

## QUANTITATIVE ASSESSMENT OF DIFFERENT ARTIFICIAL REEF DESIGNS IN MITIGATING LOSSES TO KELP FOREST FISHES

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### ABSTRACT

Determining the success of artificial reefs as a tool for mitigating human-induced losses to fish populations requires explicit standards for performance assessment, and a robust monitoring program designed to collect the information necessary to evaluate those standards. Here we describe: (1) the biological performance standards established for kelp forest fishes on an artificial reef designed to compensate for the loss of kelp forest habitat caused by the operation of a coastal power plant in southern California, (2) results of a 5 yr experiment that tested the efficacy of six artificial reef designs in meeting these standards, and (3) an assessment of two different analytical approaches to evaluate the performance standards. Our results indicated that all six configurations of reef material and bottom coverage tested provided suitable habitat for kelp forest fishes. Fish standing stock, density, species richness, and recruitment on all the artificial reef designs were either similar to, or greater than, that observed at two nearby natural reefs. The amount, but not the type, of reef material had a substantial influence on the fish assemblage, with higher densities and numbers of species occurring on artificial reef modules with greater coverage of hard substrate.

Historically, the most common use of artificial reefs has been for fisheries enhancement. Over the past two decades, there has been increasing interest in using artificial reefs to mitigate environmental impacts, and artificial reefs have been used or proposed as mitigation for impacts to estuaries, bays, and harbors (Davis, 1985; Burton et al., 2002), seagrass beds (Thorhaug, 1989; Sánchez-Jerez et al., 2002), coral reefs (Carr and Hixon, 1997; Abelson and Shlesinger, 2002; Osenberg et al., 2002), and kelp forests (Ambrose, 1994; Deysher et al., 2002). During this same period, mitigation policies and applications have evolved. Modern mitigation practices require that the goals of a mitigation project be clearly stated at the outset, that these goals become incorporated into performance standards, and that long-term monitoring be conducted to determine whether the project is successful.

The California Coastal Commission (CCC) implemented such mitigation practices when it required Southern California Edison (SCE) to construct a 61 ha artificial reef as mitigation for the loss of giant kelp forest habitat caused by the operation of SCE's San Onofre Nuclear Generating Station (SONGS) (Ambrose, 1994). The discharge from the once-through cooling system of SONGS creates a turbid plume that the prevailing current moves over the kelp forest off San Onofre. This plume reduces light and increases sedimentation and seston flux near the forest floor, which adversely affects the recruitment of giant kelp, *Macrocystis pyrifera* (Linnaeus) Agardh. These changes have caused a 72 ha reduction in the size of the San Onofre kelp forest relative to that of a nearby kelp forest (Bence et al., 1996). In addition to affecting giant kelp itself, SONGS reduces the abundances of a wide diversity of organisms living in the San Onofre kelp forest (Schroeter et al., 1993; Ambrose et al., 1996). The CCC

established performance standards for judging the success of the mitigation reef and required SCE to fund independent long-term monitoring to determine whether these standards are met and remediation if the standards are not met (CCC coastal develop permit No. 6-81-330-A). The performance standards and long-term monitoring were key elements of the CCC's mitigation decision. These standards include physical criteria such as a maximum allowable amount of burial of the reef material by sand, as well as biological criteria pertaining to the abundance and diversity of kelp forest fishes, invertebrates, and algae. The standards specify time limits for the establishment of reef biota and also include important demographic parameters and ecosystem functions such as reproduction, recruitment, and food chain support.

There are many uncertainties associated with constructing an artificial reef to replace kelp forest resources and previous attempts to do so in southern California have often failed (discussed in Ambrose, 1994; Deysher et al., 2002). To help ensure that the mitigation reef would adequately replace the resources lost due to SONGS' operations, the CCC required a two-phase approach to mitigation that consisted of an initial short-term (5 yr), small scale (~9 ha) experimental phase intended to test the efficacy of different artificial reef designs in meeting the various performance standards, and a subsequent long-term (equal to the operating life of SONGS, which is expected to be ~30 yrs), large scale (61 ha) mitigation phase intended to compensate for the resources lost due to SONGS' operation. Information obtained from the experimental phase will be used to design the larger reef built in the mitigation phase. Importantly, the performance standards established for the mitigation reef are being used during the experimental phase to evaluate the efficacy of different reef designs in meeting the project's objectives.

Here we report on results from the recently completed 5-yr experimental phase of the SONGS project intended to test the efficacy of different artificial reef designs in meeting the performance standards established for the 61 ha artificial reef required for mitigation. We focus on the response of kelp forest fishes to artificial reefs that differ in material type (recycled concrete rubble vs. quarry rock) and bottom coverage. The effects of material type and amount on other components of the kelp forest biota (e.g., kelp, invertebrates, and understory algae) observed during the 5-yr experiment are reported elsewhere (Reed et al., 2004, in press).

**SONGS PERFORMANCE STANDARDS FOR KELP FOREST FISHES.**—The abundance of fishes in the San Onofre kelp forest was reduced by approximately 70% relative to nearby San Mateo kelp forest during the impact assessment phase of SONGS Units 2 and 3 (Murdoch et al., 1989). This reduction in the relative abundance of fishes in the San Onofre kelp forest translates into an estimated loss of about 200,000 fish (weighing about 25.4 mt) 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 be at least 25.4 mt to insure 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 yr 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 young-of-year (YOY) fishes (defined as fishes < 1 yr 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 (defined as the production rate of somatic and gonadal mass) 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 experimental reef designs.

