MONITORING AND MANAGEMENT PLAN FOR THE SONGS EXPERIMENTAL KELP REEF

California Coastal Commission Staff

June 1999

MONITORING AND MANAGEMENT PLAN FOR THE SONGS EXPERIMENTAL REEF

EXECUTIVE SUMMARY

The California Coastal Commission (CCC) requires Southern California Edison (SCE) and its partners to select a site and construct an artificial reef as partial mitigation for the resource losses at the San Onofre Kelp Bed (SOK) caused by the operation of San Onofre Nuclear Generating Station (SONGS) Units 2 and 3. The reef is to be located in the vicinity of SONGS with the goal of replacing a minimum of 150 acres (= 60.70 hectares) of kelp forest community. Mitigation for losses of kelp bed resources through the construction of an artificial reef will be done in two phases; a five year experimental phase followed by a mitigation phase having a duration equivalent to the operating life of SONGS Units 2 and 3. The primary objective of the experimental phase is to determine the substrate types and configurations that best provide adequate conditions for establishing and sustaining giant kelp and other reef-associated biota during the mitigation phase. Originally the CCC required that the mitigation reef be constructed of quarry rock covering at least two-thirds of the reef. The CCC later 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 of medium to high density giant kelp and associated kelp forest biota. Thus, a major objective of monitoring the experimental reef is to collect the information needed to determine whether substrate coverages less than two-thirds and substrate types other than quarry rock (e.g. recycled concrete) can be used to meet the performance standards for the mitigation reef. The plan for the experimental phase calls for seven replicate blocks of of eight reef designs (each consisting of a 0.4-acre module) that have varying combinations of substrate cover, substrate type and kelp transplanting.

Deciding on the best design for the mitigation reef using information gathered from the experimental phase entails uncertainties that stem from the relatively small temporal and spatial scales of the experiment compared to the mitigation reef. Because of these constraints, it is possible that none of the reef designs tested in the experiment will develop a sustainable kelp community that meets the performance criteria for the mitigation reef. In this event the Executive Director will need to rely on information that best *predicts* which of the reef designs will meet the performance standards when applied to the mitigation reef. To address this possible need, the staff will take a three-part approach to evaluating the results of the experimental reef. First, physical and biological variables will be monitored to determine the degree to which the eight reef designs achieve certain performance standards that will be used to judge the larger mitigation reef (e.g.the amount of rock that has to remain on top of the sand, and the abundance and diversity of fish, invertebrates and algae that the reefs must support). Second, monitoring data will be used to evaluate the performance of the eight reef designs relative to each other. Third, experiments will be done and additional data will be collected that relate key physical and biological processes to: (1) specific aspects of community development, and (2) the degree of success in achieving the performance criteria.

The monitoring data will be used primarily to describe “what’s there”. Information obtained from experiments and focused sampling will be used to predict “what will be there over the long term”. Collectively, these data will be used to predict which design(s) will most likely be successful if applied to the mitigation reef using a weight of evidence approach. The product of this monitoring program will be a final report to the Executive Director on all findings gathered during the artificial reef experiment. The report will include a recommendation on the substrate types and coverages deemed suitable for the mitigation reef. The final report and the datasets and analyses contained within it will be made available to the SCE and other interested parties for review and comment. Those comments along with final report will form the basis for the Executive Director’s decision on the type(s) and coverage(s) of substrate allowable for the mitigation reef.

1.0 INTRODUCTION

Through its 1991 and 1997 coastal permit actions, the California Coastal Commission (CCC) adopted permit conditions that require Southern California Edison (SCE) and its partners to select a site and construct an artificial reef as partial mitigation for the resource losses at the San Onofre Kelp Bed (SOK) caused by the operation of San Onofre Nuclear Generating Station (SONGS) Units 2 and 3. The reef is to be located in the vicinity of SONGS with the goal of replacing a minimum of 150 acres (= 60.70 hectares) of kelp forest community. Performance standards for reef substrate, giant kelp, fish, and benthos specified in the permit condition will be used to evaluate whether this goal has been met.

Mitigation for losses of kelp bed resources through the construction of an artificial reef is to be done in two phases, a five year experimental phase followed by a mitigation phase having a duration equivalent to the operating life of SONGS Units 2 and 3. A preliminary plan (“San Onofre Marine Mitigation Program: Experimental Reef for Kelp”) describing the location and design of the experimental reef was submitted to the CCC by SCE on June 16, 1997 and approved by the Executive Director of the CCC on June 26, 1997. The preliminary plan was revised in April 1999 to address comments made during the environmental review. The revised plan was developed by SCE staff and consultants in cooperation with the staffs of the CCC, the California State Lands Commission, and the California Department of Fish and Game and represents a consensus of all participants. Specific details of the experimental reef including its siting and design are given in the Program Environmental Impact Report (PEIR) prepared for the California State Lands Commission (April 1999). Briefly, the plan calls for 22.4 acres (= 9.1 hectares) of hard substrate to be placed in a 2.5 km long x 0.5 km wide area between San Mateo kelp bed (SMK) and San Clemente Pier. Eight reef designs consisting of two types of hard substrate (quarry rock and recycled concrete), three levels of substrate coverage (17%, 34% and

67%) and two levels of kelp abundance (with and without transplanted kelp on 34 % coverage of rock and concrete) will be tested in the experimental phase. One 0.4 acre module of each design will be placed within each of seven blocks arranged at progressively farther distances from SMK.

The SONGS coastal development permit requires that Coastal Commission scientists develop a monitoring plan for the experimental reef that describes how the effectiveness of alternative reef designs, materials, and management techniques will be assessed. This document serves as the conceptual basis for the monitoring plan for the experimental reef. It will be the basis for a detailed work plan to follow.

