, the *Muricea* that recruited to SCAR seemed to grow faster than the rate previously reported for the species. For example, in the summer of 2004 the population of *Muricea* on SCAR consisted of three different cohorts that ranged in age from 6 months to 2½ years. Nonetheless, more than 40% of the population at this time was greater than 6 cm tall and up to 10% was greater than 15 cm tall (Figure III.D.24). By contrast, Grigg (1974) estimated that it would take a *Muricea californica* colony approximately 4 to 5 years to reach 6 cm in height and roughly 10 years to reach 15 cm in height. Thus, not only is *Muricea* density likely to remain high due to relatively low mortality and constant recruitment, it appears to be growing relatively fast and the size structure of the population will soon be large enough to out-compete giant kelp and other sessile organisms for space.

We found no evidence that the design features tested would deter *Muricea* from becoming established at densities high enough to impair the functions of the reef. Sea fan densities were not significantly affected by the type and bottom coverage of artificial substrate, depth or by position on the reef (i.e., edge vs. middle of module). Data on sea fan survivorship, though limited, suggest that mortality rates of young colonies were largely independent of the bottom cover of quarry rock, rock size, substrate inclination, and local population density. This is important because one might expect rates of mortality to be highest in young stages. Lastly, individual growth (as indicated by population size structure) in *Muricea* was roughly similar on the six different artificial reef designs.

Given the above results, it is unclear what features, if any, can be incorporated into the design of the mitigation reef to deter the invasion of *Muricea,* and still provide adequate habitat for a natural kelp forest community. Additional insight into the factors controlling the distribution and abundance of *Muricea* may be obtained through continued monitoring of SCAR, and correlative studies and small-scale manipulative experiments involving sites that vary greatly in sea fan abundance. Remediation will be required in the event that *Muricea* invades the mitigation reef and reaches densities and sizes that are large enough to impair the important functions of the reef community. Cost effective and environmentally acceptable methods for managing *Muricea* should be explored and developed during the interim period prior to the construction of the mitigation reef to ensure the goal of in-kind compensation for the loss of kelp forest habitat at San Onofre caused by the operation of SONGS Units 2 and 3.

Table IV.A.1. Comparisons among the different artificial reef designs in meeting the performance standards using (a) the Universe approach and (b) the Sample approach. Comparisons are based on data from 2004. 1 indicates that the mean value of the artificial reef design was at or above the minimum value needed to meet the performance standard; 0 indicates that the mean value of the artificial reef design was below the minimum value needed to meet the performance standard. Totals are the summed values for all performance standards (13 = maximum possible summed value). * indicates fixed performance standard. Abbreviations for the artificial reef designs are as follows: LR = low-coverage rock, MR = medium-coverage rock, HR = high-coverage rock, LC = low-coverage concrete, MC = medium-coverage concrete, HC = high-coverage concrete.

**a) Universe Approach**

| | Artificial Reef Design | | | | | |
|---|---|---|---|---|---|---|
| Performance Standard | LR | MR | HR | LC | MC | HC |
| Hard substrate* | 1 | 1 | 1 | 1 | 1 | 1 |
| Adult kelp* | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish density | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish species richness | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish density | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish species richness | 1 | 1 | 1 | 1 | 1 | 1 |
| Fish standing stock* | 1 | 1 | 1 | 1 | 1 | 1 |
| Algal percent cover | 0 | 0 | 0 | 0 | 0 | 0 |
| Algal density | 0 | 0 | 0 | 0 | 0 | 0 |
| Algal species richness | 0 | 0 | 0 | 0 | 0 | 0 |
| Invertebrate percent cover | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate density | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate species richness | 1 | 1 | 1 | 1 | 1 | 1 |
| Totals | 10 | 10 | 10 | 10 | 10 | 10 |