**LOCATION AND DESIGN OF EXPERIMENTAL ARTIFICIAL REEF.**—The experimental artificial reef for SONGS mitigation is located approximately 1 km offshore of the city of San Clemente, California (Fig. 1). The experimental phase of the San Clemente Artificial Reef (hereafter referred to as SCAR) was constructed in August and September 1999 on a mostly sand bottom at 13–16 m depth. The experiment 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 material types (quarry rock and recycled concrete rubble), three levels of bottom coverage of each material type (low,

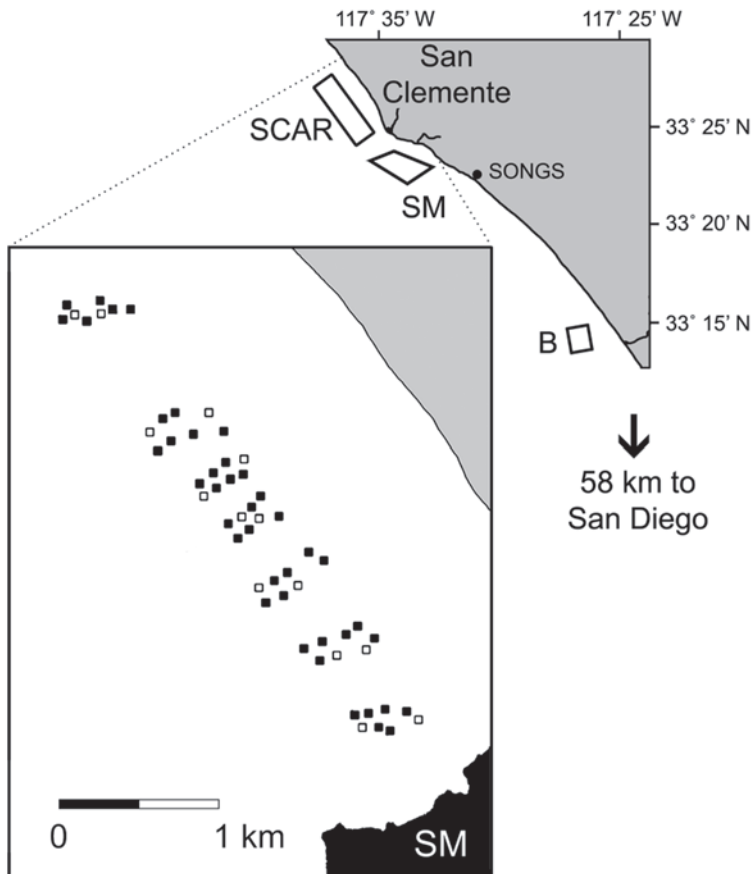


Figure 1. Location and layout of the SONGS experimental artificial reef (SCAR) and the natural reference reefs at San Mateo (SM), and Barn (B). The San Onfre kelp forest (not shown), which was adversely affected by SONGS's operations, is located directly offshore of SONGS. Square symbols with solid fill represent the 42 modules analyzed in this study. Squares with open fill indicate the 14 additional "kelp transplant" modules that were not used in our analyses.

medium, and high, which roughly corresponded to 40%, 60%, and 80% coverage), and two levels of kelp abundance (natural and augmented with transplanted juvenile kelp) applied only to modules with medium bottom coverage. Each artificial reef module was roughly 40 × 40 m in area and the 56 modules collectively covered about nine hectares of the sea floor. All modules were constructed to form low-lying reefs < 1 m tall that mimicked natural reefs in the region. The size and shape of the two construction materials differed slightly, causing only small-scale topographic differences between rock and concrete modules (Reed et al., 2004). The kelp-transplanting portion of the experiment was completed in 2001 upon which time sampling of the 14 kelp transplant modules was discontinued. Consequently, we restricted our analyses of kelp forest fishes to the 5-yr time series of the 42 modules that did not receive transplanted kelp. The naturally occurring kelp forests on the nearby low-relief cobble/boulder reefs at San Mateo and Barn (located ~0.5 and 14 km south of the experimental artificial reef, respectively; Fig. 1) served as reference reefs for evaluating the SONGS performance standards. The bottom topography and depth at San Mateo and Barn are similar to both SCAR and the damaged kelp forest at San Onofre located offshore of SONGS. The mean coverage of hard substrate at San Mateo and Barn was 48% and 50%, respectively.

## METHODS

**DATA COLLECTION.**—Fish abundance and size were recorded at three depth strata along fixed transects on the artificial reef modules and reference reefs once per year in the fall (September and October). Sampling was done near the surface in the region of the kelp canopy (0–2 m depth below the water surface), midwater (approximately 7 m depth between the surface and bottom), and at the bottom (14–15 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 parallel transects separated by 20 m and running the length of an artificial reef module were sampled on each module during each survey for a total of 14 transects for each reef design (two transects per module × seven replicate modules). Similarly, we sampled two parallel transects at each of seven sampling stations at Barn and San Mateo during each survey for a total of 14 transects for each reference reef, except in 2000 when only one transect was surveyed at each reference reef sampling station. Each transect was 2 m wide × 2 m high × 40 m long representing a total sample volume for the two transects of 320 m<sup>3</sup> per depth strata for each artificial reef module or reference reef station. To avoid disturbing fish by air bubbles expelled from divers, the surface stratum was sampled first, followed sequentially by the midwater and bottom strata. The effects of daily variation in fish abundance and species richness on differences among the various artificial and natural reefs were minimized by sampling one module from each artificial reef location and one station from each reference reef on any given sample date. Using this method, a total of seven sample dates were needed to complete each survey.

Every reef-associated fish encountered along each transect was recorded and its total length (TL) was estimated to the nearest cm. For aggregating species such as the blacksmith, *Chromis punctipinis* Cooper, 1863, and salema, *Xenistius californiensis* (Steindachner, 1876), the number and mean size of individuals in a group were estimated. Cryptic species such as the blackeye goby, *Rhinogobios nicholsii* (Bean, 1882), and the California scorpionfish, *Scorpaena guttata* Girard, 1854, were recorded along the two bottom transects at each artificial reef module and reference reef station as divers returned along the bottom after completing sampling of less cryptic fish. Divers did not overturn rocks or sort through algae when surveying fish, which likely resulted in under estimates of the density of highly cryptic and camouflaged fishes. Data on TL were used to classify a fish as either a YOY or a resident.