2.0 RATIONALE FOR MONITORING APPROACH

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 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., recycled 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 to meet the permit conditions.

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. meet the performance criteria) will continue to perform successfully in the future. Given these uncertainties, it is possible that none of the experimental modules will develop a sustainable kelp community that meets the performance criteria for the mitigation reef. In this event the Executive Director will need to rely on information that best *predicts* which of the reef designs will meet the performance standards when applied to the mitigation reef.

To address this possible need, the Commission staff scientists will take a three-part approach to evaluating the results of the experimental reef. First, physical and biological variables will be monitored to determine the degree to which the eight reef designs achieve the performance criteria. Second, monitoring data will be used to evaluate the performance of the eight reef designs relative to each other. Finally, experiments will be done and additional data will be collected and used to predict which design(s) will most likely be successful if applied to the mitigation reef. These data will relate 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 it. 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 species (e.g., sea fans) which can monopolize space on hard substrates and prevent the establishment of kelp. Results from these process studies will be used to predict whether the criteria for evaluating the performance of the different reef designs are likely to be met and how long it will likely take to meet them. Data on rates of propagule settlement, recruitment and survivorship (which will not be collected in the routine monitoring) will be particularly useful for making these predictions. Information obtained from process studies also will be 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).

Our 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 the state variables that describe the state of the community will be obtained from spatially representative monitoring of the experimental modules and reference reefs to describe “what’s there.” Insight into processes will be obtained from focused sampling and experiments aimed at predicting “what will be there over the long term.”

3.0 CRITERIA FOR EVALUATING THE EXPERIMENTAL REEF

Although success of a particular reef design does not depend on the achievement of specific performance standards, the criteria by which the experimental reef will be evaluated are a subset of the permit performance standards by which the success of the larger mitigation reef will be judged. This choice of criteria was motivated by the need to predict which of the reef designs are most likely to produce a full-sized mitigation reef whose performance will meet the standards of the permit. These standards 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.

Not all of the performance standards to be applied to the mitigation reef are appropriate for evaluating the results of the experimental reef. For example, because fish are likely to move among different reef modules, the relatively small size of the modules (0.4 acres) precludes obtaining reasonable estimates of fish production, reproductive rates, and standing stock that can be scaled up to the size of the mitigation reef. Given these kinds of constraints, only the following subset of the performance standards for the mitigation reef will be used as criteria to evaluate the performance of the different experimental reef designs:

1) 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) there must be a sustained giant kelp density of at least 4 adult plants per 100 m^2.

3) adult and young-of-year fish assemblages must be similar in density and species number to natural reefs within the region (although fish may move among modules, the extent to which their density and species number varies with module type should provide some insight into the ability of the different reef designs to meet the other performance standards for fish required of the mitigation reef).

4) algal and macroinvertebrate assemblages must be similar in abundance (density or % cover) and species number to natural reefs within the region.

It is important to note that the four performance criteria listed above are not the only ones by which the different reef designs will be evaluated. Information on the performance of different designs relative to each other, and on the biological and physical processes that affect their performance will also be used to evaluate their potential to meet the performance standards of the mitigation reef over the long term.

4.0 REFERENCE SITES

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 those on the natural reefs used for reference. One way to help ensure that this will be the case is to select reference reefs that are close to and 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 will help ensure that regional changes in oceanographic conditions affecting the experimental reef will be reflected in the performance criteria, since nearby natural reefs will be subjected to similar changes in oceanographic conditions.

Plots with spatial dimensions similar to experimental modules will be selected from kelp beds within the region near SONGS and used as natural reference reefs. Coverage of hard substrate will not be an explicit criterion for selecting reference reefs. Instead, the criteria to be used in choosing plots within reference reefs shall be 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 reef module have persistent stands of giant kelp is 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 is important that it be present on the natural reference reefs during the five-year experiment. Because species composition and abundance varies greatly within and among natural reefs it is important that the number and spacing of reference plots be sufficient to allow the performance of different reef designs to be compared to the wide range of variation that occurs naturally. Also 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). This is a concern for the experimental reef because the plant and animal assemblages associated with persistent populations of kelp are needed to evaluate the performance of the different reef designs. The use of multiple reference plots will help to ensure a standard for comparison for the experimental reef is maintained, even in the event of localized extinctions of giant kelp. At present six to nine reference plots are anticipated and possible locations for them include San Mateo Point, Barn kelp bed, and the down coast portion of San Onofre kelp bed. The number of reference sites and their locations will be not be decided upon prior to the completion of reef construction.

5.0 DATA COLLECTION

All experimental modules and natural reference plots will be monitored for the entire five year experiment. The purpose of collecting data throughout the experiment is to assess differences in rates of development (and processes affecting development) between the different reef designs, and to determine whether the biota on the different reef designs has stabilized. Monitoring reference plots for the duration of the experiment is critical. If the biological assemblages on any of the experimental modules have not stabilized after five years, then data collected from natural reference reefs will be used to determine whether the lack of stability reflects natural variability in the region. Permanently fixed quadrats and transects will be used to ensure that differences observed over time reflect temporal rather than spatial variability in the performance of the experimental modules. Additional randomly placed quadrats and transects will be sampled periodically to ensure that the permanent areas sampled provide an accurate description of each reef module.