**b) Sample Approach**

| | Artificial Reef Design | | | | | |
|---|---|---|---|---|---|---|
| Performance Standard | LR | MR | HR | LC | MC | HC |
| Hard substrate* | 1 | 1 | 1 | 1 | 1 | 1 |
| Adult kelp* | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish density | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish species richness | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish density | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish species richness | 1 | 1 | 1 | 1 | 1 | 1 |
| Fish standing stock* | 1 | 1 | 1 | 1 | 1 | 1 |
| Algal percent cover | 0 | 0 | 0 | 0 | 0 | 0 |
| Algal density | 0 | 0 | 0 | 0 | 0 | 0 |
| Algal species richness | 0 | 0 | 0 | 0 | 0 | 0 |
| Invertebrate percent cover | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate density | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate species richness | 1 | 1 | 1 | 1 | 1 | 1 |
| Totals | 10 | 10 | 10 | 10 | 10 | 10 |

Table IV.A.2. Comparisons among the different experimental artificial reef blocks (i.e., 1 through 7) in meeting the performance standards using (a) the Universe approach and (b) the Sample approach. Comparisons are based on data from 2004. 1 indicates that the mean value of the block was at or above the minimum value needed to meet the performance standard; 0 indicates that the mean value of the block was below the minimum value needed to meet the performance standard. Totals are the summed values for all performance standards (13 = maximum possible summed value). * indicates fixed performance standard.

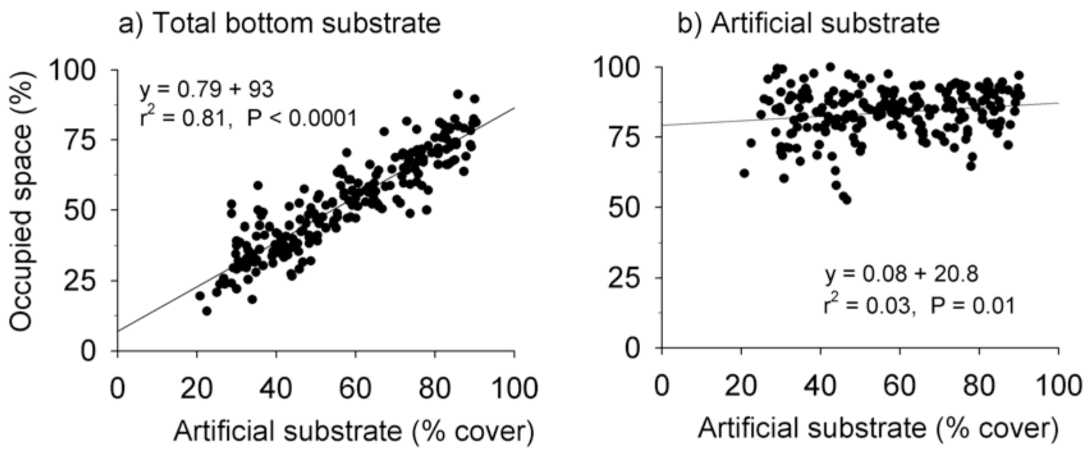
**a) Universe Approach**

| | Block | | | | | | |
|---|---|---|---|---|---|---|---|
| Performance Standard | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Hard substrate* | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| Adult kelp* | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish density | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish species richness | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish density | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish species richness | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fish standing stock* | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Algal percent cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Algal density | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Algal species richness | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Invertebrate percent cover | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate density | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate species richness | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Totals | 9 | 10 | 10 | 10 | 10 | 10 | 10 |

**b) Sample Approach**

| | Block | | | | | | |
|---|---|---|---|---|---|---|---|
| Performance Standard | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Hard substrate* | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| Adult kelp* | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish density | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Resident fish species richness | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish density | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| YOY fish species richness | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fish standing stock* | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Algal percent cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Algal density | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Algal species richness | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Invertebrate percent cover | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate density | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Invertebrate species richness | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Totals | 9 | 10 | 10 | 10 | 10 | 11 | 10 |

Figure IV.B.1. Relationship between the percent cover of artificial substrate and the percent of space occupied by reef algae and invertebrates on (a) the bottom (soft and hard substrates combined) and (b) artificial substrate. Data are annual means of the artificial reef modules of all six artificial reef designs for the period 2000–2004. N = 42 modules per year.



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