**PERFORMANCE EVALUATION.**—The performance standard for fish standing stock was evaluated for each reef design by estimating the biomass of fishes throughout the water column per  $\text{m}^2$  of reef and scaling 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,b; Wildermuth, 1983; Mahan, 1985; Stepien, 1986; DeMartini et al., 1994). These values were used to estimate the mean mass of all fish species per  $\text{m}^3$  of bottom, midwater, and surface habitats. The amount of midwater habitat was defined as the depth in m minus the 2 m strata at the surface and bottom (i.e., midwater =  $Z - 4$  m). Fish mass in the surface, midwater, and bottom habitats was summed to obtain the standing stock of fishes throughout the water column per  $\text{m}^2$  of reef. This value was converted to  $\text{mt } 61 \text{ ha}^{-1}$  for the purpose of evaluating the performance standard for fish standing stock.

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 SCAR 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 abundance and species richness of resident and YOY fishes 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 abundance on low coverage rock reefs) 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 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 were done using data from 2004, the last year of the 5-yr experiment. 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 to their proportional volume of the water column, thus providing a mean estimate of the number of fish in the water column over  $160 \text{ m}^2$  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 species richness was calculated using the combined number of distinct species present in the two replicate transects of the three depth strata, thus providing an estimate of the number of fish species in the water column over  $160 \text{ m}^2$  of bottom for each artificial reef design and for each natural reference reef.

While the degree of similarity in the species assemblages of the artificial and reference reefs is not a standard that the CCC chose to use 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 resident fishes between the different artificial reef designs and the reference reefs using Czekanowski’s index of similarity (Pielou, 1984) that was modified for use with relative abundances (percentages) such that:

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

where  $P_{Xi}$  is the relative abundance of species  $i$  at artificial reef design  $X$ .  $P_{Yi}$  is the relative abundance of species  $i$  at reference site  $Y$ , which is the combination of San Mateo and Barn. Using this index  $S$  ranges from 0 (no species in common) to 100 (all species in common).

## RESULTS

**TEMPORAL PATTERNS OF ABUNDANCE AND SPECIES RICHNESS OF RESIDENT FISHES.**—Reef-associated fishes > 1-yr old rapidly colonized the bottom 2 m of the artificial reef modules and by summer of 2000 all six reef designs displayed densities of resident fishes that were similar to or greater than those observed on the nearby reference reefs (Fig. 2). The most abundant species at this time included the seniorita, *Oxyjulis californica* (Günther, 1861), sand bass, *Paralabrax nebulifer* (Girard, 1854), pile perch (*Damalichthys vacca*), and the blacksmith, *C. punctipinnis*. In contrast, resident fishes did not colonize the mid and surface portions of the water column until the following year (2001, Fig. 2) when giant kelp, *M. pyrifera*, had grown large enough to form a surface canopy on all the artificial reef modules (Reed et al., in press). Fish abundance near the bottom on the artificial reef was usually 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, *X. californiensis*, were observed near the bottom on two of the low cover rock modules, and in 2004 when large numbers of the small wrasse, *O. 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.

All the artificial reef designs typically supported more species of resident fishes than the natural reference reefs (Fig. 3). 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 similar, whereas 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 2 yrs, and by the end of the 5-yr experiment differences in species richness among modules with different bottom coverages were less obvious, particularly on concrete modules.

The overall assemblages of resident fishes on the artificial reefs showed a high degree of similarity to that of the natural reefs (Fig. 4). 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 5-yr experiment averaging 78%. The blacksmith, *C. punctipinnis*, the seniorita, *O. californica*, and the kelp perch, *Brachyistius frenatus* Gill, 1862, were the most numerically abundant fishes