Described below are the monitoring activities and process-oriented studies proposed for each of the four criteria (which are subsets of the permit compliance standards for the mitigation reef) used to evaluate the performance of the different reef designs. Information obtained from both monitoring and process studies will be used to determine the best design for the mitigation reef. Monitoring will be done on experimental modules and natural reference reefs. Process studies will be done mainly on experimental modules, although in some cases natural reference reefs will be studied as well. Modifications in these activities may be necessary to accommodate new information obtained during the course of the five-year experiment. The work schedules for the monitoring and process studies described below are summarized in Table 1 and Table 2 on page 23.

5.1 *CRITERION 1:* AT LEAST 90% OF THE INITIAL AREA OF HARD SUBSTRATE (AS DETERMINED BY THE FIRST POST-CONSTRUCTION SURVEY) MUST REMAIN AVAILABLE FOR ATTACHMENT OF REEF BIOTA.

Monitoring*.* High-resolution surveys using side-scanning sonar (or other technology if found to be more appropriate) will be done once each year in the summer to map the boundaries of each module, and to determine the topography and coverage of hard substrate and the coverage and distribution of sand. Additional surveys may be done to evaluate the effects of any extreme oceanographic events on changes in the coverage of hard substrate. Sonic positioning buoys will be used to ensure that vessel tracks are within +/-1 meter on repeated surveys. This will allow for synoptic side-scan pictures of each module (which will include module area or “footprint”, percent coverage of hard substrate and sand, and topography) that will reflect temporal rather than spatial variability. The high-resolution side-scanning sonar has a resolution of several cm and includes sophisticated image analysis software that allows one to distinguish between sand and hard substrate at that scale. Initially, diver surveys will be done in combination with the side-scanning sonar surveys to ground truth the maps and substrate coverage of each module.

Process studies. The loss of available hard substrate on a reef can result from subsidence of reef material or burial due to sediment accumulation. While high-resolution side-scanning sonar can be used to accurately measure both small and large physical attributes of the reef modules, it may not be able to distinguish between burial due to subsidence vs. burial due to accretion. Such information is needed to determine whether the rate of burial of a particular design is likely to vary in different locations in the San Clemente lease site that vary with respect to sand depth and accretion. Therefore, data on subsidence and accretion will be collected by divers from marked stakes placed on the bottom at various locations on each of the experimental modules. Sediment thickness at the stakes will be sampled during winter and summer, which is when it is expected to be at its maximum and minimum levels. Stakes will be placed only on experimental modules since the purpose for these studies is to determine the degree to which rates of subsidence and accretion vary as functions of the size, shape, type and coverage of hard substrate, location within a module, and module location within the San Clemente lease site. Winter and summer surveys are likely to capture the effects of extreme oceanographic conditions that affect burial. Additional opportunistic sampling will be done to capture rare oceanographic events

5.2 *CRITERION 2:* THERE MUST BE A SUSTAINED GIANT KELP DENSITY OF AT LEAST 4 ADULT PLANTS PER 100 M^2.

Monitoring. Adult giant kelp will be monitored by divers in multiple transects totaling 480 m^2 per module. This is the size of the replicate sampling areas used in the Marine Review Committee's down-looking sonar estimates of adult kelp, which were used to calculate kelp losses. Adult giant kelp is defined as having eight or more fronds, which was the resolution of the down-looking sonar used to estimate kelp losses. Each 480 m^2 area will be made up of four permanently marked transects that will be ~ 40 m long X 3 m wide. The fixed transects will ensure that the counts reflect temporal rather than spatial variability. The exact lengths and positions of these transects will be determined after the boundaries of the modules have been determined from the post-construction side-scan sonar surveys. Each adult plant encountered on the transects will be tagged and its location on the transect will be recorded. Divers will also count the number of fronds > 1 m tall for each adult, and measure the diameter of the holdfast and the size of the substrate to which it is attached. Diver surveys will be done in the winter and summer each year (corresponding to the periods of minimum and maximum kelp density).

Process studies. The types of studies of giant kelp will depend on whether kelp becomes quickly established. If giant kelp fails to become established quickly on the experimental modules, then studies and experiments will be done to determine the cause(s) of this failure. The lack of kelp on an experimental module can result from: (1) insufficient settlement of kelp spores, or (2) processes occurring after spore settlement that adversely affect the survivorship of microscopic and macroscopic kelp stages.

To determine whether the absence of kelp on an experimental module is due to insufficient spore settlement, microscope slides will be placed in the field for short periods of time (~ one week) to measure kelp spore settlement and gametophyte recruitment[1]. The influence of substrate type and coverage on spore availability is expected to be small relative to that of distance from a large kelp bed. Consequently, spore settlement will be examined relative to distance from SMK rather than as a function of reef design. To accomplish this, microscope slides will be placed on or near the bottom in a linear array at increasing distances from SMK throughout the lease site.

Factors influencing the survivorship of microscopic and juvenile macroscopic benthic stages of kelp will be investigated on the experimental modules only by monitoring their abundance at spatial scales appropriate for their small size, and through the use of transplant experiments. Samples collected in the field and grown out in the laboratory will be used to estimate natural densities of early life stages during the spring, which is the time of peak abundance. Sampling of natural populations will be supplemented with transplant experiments to evaluate factors affecting stage-specific survivorship[2]. These experiments will be designed to complement additional monitoring of growth and mortality of marked individuals on modules that contain transplanted kelp as part of their design. Monitoring and experiments will be designed to determine the extent to which survivorship and growth of microscopic and macroscopic stages of kelp vary with reef design, substrate size, location within a module (i.e., edge vs. middle), location within the San Clemente site, and interactions with other species (e.g., sea urchins, or sea fans).

---

[1] Reed, D. C., D. R. Laur, and A. W. Ebeling. 1988. Variation in algal dispersal and recruitment: the importance of episodic events. Ecological Monographs **58**:321–335.

