Artificial Reef Site Selection: Geophysical Surveys for San Clemente Kelp Reef

Neil Marshall and Tim Norall
EcoSystems Management Associates, Inc.
2270 Camino Vida Roble, #L
Carlsbad, CA 92009 USA
neil@eco-m.com
tim@eco-m.com

Robert S. Grove
Southern California Edison Company
2244 Walnut Grove Avenue
Rosemead, CA 91770 USA
grovers@sce.com

M. Hany S. Elwany, Ph.D.
Scripps Institution of Oceanography
Integrative Oceanography Division 0209
La Jolla, CA 92093 USA
hany@coast.ucsd.edu

***Abstract* – A critical component of artificial reef development is a thorough geophysical and geological evaluation of the potential reef sites. Artificial reefs are typically designed to: 1) enhance specific biological communities, and 2) maintain their structural and functional integrity for many years without: deteriorating or being permanently covered by sediment. In this context, having reliable and detailed ocean bottom characterization data is necessary to properly site and design artificial reefs. Southern California Edison is constructing the 150-acre San Clemente Artificial Reef in response to a California Coastal Commission/Marine Review Committee (CCC) Study, which determined that San Onofre Nuclear Generating Station (SONGS) was impacting a nearby kelp bed community. The reef is being designed specifically to grow giant kelp (*Macrocystis pyrifera*). The 22.4-acre experimental phase of the mitigation project was built in September 1999. A five-year study is now underway to determine and refine the best construction techniques, the best material type (either concrete or quarry rock) and the most effective reef material spacing on the bottom. Detailed geophysical and geological surveys were carried out in the siting phase of this project at eleven different potential kelp artificial reef sites between 1991 and 1998. Once the San Clemente site was chosen, even more detailed bottom characterization studies were performed to assure the successful placement of the San Clemente Artificial Reef. These surveys utilized a precision fathometer, side-scan sonar, and a sub-bottom profiler, as well as ground-truthing surveys. This work was done not only to assure the successful placement of the reef, but also as critical input to the design of the reef itself.**

I. INTRODUCTION

Artificial reefs can be designed to enhance or restore marine habitats [1,2]. As such, they typically target the enhancement of specific biological communities that have well-defined depth ranges and seafloor constraints. One of the critical components of successful artificial reef development is a thorough geophysical and geological evaluation of candidate reef sites.

Artificial reefs need to be designed and properly placed to withstand the harsh oceanographic conditions and unstable bottom characteristics of the nearshore environment. In this context, having reliable and detailed ocean bottom characterization data is necessary to effectively site and design artificial reefs.

In species diversity, biomass, and productivity, a kelp forest is the temperate nearshore marine equivalent of a tropical rainforest or coral reef [3]. Kelp habitat is also about 19 times more productive than adjacent sandy seafloor habitat [4]. The potential exists to mitigate impacts caused by coastal development by installing artificial reefs to create or expand kelp forest communities. If impacts in the coastal zone directly affect a local kelp forest community, then the priority to provide successful "in-kind" mitigation is especially critical. Kelp beds are typically located on hard substrate in harsh nearshore areas with shifting sand. Therefore, the design of an artificial reef that targets kelp enhancement is critically reliant on the proper characterization of bottom conditions and coastal processes, both during the feasibility stage and during the siting and design phase.

A. San Onofre Impacts and Mitigation

The SONGS (Fig. 1) is located south of San Clemente, California, and uses ocean water as the primary coolant for the steam cycle process in generating electricity. Southern California Edison Company (SCE) operates SONGS. A 15-year study was conducted by the Marine Review Committee of the California Coastal Commission to assess the impact that the SONGS cooling system is having on the surrounding nearshore environment. This study determined that the operation of the SONGS cooling system was impacting local fish and the adjacent natural kelp forest community. In 1991, the CCC required SCE to create a kelp forest community on a 150-acre artificial reef to mitigate the impact of SONGS on the nearby San Onofre Kelp Bed [1]. Through a series of further studies and public hearings, the San Clemente Artificial Reef Project was developed to satisfy the CCC permit kelp mitigation requirement [5].