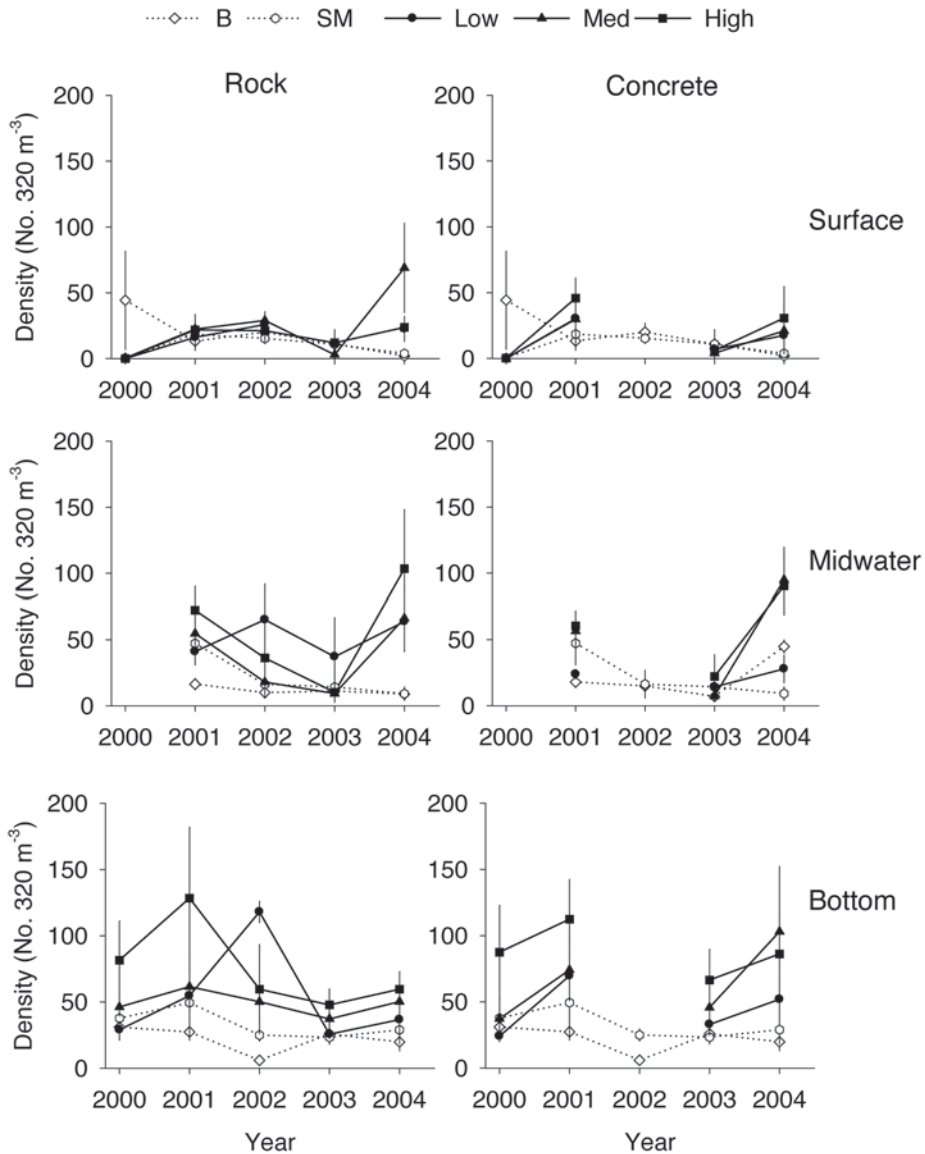


Figure 2. Change in the mean ( $\pm$  SE) density of resident kelp forest fishes over time at the bottom, midwater, and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high), and for the reference reefs (B and SM).

on the artificial reef modules in 2004 accounting for nearly 65% of all the fishes observed (Fig. 5). Senorita and blacksmith were also among the most abundant species at the reference reefs, however, kelp perch were conspicuously absent there. 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 (Reed et al., in press). Another noteworthy difference in the fish assemblages on the artificial and natural reefs is that the relative abundance of predatory basses (*P. clathratus* and *P.*

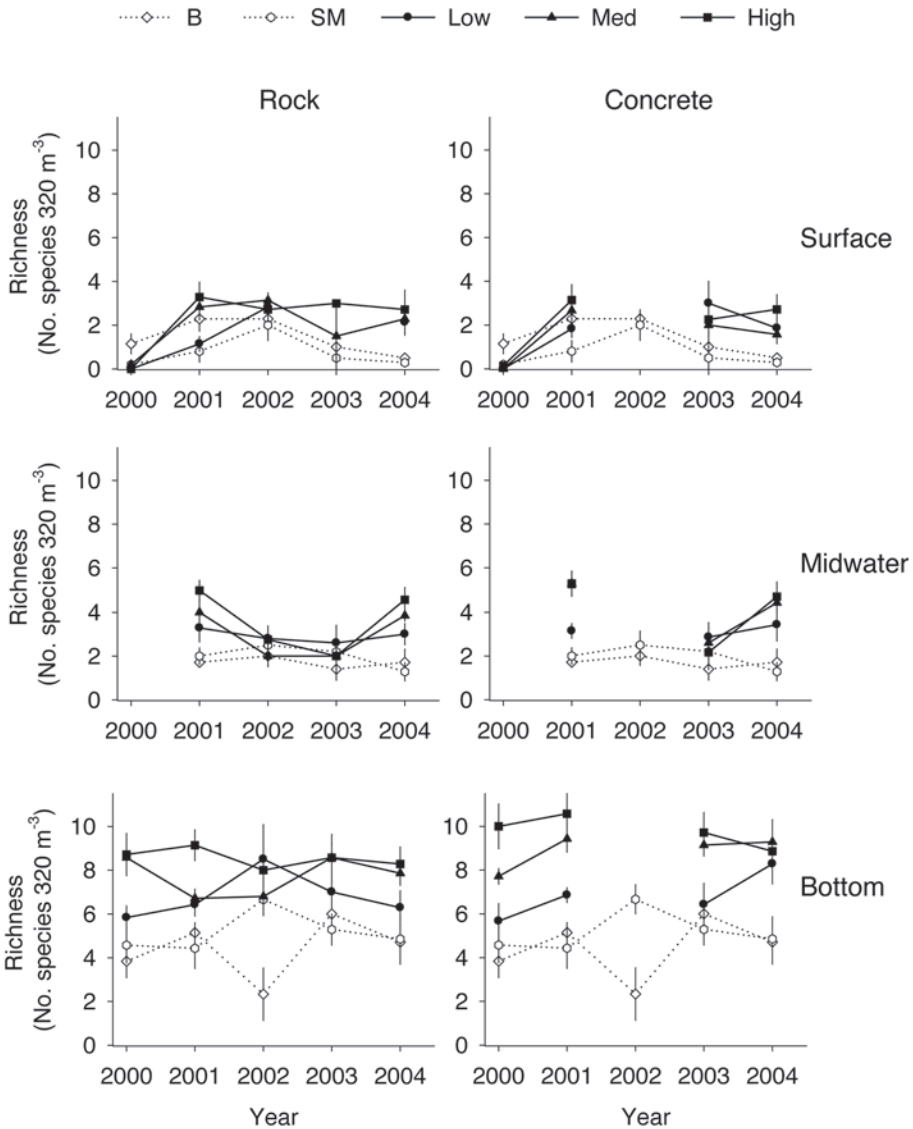


Figure 3. Change in the mean ( $\pm$  SE) number of species of resident kelp forest fishes over time at the bottom, midwater, and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high), and for the reference reefs (B and SM).

*nebulifer*) was about three times less on SCAR compared to Barn and San Mateo (7% vs 20%; Fig. 5).

TEMPORAL PATTERNS OF ABUNDANCE AND SPECIES RICHNESS OF YOY FISHES.— The recruitment of YOY fishes varied markedly among years (Fig. 6). 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 (*C. punctipinnis*) and seniorita (*O. californica*) recruited to the bottom habitat of the artificial reef modules and to a lesser extent the natural reefs.