Reed, D.C., A.W. Ebeling, T.W. Anderson, and M. Anghera. 1997. Role of reproductive synchrony in the colonization potential of kelp. Ecology **78**:2443–2457.

[2] Dean, T. A., and F. R. Jacobson. 1984. Growth of juvenile *Macrocystis pyrifera* (Laminariales) in relation to environmental factors. Marine Biology **83**:301–311.

Dean, T. A., and F. R. Jacobson. 1986. Nutrient-limited growth of juvenile kelp, *Macrocystis pyrifera*, during the 1982-1984 ‘El Niño” in southern California. Marine Biology **90**:597–601.

Reed, D. C. 1990. The effects of variable settlement and early competition on patterns of kelp recruitment. Ecology **71**:776–87.

Reed, D. C., R. J. Lewis, and M. Anghera. 1994. Effects of an open coast oil production outfall on patterns of giant kelp (*Macrocystis pyrifera*) recruitment. Marine Biology **120**:26–31.

5.3 *CRITERION 3:* ADULT AND YOUNG-OF-YEAR FISH ASSEMBLAGES MUST BE SIMILAR IN DENSITY AND SPECIES NUMBER TO NATURAL REEFS WITHIN THE REGION

Monitoring. Diver surveys will be done to estimate species richness and abundance of fish on each experimental module and in each reference reef plot. Divers will count all fish occurring along a permanent 2 m x 2 m x 40 m transect at the bottom, mid depth and surface. Counts will be grouped into different age categories (e.g., young-of-year, subadults, and adults) for every species encountered. Sampling will be done in the fall when water clarity is greatest. Because fish abundance can vary greatly over short time periods, each experimental module and control plot will be surveyed once a month for three months. All eight modules within a given block plus one reference plot will be surveyed on the same day to avoid introducing bias in estimates of the different reef designs as a result of daily variability in fish abundance. Within-day variability is believed to be small as the abundances of most kelp-bed fish vary little during daylight hours (M. Carr personal communication).

Process studies. Due to the mobility of fish and the small size and close spacing of experimental modules, it will be difficult to predict how fish production and reproductive rates will be influenced by the different reef designs. One solution to this problem is to measure easily sampled attributes that are correlated with growth and reproduction. Estimates of somatic production can be obtained from size frequency data in species having one or more age classes that maintain residence on a single module for at least one year. The juvenile stages of several species appear to satisfy this criterion (e.g. the black surfperch, blacksmith, senorita, and rock wrasse. Somatic production for species that satisfy this criterion will be obtained by estimating their densities in finely divided size classes (e.g. 2 cm intervals) and converting these estimates to total numbers in each size classes on a given experimental module or reference plot. These data will then be used to calculate annual somatic production of these subsets of the population for each experimental module and reference plot using the “Size-frequency” or “Hynes” method[3]

The basis of the method is the calculation of an average cohort or size distribution by sampling at uniform intervals over the life-span of the species (generally a year for the insects for which the method was originally devised) which is an approximation of survivorship[4]. Production is then calculated as the sum of the losses between successive pairs of size classes. For a population with an average life span of 1 year and with n size classes, it is assumed that the time in a size class is 365/n (assumes linear growth), and therefore, there are n “average cohorts” during the year. Somatic production of the average cohort is multiplied by n to obtain total annual production (P_{SF}).

---

[3] J.D. Dixon, S.C. Schroeter, and J.S. Stephens. The Use of “Fish Services” as a common measure of ecological losses form Injury to marine habitats and ecological gains from restoration activities. Report to NOAA Damage Assessment Division. February 27, 1998.

[4] Benke, A.C. 1979. A modification of the Hynes method for estimating secondary production with particular significance for multivoltine populations. Limnol. & Oceanogr. 24:168-171.

$$P_{SF} = n \sum_{i=1}^{n} (\bar{N}_i - \bar{N}_{i+1}) \bullet [(W_i + W_{i+1}) / 2]$$

Where n is the number of size classes, $\bar{N}_i$ is the average number of individuals in size class i during the year, and W_i is the average weight of individuals in size class i (estimated from allometric relationship between weight and length). Generally the average weight of individuals is calculated using a geometric rather than an arithmetic mean:

$$P_{SF} = \bar{N}_{i=n} W_{i=n} + n \sum_{i=1}^{n-1} (\bar{N}_i - \bar{N}_{i+1}) \bullet (W_i W_{i+1})^{0.5}$$

Where the first term ($\bar{N}_{i=n} W_{i=n}$) is the biomass of the last size interval and n is equal to the number of size classes measured. Growth estimates will be used to determine the appropriate class intervals. Initial estimates will be made using growth data from fish production studies conducted in southern California near the proposed experimental reef site in the early 1990's[5].

The extent to which the different reef designs influence fish reproduction will be evaluated in species likely to remain on a single module during their adult life (e.g. gobies, clinids, blennies). Adults of these species will be collected prior to parturition and their reproductive condition (gonad mass / somatic mass) will be determined. Fish will be collected from both experimental modules and reference reef plots.

5.4 *Criterion 4:* Algal and macroinvertebrate assemblages must be similar in abundance (density or % cover) and species number to natural reefs within the region.

Monitoring. Algae and macro-invertebrates will be monitored once a year in the summer. Large solitary algae and mobile macro-invertebrates will be counted in four permanent 10 m x 1 m quadrats placed systematically along each of the four permanent transects of each experimental module and reference plot. Counts for certain species will be categorized according to size class (i.e., young-of-year, subadult, adult). Subsampling will be done as needed for species that are too abundant to easily count in the 10 m x 1m quadrats.

[5] Johnson, T.D., A.M. Barnett, E.E. DeMartini, L.L. Craft, R.F. Ambrose, and L.J. Purcell. 1994. Fish production and habitat utilization on a southern California artificial reef. Bulletin of Marine Science 55: 709-723. MEC Analytical Systems. 1991. Production and valuation study of an artificial reef off southern California. Final report to the Ports of Long Beach and Los Angeles and the National Marine Fisheries Service dated April 1991.

The abundance of understory algae and sessile invertebrates (which are generally difficult to distinguish and count as individuals) will be estimated from measurements of percent cover using a point contact method that takes into account vertical layering. At every 1 meter interval on each of the four transects a diver will record all understory algae, sessile invertebrates and substrate type contacted by an imaginary vertical line that intersects the the transect line. Similar measurements will be made at points located 1 m to either side of the line for a total of 120 sample points per transect (3 points per m X 40 m). Using this method the percent cover of all species combined can exceed 100%. Table 3 lists common species of algae and macro-invertebrates that are likely to be monitored for criterion 4.

Process studies. Focused monitoring and experiments will be done to determine how different reef designs affect the recruitment and survival of species known to inhibit the development of a mature kelp forest community. One such species is the sea fan, *Muricea* spp., which has been shown to monopolize space and exclude kelp on other artificial reefs. Because *Muricea* grows slowly it is unlikely to dominate any of the experimental modules even if it were to recruit during the first year following reef construction. Therefore, transect monitoring may not reveal a *Muricea* “problem” within the five year experiment if one were to exist. To address this concern, studies aimed at *predicting* how the different reef designs will enhance or inhibit *Muricea* and other non-desirable species will be done. Studies will be done both on experimental modules and on natural or other artificial reefs where *Muricea*(or other species of concern) are abundant.

To make accurate predictions about population size and structure requires information on patterns of recruitment, growth and mortality and the factors that affect them. Information on patterns of recruitment, growth and mortality will be obtained from focused monitoring; information on the factors that affect these patterns will be obtained from experiments.

Monitoring will be done to determine densities of all age/size classes of *Muricea* and other species deemed to be important. Densities of new recruits will be monitored monthly on artificial or natural substrates to estimate recruitment rates of new individuals. Densities of larger/older stages will be monitored in permanent quadrats. Individuals will be identified and their growth and mortality will be followed over time. Sampling of natural populations will be supplemented with transplant experiments to evaluate factors affecting stage-specific growth and survivorship. Field sampling and experiments will be designed to determine the extent to which recruitment, growth and survivorship of *Muricea* and other species are dependent on reef design, substrate size, location within a module (i.e., edge vs. middle), location within the San Clement site.

6.0 DATA ANALYSIS

Information from previous studies of artificial and natural reefs suggests that community development proceeds to one of several biological configurations or endpoints. From the viewpoint of this project, the most desirable of these configurations is a forested community characterized by giant kelp and a diverse assemblage of other algae, invertebrates and fish. Less desirable configurations include densely vegetated communities lacking giant kelp, and sparsely vegetated communities dominated by invertebrates such as sea urchins, sea fans, and bryozoans. The hope is that development of the reef community will follow a relatively deterministic path that leads to one of these biological configurations within five years. The reality is that this may not happen. Moreover, the dearth of data on the development of kelp communities on artificial reefs makes predicting their ultimate biological configuration problematic.

Determining the most appropriate design for the mitigation reef will be made easier if the communities on the experimental modules reach (or appear to be reaching) a biological endpoint at the end of five years. In this case monitoring data and results of process studies will be analyzed largely to determine which reef designs meet (or are likely to meet) the performance criteria established for the mitigation reef. More uncertainty is involved in recommending the “best” reef design in the case where the communities on the experimental modules do not reach (or do not appear to be reaching) a definitive endpoint after five years. In this event, determining the most appropriate reef design for the mitigation reef will be done using a weight of evidence approach rather than relying on results of one (or a few) statistical tests. Rather than focusing on whether a particular design does or does not meet a specific performance criteria, analyses will concentrate on (1) predicting which of the reef configurations is likely to meet the performance criteria in the future and (2) estimating how performance varies among experimental reef designs. Information obtained from process studies that provide insight into the causes of any differences observed in the performance of the different reef designs will be a key element in interpreting the results of these analyses. That the “best” design may be one that combines features from more than one of the eight designs tested in the experiment is a real possibility and will be considered in determining the most appropriate reef design. For example, if process studies indicate that kelp and invertebrates perform differently with respect to substrate type and coverage, then a reef having high and low coverage of both types of substrates may have the greatest chance of meeting the performance criteria. Ultimately, best professional judgement that considers all the information collected during the experiment will be used in determining the most appropriate reef design for the mitigation phase. Below we discuss the types of analyses that are planned for the data collected from the experimental phase of the kelp mitigation project. These analyses fall into three types: (1) analyses that determine which of the eight experimental reef designs meet the four performance criteria; (2) analyses that predict if and when a particular reef design will meet the performance criteria and how its performance compares to those of other reef designs; and (3) analyses that evaluate the degree to which biological and physical processes explain differences in the observed and predicted performance of the different reef designs

6.1 METHODS FOR EVALUATING WHICH EXPERIMENTAL REEF DESIGNS MEET THE FOUR PERFORMANCE CRITERIA

Determining whether a particular reef design has met the four performance criteria is most appropriate if community development on the experimental modules has reached or appears to be reaching an endpoint. The following sections describe the analytical procedures that will be used to evaluate each of the four performance criteria. In all cases, temporal trends of the variables of interest will be examined to determine whether a particular design has reached a biological endpoint with respect to each of the four criteria.