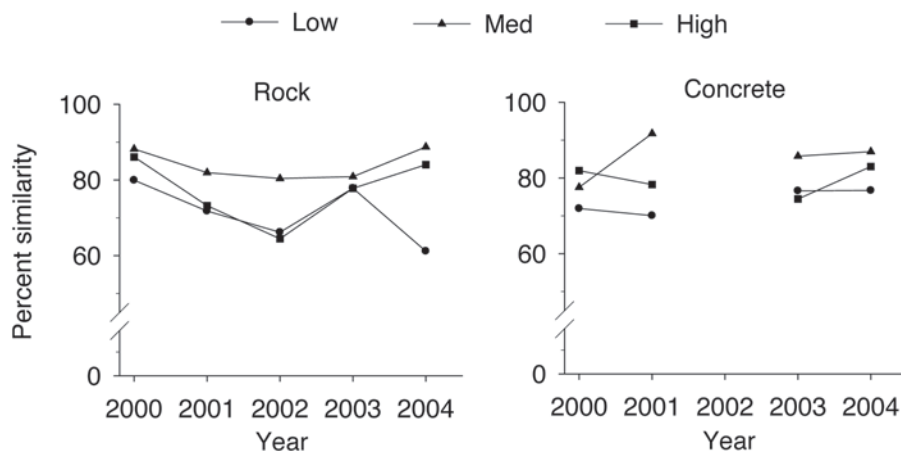


Figure 4. Percent similarity in the assemblages of resident kelp forest fishes between the mean of the reference reefs and artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high).

As was observed with older fish, 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 seniorita occasionally recruited to these habitats.

Species richness of YOY was generally low at the artificial reef and reference reefs throughout the study and rarely averaged more than two species per every two transects sampled (Fig. 7). In total, only 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 greatest near the bottom. YOY species richness also roughly scaled to the bottom coverage of reef material, but the pattern was much less pronounced than the one seen for abundance.

**STANDING STOCK OF KELP FOREST FISHES.**—Similar to fish density and species richness, the standing stock of kelp forest fishes tended to be higher on artificial reefs with greater bottom coverage (Fig. 8). 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 (Fig. 8). The standing stock of fishes projected to 61 ha was near or above the 25.4 mt performance standard on all artificial reef designs for each year of the 5-yr experiment. By contrast, estimates of fish standing stock on a 61 ha equivalent of the nearby natural reefs (actual areas of Barn and San Mateo were ~ 70 and 166 ha, respectively) were almost always less than the performance standard.

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* Ayres,

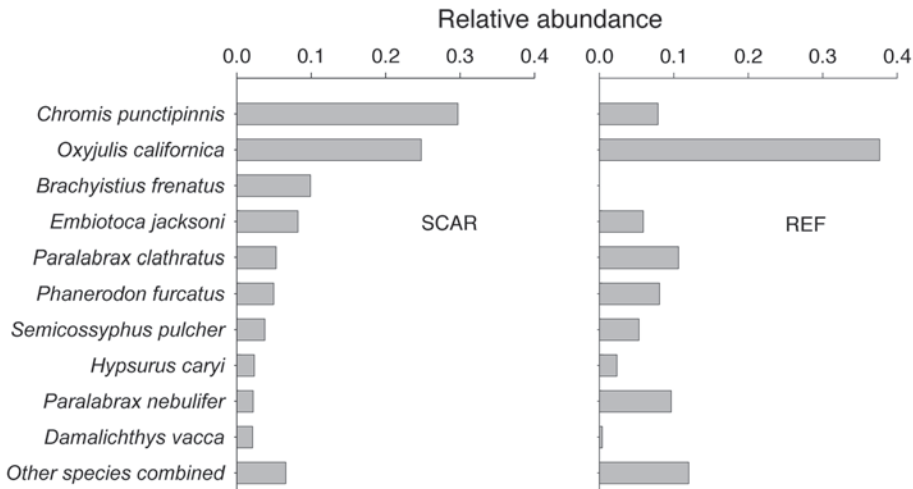


Figure 5. Relative abundance (shown as a proportion of total abundance) of the ten most common species of resident fish on the artificial reef (SCAR) and the natural reference reefs, Barn and San Mateo combined (REF) in summer 2004.

1859 at one of our stations at San Mateo in 2001 (Fig. 8). This once abundant large grouper has been over-fished throughout most of its range and is now 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 (Fig. 8), and the overall relationship between standing stock and density of resident fishes improved dramatically ( $R^2 = 0.587$ ).

EVALUATION OF PERFORMANCE STANDARDS.—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 (Fig. 9). However, the differences between the two approaches had little effect on the conclusions pertaining to compliance of the performance standard for either resident or YOY kelp forest fishes. The total density and species richness of resident fishes were well above the critical ranges set by both approaches for all six artificial reef designs. 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. 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. With one exception, the analytical approach used had little effect on whether the performance standards for YOY were attained. The single exception was for species richness on medium covered rock, which was slightly above the critical range set by the universe approach and slightly below the range set by the sample approach. Importantly, none of the artificial reef designs had mean values of either resident or YOY fishes that were below the performance standards.