6.1.1 *CRITERION 1:* 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

The objective for the analysis will be to determine the fractional loss of hard substrate associated with each reef design as well as the rate at which such loss occurs. This will be done using data collected from semi-annual sidescanning sonar and diver surveys of the coverage of hard substrate of each module. Results of these analyses will be useful in determining whether the nominal coverage of hard substrate required by the mitigation reef will likely need to be adjusted to meet the substrate standard that at least 90% remain unburied. The relatively small size of the experimental modules is an important consideration in making this determination because the modules will have a much greater perimeter to area ratio than the larger mitigation reef. Therefore, special attention will be paid to the degree to which subsidence and accretion vary as a function of location on the module (i.e. perimeter vs. middle). If subsidence and accretion vary monotonically from the edge of the module to the middle, then it is unlikely that proportional loss of substrate on the modules will be a good predictor of loss on the mitigation reef. The data will not be used to determine whether the nominal coverage of hard substrate needs to be adjusted in this case, unless we can estimate the effects of distance from perimeter on subsidence and accretion.

6.1.2 *CRITERION 2:* THERE MUST BE A SUSTAINED GIANT KELP DENSITY OF AT LEAST 4 ADULT PLANTS PER 100 M^2

The permit requires the mitigation reef to produce a sustained abundance of 4 adult giant kelp plants per 100 m^2. This translates into a sustained population of 19.2 adult giant kelp plants for each 480 m^2 area censused on each module. If there is no effect of block and if the effects of reef design varies consisting among blocks, then a particular reef design will meet criterion 2 if all seven of its modules sustain a giant kelp density of at least 19.2 adults per 480 m^2 area. If all eight modules within a block fail to meet the criteria, then that block will be not be used to evaluate the criterion. If the effects of reef design on the density of adult kelp vary among blocks, then the mean density of adult kelp (averaged among transects within modules) will be examined as a means of evaluating this criterion. .

6.1.3 *CRITERION 3*: ADULT AND YOUNG-OF-YEAR FISH ASSEMBLAGES MUST BE SIMILAR IN DENSITY AND SPECIES NUMBER TO NATURAL REEFS WITHIN THE REGION

CRITERION 4: ALGAL AND MACROINVERTEBRATE ASSEMBLAGES MUST BE SIMILAR IN ABUNDANCE (DENSITY OR % COVER) AND SPECIES NUMBER TO NATURAL REEFS WITHIN THE REGION.

In contrast to the fixed performance criteria for hard substrate and adult giant kelp abundance, the performance criteria for fish, understory algae, and macro-invertebrates inhabiting the kelp forest are “relative.” The permit requires that these assemblages be “similar in density and species number to natural reefs within the region.” Thus, the standards do not require that the mitigation reef have the same species as natural reefs, or that each species occurs in the same abundance. The CCC required only that the total density and number of species to be similar, in part to avoid making the performance standards too difficult for the mitigation reef to achieve. If similarity is defined too stringently, then a given reef design might not be considered for the larger mitigation reef even if it has a high chance of producing abundant resources. On the other hand, if similarity is defined too loosely, then incorporation of a substandard experimental design could result in the mitigation reef meeting all legal obligations, but being a biological failure because it doesn’t provide adequate compensation for lost resources.

Judging whether a module's performance complies with the permit requirements with regards to the fixed standards measured by criteria 1 and 2 requires fairly simple analyses. By contrast, evaluating the relative standards measured by criteria 3 and 4 involves measures of similarity, which rely on more complicated statistical techniques for evaluation. Unfortunately, there is no single best approach for determining similarity in criteria 3 and 4. Therefore, we will use three approaches; one using univariate statistics and two using multivariate statistics. Because we are most interested in detecting effects that are biologically meaningful, analyses will emphasize high power to detect a failure to meet the criteria rather than the level of statistical significance. Statistical power (the probability of detecting a given effect size) will be maximized by increasing the type I error (or alpha) above the commonly used value of 5%, however, in no case will alpha be increased to > 20%.

6.1.3.1 Univariate tests.

The univariate analysis to be used to test for similarity between a particular reef design and natural reference reefs will be a series of one-tailed t-tests on each of the following 10 variables. These include the following:

1) number of species of fish
2) total density of fish
3) number of species of young-of-the-year fish
4) total density of young-of-the-year fish
5) number of species of invertebrates
6) total coverage of colonial invertebrates
7) total density of solitary invertebrates
8) number of species of benthic algae
9) total coverage of clonal benthic algae
10) total density of solitary benthic algae

These variables are those listed as performance standards in the permit with the exception that abundance of invertebrates and algae are separated into solitary and colonial/clonal forms. This separation is necessary to solve the analytical problem of combining abundance estimates of solitary forms that are based on counts with those of colonial and/or clonal forms that are based on percent cover.

Each t-test will test the null hypothesis that the mean value of an independent variable for a given reef design is equal to or greater than the mean of the reference plots. Replication for these analyses will come from the seven blocks arranged at increasing distance from SMK. Separate analyses will be done for each sample period and the use of repeated measures analyses will be explored if the criteria are met for more than one survey. A design will be considered to have met criterion 3 only if the results of the t-tests show no significant difference between that design and the reference plots for all four of the variables that pertain to this criterion (i.e., variables 1 through 4 above). Similarly, a design will be considered to have met criterion 4 only if the results of the t-tests show no significant difference between that design and the reference plots for all six of the variables that pertain to this criterion (i.e., variables 5 through 10 above).

The variables listed in the permit and used in this univariate approach combine the abundances of all species and thus weigh them all equally (e.g., three barnacles have the same value as three sea stars). However, species naturally occur in different abundances, especially those that occupy different trophic levels (e.g., barnacles are typically more abundant than the sea stars that prey on them). Consequently, spurious conclusions may be reached if evaluation of the criteria is based solely on this approach

6.1.3.2 Multivariate similarity analyses

An alternative to the univariate approach above is to use analyses that deal with all of the components of criteria 3 and 4 simultaneously. A variety of methodologies have been developed to evaluate the similarity of ecological communities, the most common being cluster analysis. These techniques can be used to evaluate the degree of similarity between the various reef designs and the natural reference reefs. While these analyses would be useful for understanding the nature of the similarity between communities on the experimental modules and natural reefs, they unfortunately cannot be used to evaluate whether a reef design has met performance criteria 3 and 4.

6.1.3.3 Binomial tests.

A multivariate approach that can be used to evaluate whether a reef design meets criteria 3 and 4 is one that evaluates similarity using a binomial model. In this approach we will assume interactions exist among all four experimental factors (i.e., substrate type, substrate coverage, kelp transplanting and distance from SMK) and test each of the 56 experimental modules separately against each criterion. Moreover, rather than using the few broad categorical variables listed in the permit to evaluate similarity such as proposed for the univariate approach, the binomial approach will use many relatively small taxonomic groupings as variables in testing whether a given criterion has been met (e.g., the variables used to evaluate criterion 4 using the binomial approach might be the abundances of the different taxa listed in Table 3).

The null model in the binomial approach is that the resource value of an experimental module represents a sample from the same population as the reference plots. In a example where there are seven reference plots, it follows that each of the eight sites (i.e., the experimental reef module and the seven reference plots) has an equal 12.5% chance (i.e., 1/8) of having the poorest (which is generally the lowest) value for any variable. Therefore, based on chance alone, the probability of the value for a single variable being lower on a given experimental module than on any of the reference plots will be 0.125. In a case where a criterion was estimated from 40 variables an experimental module would fail to meet the criterion if it had the lowest values for significantly more than 5 variables (i.e., 40 variables x 0.125 = 5).

In contrast to the univariate approach which groups trophically diverse species into a few large variables, the binomial approach to assessing similarity uses many individual species or small taxonomic guilds as variables. Moreover, unlike the univariate approach the binomial approach does not require that the value of *every* variable be as high as on natural reefs, but instead evaluates the variables collectively to determine whether a particular reef design is likely to provide fish or algal/invertebrate resources that are similar to those provided by natural reefs in the region. If it is determined that some variables are considered to be more important than others, then they can be weighted accordingly. For example, species richness may consist of a single variable while species abundance will be estimated using a variable for each taxon. Thus, it may be necessary to weight species richness more heavily than the abundances of individual species to meet the goals of the permit. Similarly, it may be necessary to weight species that have a disproportionate influence on community structure (e.g., sea urchins, *Muricea*, etc.) differently than less influential species (e.g., anemones, sponges, etc.).

6.2 METHODS FOR COMPARING THE PERFORMANCE OF DIFFERENT REEF DESIGNS.

Comparisons among the different reef designs will be particularly useful in the event that the biological configurations of the modules do not reach an endpoint within the five year experiment. The objective in this case will be to predict which of the reef configurations is likely to meet the performance criteria in the future. The initial analyses will be a series of regression models to evaluate trends in a particular variable (e.g., adult kelp density) as a function of time, reef design and distance from SMK (repeated measures analyses could also be employed if found to be more appropriate). The line equations generated for the relationship between time and response for each reef design (for sake of simplicity assume that distance from SMK is unimportant or accounted for as a covariate) will allow prediction of the time until the performance criteria for that variable (e.g. μ 4 adult kelp per 100 m^2) is met. Using criterion 2 as an example, if adult kelp density on a particular reef design increased at a rate of 0.5 plant /100 m^{-2} / yr^{-1}, then one would predict that the standard of 4 plants per 100 m^2 would be met in 8 years. The line equations could also be used to compare the predicted “time to compliance (TTC)” among reef designs. A similar analysis will be used to predict which reef designs are likely to meet Criterion 1 with the exception that the variable of interest (the percentage of substrate cover that remains unburied) will be evaluated for the likelihood that it will fall below the performance criteria (set at μ90%). Here the only likely trend of concern is one that goes down so regression analyses will be used for each of the different reef designs to predict when (if ever) more than 10 % of the hard substrate will become buried. In the case of criteria 3 and 4 separate analyses will be done using the deltas (experimental mean - control mean) for each of the ten independent variables listed in Section 6.1.3.1. Regression results from the different criteria could be used to rank the different reef designs in terms of their probability of success by comparing mean TTCs (or weighted TTCs if some variables were deemed more important than others).

If the above regression analyses do not show trends for any of the reef designs or they only show trends that indicate the time to reach compliance is longer than that which is deemed acceptable, then additional analyses will be done. Here emphasis will be placed on examining smaller scale features of each design that were not explicitly tested in the experiment. For example, each design tests a specific configuration of substrate type and substrate coverage. However, within each module there will be small-scale features such as the size and shape of individual pieces and aggregate clumps of hard substrate. Such features could be evaluated as models for the final design even though they were not explicitly tested in the experiment. For instance, if aggregations of substrate that were smaller (or larger) than a particular size generally trended towards compliance even though no design tested in the experiment did, then a requirement for aggregation size might be added to the design of the mitigation reef using this information.