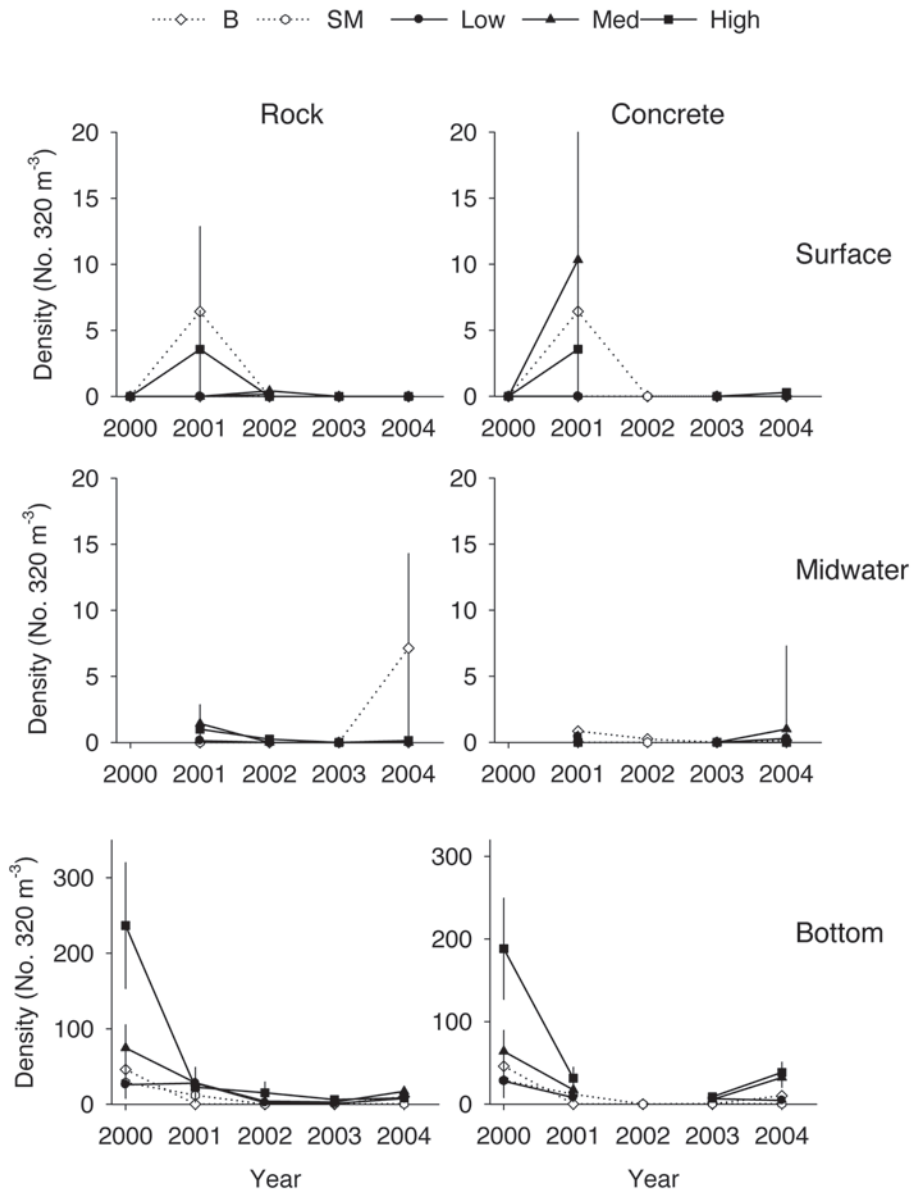


Figure 6. Change in the mean ( $\pm$  SE) density of YOY kelp forest fishes over time at the bottom, midwater, and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high), and for the reference reefs (B and SM).

### DISCUSSION

Our results show that fish standing stock, density, species richness, and recruitment on all the artificial reef designs were either similar to or greater than that observed at the nearby natural reefs at San Mateo and Barn. These findings are consistent with those of previous studies that found the numerical and biomass densities of fishes to

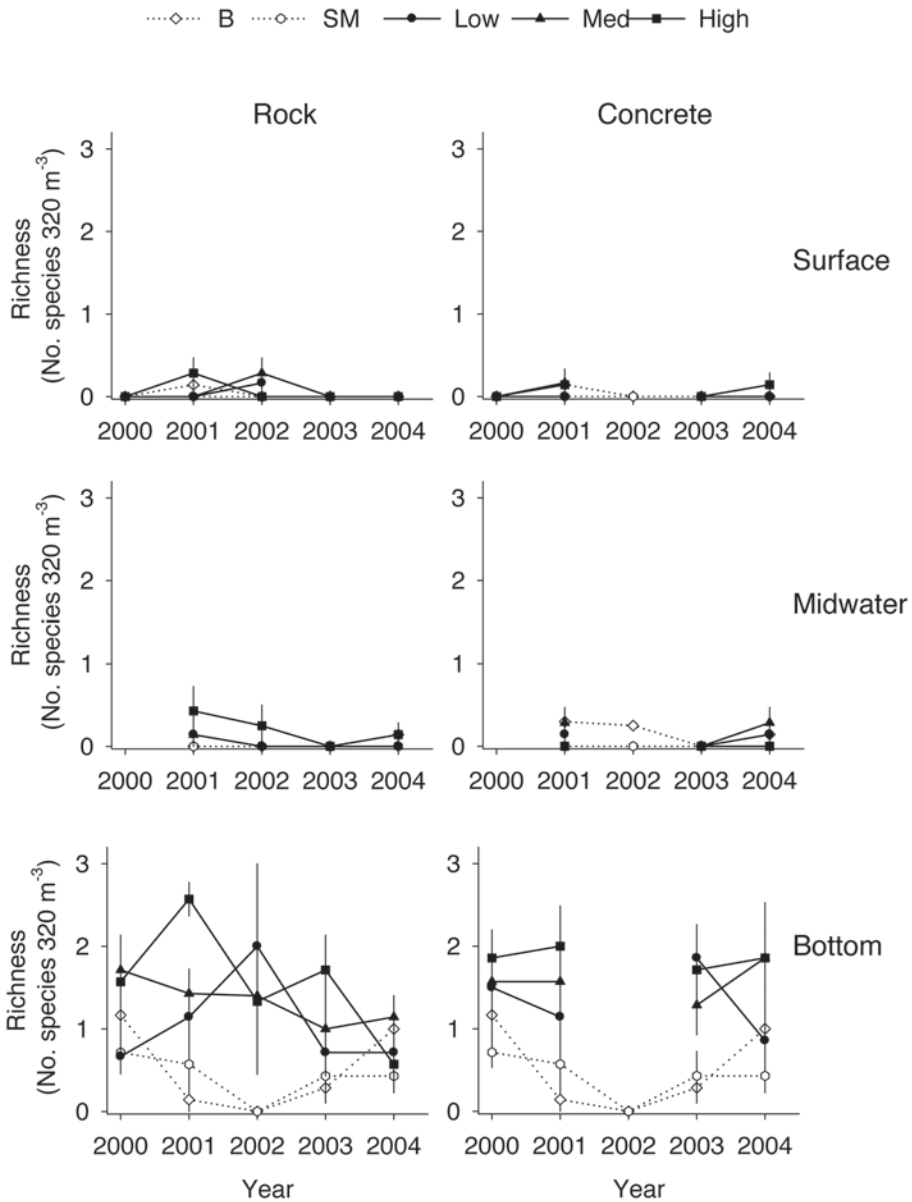


Figure 7. Change in the mean ( $\pm$  SE) number of species of YOY kelp forest fishes over time at the bottom, midwater, and surface canopy for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low, medium, and high), and for the reference reefs (B and SM).