6.3 METHODS FOR EVALUATING PROCESS STUDIES.

In approving the amended permit, the Coastal Commission specified that the experimental phase last five years rather than the ten years recommended in the staff report. The Commission was advised that five years would likely not be sufficient time to determine the long-term performance of the experimental reef based on monitoring data alone, and they approved the use of additional experiments and studies to aid in predicting the long-term performance of the different designs tested in the experimental reef. These “process studies” will be designed to determine: (1) sources of variability in the recruitment and survivorship of key species that influence the long-term biological configuration of a reef, and (2) whether the processes that control recruitment and survivorship of these key species are affected by specific features of reef design. Information obtained from processes studies will be used to predict trajectories that will aid in determining whether the performance criteria are likely to be met and how long it will likely take to meet them in the event that an endpoint is not reached during the five year experiment. Results from process studies will also provide insight into how reef performance is affected by different reef characteristics, which will be useful for evaluating alternative designs that are not explicitly tested in the experiment.

The specific analysis to be used in the process studies will undoubtedly vary with the experiment or study undertaken. Studies that use time series data to evaluate how certain physical and biological process vary with reef design and location will be analyzed by repeated measures ANOVA (or ANCOVA if it is determined to be more appropriate). For example, the extent to which reef subsidence/accretion varies among reef designs and distance from SMK could be determined by a two factor repeated measures ANCOVA where reef design is is considered a fixed factor, survey date a random factor, and distance from SMK a covariate. Similar analyses could be used to evaluate recruitment, growth, and mortality in kelp, gorgonians, or other organisms. Again, emphasis in these analyses will be placed on high power to detect differences among treatments rather than on levels of significance.

7.0 DISSEMINATION OF RESULTS

In order to meet the goals and objectives of the experimental reef project, close interaction with SCE and state and federal resources agencies during the experimental phase of the artificial reef mitigation project is essential. Three procedures will be followed to ensure efficient and effective communication with the above entities: (1) copies of the data will be made available as soon as data has been verified, (2) regular meetings will be held to discuss results and potential changes in monitoring design, and (3) annual meetings will be held with all interested parties.

The product of this monitoring program will be a final report to the Executive Director on all findings gathered during the artificial reef experiment. The report will include a recommendation on the substrate types and coverages deemed most suitable for the mitigation reef. If the results indicate that it is unlikely that any reef design will meet the performance standards, then recommendations on alternative ways of mitigating kelp bed losses caused by SONGS operations will be provided. The final report and the data sets contained within it will be made available to SCE and other interested parties for review and comment. The final report and comments on it will form the basis for the Executive Director's decision on the type(s) and coverage(s) of substrate allowable for the mitigation reef.

Table 1: Annual work schedule for monitoring activities.

SAMPLING METHOD	VARIABLES SAMPLED	TIME OF YEAR SAMPLED											
		J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Side-scanning sonar	% cover and height of hard substrate								8				
Diver surveys of adult kelp	giant kelp abundance		8						8				
Fish transects	Abundance and age class of fish									8	8	8	
Benthic quadrats	Abundance and age class of large solitary algae and macro invertebrates						8	8	8				
Line intercept	% cover of substrate types, understory algae, and sessile invertebrates						8	8	8				

Table 2: Annual work schedule for process studies.

CRITERION	VARIABLES SAMPLED	TIME OF YEAR SAMPLED											
		J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
1. Substrate	Subsidence and sediment accumulation	8	8	8				8	8	8			
2. Giant kelp	spore set, gametophyte recruitment	8	8	8	8								
	juvenile survivorship				8	8	8	8	8				
	adult size, mortality	8	8			8	8			8	8		
3. Fish	feeding rates								8	8			
4. Invertebrates/Algae	Recruitment	8	8	8	8	8	8	8	8	8	8	8	8
	size, mortality		8						8				

Table 3 Algae, macro-invertebrates and substrates commonly observed in San Mateo kelp bed (Schroeter and Dixon 1988) that are likely to be encountered on the experimental reef and the method of sampling that will be used to monitor them. q = counted in quadrats. pc = percent cover estimated with point contact.

TAXON	SAMPLING METHOD
Algae	
Macrocystis pyrifera,	q
Pterygophora californica	q
Eisenia arborea	q
Laminaria farlowia	q, pc
Desmarestia ligulata	q, pc
Cystoseira osmundaceae	q, pc
foliose brown algae	pc
erect fleshy red algae	pc
erect calcified red algae	pc
crustose fleshy red algae	pc
crustose calcified red algae	pc
green algae	pc
MACRO-INVERTEBRATES	
Styela monteryensis	q
Strongylocentrotus purpuratus	q
Strongylocentrotus fransciscanus	q
Lytechinus anamesus	q
Parastichopus parvimensis	q
Pisaster giganteus	q
Asterina miniata	q
Dermastarias imbricata	q
Astrometis sertulifera	q
Orthosterias koehleri	q
Pycnopodia helianthoides	q
Panulirus interruptus	q
Haliotis spp.	q
Astraea undosa	q
Kelletia kelletii	q
Conus californicus	q
Pteropurpura festiva	q
Muricea californica	q
Muricea fruticosa	q
Tethya aurantia	q
Diopatra ornata	pc
Phragmatopoma californica	pc
colonial tunicates	pc
Bryozoans	pc
barnacle spp	pc
bivalve molluscs	pc
hydroids spp	pc
anenome spp	pc
Sponges	pc

Table 3 (continued).

TAXON	SAMPLING METHOD
SUBSTRATES	
Concrete	pc
Rock	pc
Sand	pc
Silt	pc

6

Schroeter, S. C. and J. D. Dixon. 1988. Studies of benthic organisms in kelp forests near the San Onofre Nuclear Generating Station 1980-1986. Final Report to the Marine Review Committee. [6]