be higher on artificial reefs compared to natural reefs in southern California (Jesse et al., 1985; Ambrose and Swarbrick, 1989; DeMartini et al., 1989) and elsewhere (reviewed in Bohnsack and Sutherland, 1985). Similar to earlier studies (Stephens et al., 1984; Ambrose and Swarbrick, 1989), we also found that the species assemblages of fishes on the artificial reef modules displayed a high degree of similarity to the natural reference reefs. Collectively, our results indicate that all of the reef designs

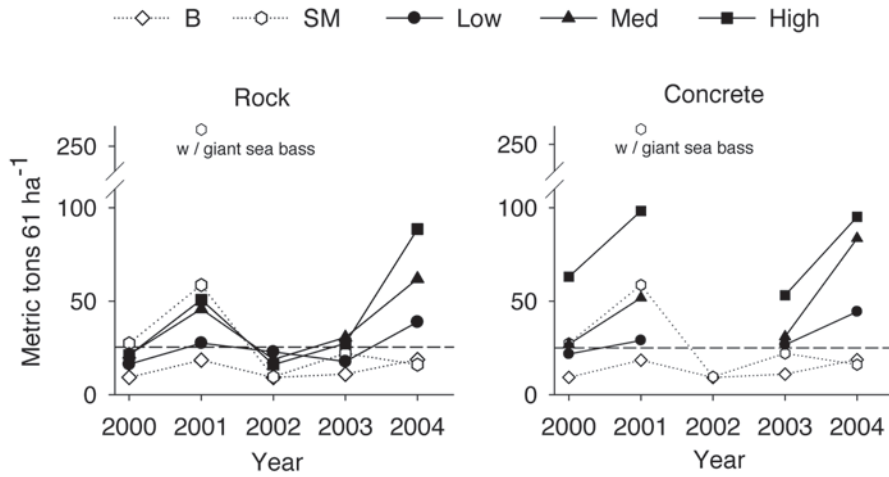


Figure 8. Change in the projected standing stock of kelp forest fishes over time for artificial reef designs with different substrate types (rock and concrete) and bottom coverages (low medium and high) and for the reference reefs (B and SM). The dashed horizontal line indicates the permit standard of 25.4 mt for the 61 ha mitigation reef. See text for how projections were made.

tested in the experiment are likely to provide adequate in-kind compensation for the loss of kelp forest fishes caused by SONGS’s operation.

Quarry rock and rubble concrete are the two materials most preferred by the California Department of Fish and Game for constructing artificial reefs in California (Wilson et al., 1990). Little is known, however, about the extent to which the biota on quarry rock and concrete reefs in California differ. Typically there are large differences in the sizes and shapes of quarry rock and concrete used to build artificial reefs in California, which makes it difficult to evaluate the effects of the material properties of rock and concrete on reef biota. The confounding factors often associated with large difference in the sizes and shape or rock and concrete were minimized in the construction of SCAR, making it possible to isolate differences between similar sized reefs constructed of quarry rock and concrete rubble in a large-scale replicated experiment. We found very similar patterns between rock and concrete reefs for the density and species richness of resident and YOY fishes, indicating that kelp forest fish assemblages may be relatively insensitive to the properties of these two materials that are commonly used to construct artificial reefs in California. Physical characteristics other than material properties, however, may greatly influence the abundance and diversity of fishes on artificial reefs. For example, we found that the amount of the bottom within the reef footprint covered by hard substrate (something which previously had not been systematically manipulated) had a substantial influence on the fish assemblage, with higher densities and numbers of species occurring on artificial reef modules with greater bottom coverage. Others have suggested that topographic relief and microhabitat features (characteristics not examined in our study) have a large effect on the assemblage of fishes inhabiting artificial reefs with higher relief reefs supporting greater densities and numbers of species than lower relief reefs (Jesse et al., 1985; Ambrose and Swarbrick, 1989; Patton et al., 1994) and reef crest and slope habitats supporting different densities and ages of fishes than the reef margins and adjacent sand flats (Anderson et al., 1989; Andrews and Anderson, 2004).

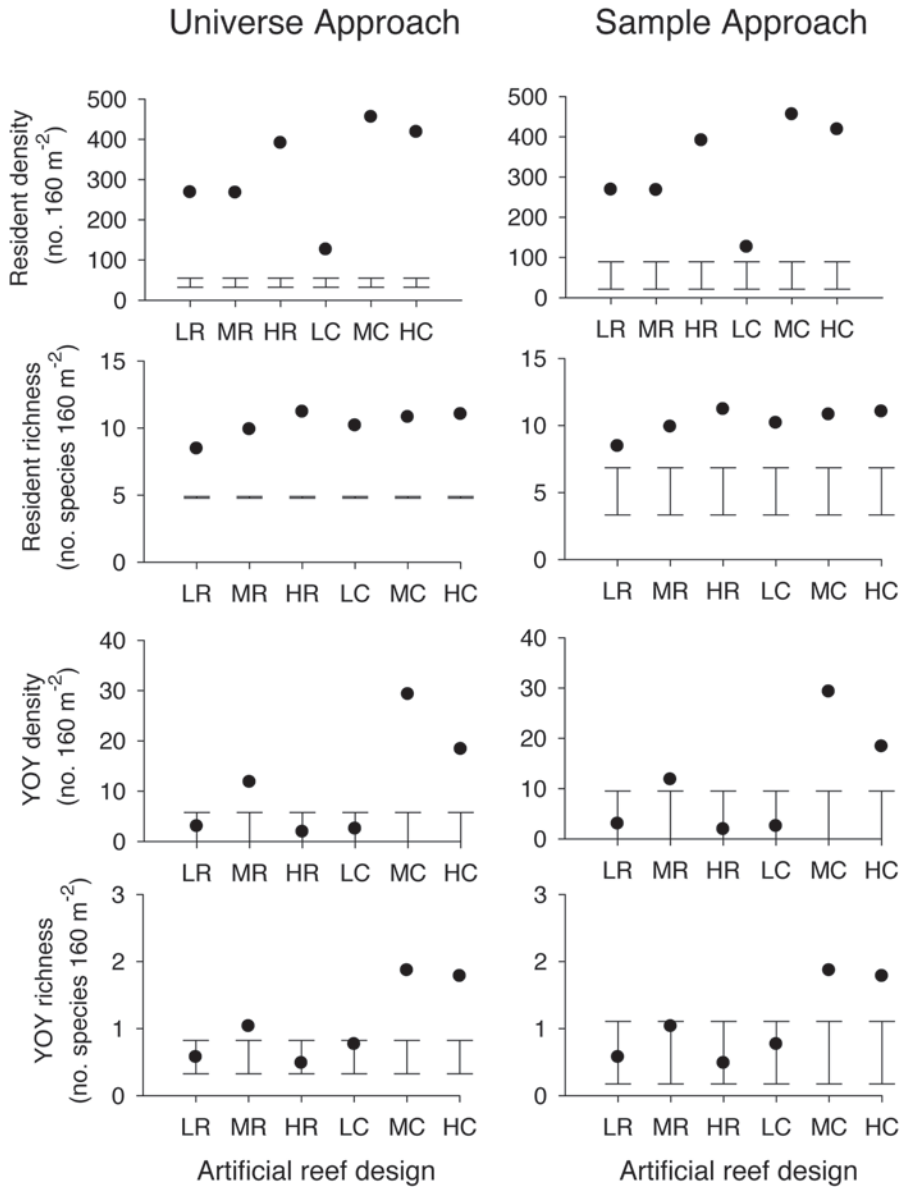


Figure 9. Evaluation of the SONGS relative performance standards pertaining to the density and species richness of resident and YOY kelp forest fishes using the universe and sample approaches (see text for details on approaches). Solid circles indicate the means of the artificial reef designs ( $n = 7$  modules). Vertical bars with horizontal caps indicate the critical ranges used to evaluate similarity between the different artificial reef designs and the natural reference reefs (SM and B). 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.

Despite their seemingly high potential for serving as suitable habitat for kelp forest fishes, the different artificial reef designs may not be entirely compatible with all the SONGS performance standards pertaining to kelp forest fishes. The standards require that the densities and species richness on the artificial reef be similar to that on natural reference reefs within the region. However, in many cases the densities and number of species of kelp forest fishes on the artificial reefs actually exceeded the critical levels used for measuring similarity with the natural reefs. 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. 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 (Carlise 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).

Giant kelp is currently abundant on the artificial reef modules off San Clemente (Reed et al., 2004, 2005). Whether it remains abundant on the future larger mitigation reef undoubtedly will depend in part on the physical characteristics of the reef. Incorporating topographic features that help to control rates of fish grazing into the design of the SONGS mitigation reef will serve to maximize the likelihood that mitigation project meets the performance standards for all components of the kelp forest community. Patton et al. (1994) found that the intensity of fish grazing and its adverse effects on giant kelp were positively correlated with high bottom relief, whereas we found that fish density was positively correlated to high bottom coverage (our study was not designed to examine the effects of bottom relief). Low bottom coverage of rock might result in low grazing intensities, but it would likely also have densities of fishes below the densities on natural reefs used for reference. Collectively, these findings suggest that a low relief artificial reef with mean bottom coverage similar to that of nearby natural reefs (as was the case in our low coverage modules) is likely to prove most successful in attaining the goals of the SONGS mitigation project.

The experimental phase of the SONGS artificial reef project is one of the largest artificial reef experiments ever attempted. Despite its relatively large scale (56 modules that collectively covered 9 ha of the seafloor), there are still limitations to what it can tell us about the performance of a 61 ha reef needed for mitigation. There are potential problems with scaling up the results obtained from 0.16 ha experimental modules to the mitigation reef. Any edge or "island" effects present on the experimental modules may be quite different from those that occur on an artificial reef that is nearly 400 times as large. Also, the relatively small size of the modules coupled with the movement patterns of many species made it difficult to evaluate performance standards pertaining to fish reproduction and biomass production. Other limitations come from sampling constraints that are independent of reef size. For

example, the inherent spatial and temporal patchiness in fish abundance may require additional sampling effort to better resolve differences between the natural and mitigation reefs, which may prove costly. We found that the occurrence of a few large fish profoundly influenced our estimates of density and biomass in the midwater, suggesting that additional transects may be needed before attempting to extrapolate fish densities and standing stock throughout the water.

In conclusion, our experimental results indicate that low-relief artificial reefs having a wide range in the bottom coverage of rock or concrete coverage generally appear to be suitable for mitigating impacts to kelp forest fishes. By most measures, all the configurations of reef material and bottom coverage that we tested in the experimental phase of SCAR provided suitable habitat for kelp forest fishes. However, like most artificial reef projects, an important objective of the SONGS artificial reef project is that the mitigation reef be successful in producing new fish biomass and not simply attract fishes from other areas (Bohnsack and Southerland, 1985). We did not examine fish production on the experimental reef modules, although it is a performance standard that will be evaluated on the larger 61 ha mitigation reef. Previous studies have shown that fish production was enhanced by artificial reefs in the region (DeMartini et al., 1993; Johnson et al., 1994), however, the authors made no attempt to compare fish production on those artificial reefs to that of nearby natural reefs. Nonetheless, fish density, standing stock, recruitment, and species composition on the artificial reef modules were all similar to or greater than that of nearby natural reef, suggesting that a low-relief artificial reef may be broadly suitable for compensating for losses of kelp forest fishes caused by the operation of SONGS. Because the SONGS mitigation reef is intended to compensate for the loss of an entire community of algae, invertebrates and fishes, its ultimate design will need to be "tuned" to meet the overall project objective of producing a balanced kelp forest community that has the appropriate representation of all trophic elements.

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