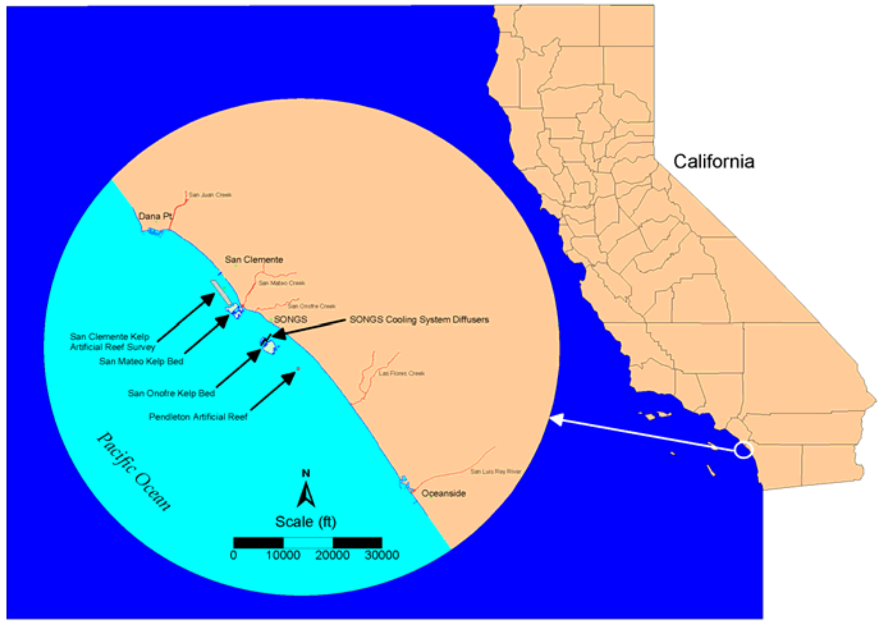

Fig. 1. Location of San Clemente Kelp Mitigation Artificial Reef, San Onofre Nuclear Generating Station, and the Pendleton Artificial Reef.

B. Reef Design Issues

Assessment of artificial reefs in southern California over the last 40 years has revealed that they can be poorly designed with respect to their surrounding physical environment as well as to their proposed biological function [6,7]. Pendleton Artificial Reef (PAR) is an example of an over-designed artificial reef that failed to meet its biological function. It was built in 1981 (location noted in Fig. 1) as a research reef and was intended to create a habitat for giant kelp (*Macrocystis pyrifera)* [8,9]. However, the design was based primarily on fish attraction reefs [10,11]: The reef consisted of high (2-3 m), vertical relief modules of rock mound clusters, separated by sandy seafloor. Spacing of the modules was intended to produce more varied ecological zones and create current patterns that would trap drift kelp. The design features did not appear to demonstrate any benefit in growing persistent kelp on PAR [12].

The high vertical relief of PAR also turned out to be problematic for successful persistent kelp growth [13, 14]. Patton et al. [14] determined, through the study of 24 different artificial and natural reefs in Southern California, that high relief (>1.5 m) reefs: 1) create more turbulence than lower relief reefs, and 2) are ideal habitat for kelp-grazing fish. Both of these factors appear to contribute to poor kelp growth. Also, high relief reefs appear to favor longer-living attached organisms, such as the sessile invertebrate sea fan *Muricea californica,* which can have longevity of over 45 years. Patton et al. [14] attributed this to the structural stability of high relief reefs. These types of reefs are much less disturbed by storm wave and high current conditions with respect to: 1) sediment scour, 2) periods of high sand abrasion, 3) episodic reef rock overturning, and 4) intermittent burial. In contrast to *Muricea*, giant kelp is often one of the first organisms to appear on newly introduced bare rock or recently disturbed hard substrate. Giant kelp has many of the characteristics of organisms specializing in often-disturbed habitats: It is dispersive, fast-growing, short-lived, fecund, fertile all year, and can have massive recruitment after heavy storms [6,14,15].

Artificial reefs can also be poorly designed from the materials selection and placement standpoint. For example, some of the 1960s reefs were constructed with material of opportunity that deteriorated quite rapidly [7]. Additionally, some southern California artificial reefs were improperly designed, such that the reef material moved out of the intended habitat area during storms. Other unsuccessful reefs were not properly designed for withstanding conditions in areas: in front of river mouths, of high sand movement, of soft silt, in deep sand, and over unstable substrate bottoms [7,11,16].

C. Reef Siting Considerations

Enhancing kelp forest communities involves placing additional hard substrate habitat over sandy seafloor environments. These sandy seafloor areas must be fully characterized to allow for prudent siting of artificial reefs. For example, it is wise to avoid placing hard substrate in areas of especially intense sand migration or deep sand, or on top of fine sand, silt, and mud. The coastal engineering challenges for long-term reef stability are daunting and costly, when confronted with unstable and high energy environments.

Siting guidelines for the placement of additional hard substrate for the SONGS kelp mitigation project are governed by the following physical conditions and CCC-permit constraints [1,17]:

1) suitable kelp growth depths–approximately 11 to 16 m;
2) a thin, less than 0.5 m, layer or veneer of sand on top of bedrock or existing natural hard substrate (to avoid having the reef disappear into soft, deep sand);
3) near-persistent natural kelp forests;
4) not directly on existing natural hard-bottom substrate (in order to avoid impacts on or disruption of possible sensitive or rare benthic habitat and associated communities);
5) at a distance from areas with major sediment deposition, such as river mouths;
6) at a distance from areas near wastewater discharge or other human perturbations;
7) at a distance from areas of historical or cultural resources (including areas where there is evidence of possible buried shipwrecks); and
8) as near as practical to the SONGS-impacted natural kelp reef (in an effort to achieve reasonable in-kind, in-place mitigation), and not further than South Laguna Beach to the north and Leucadia to the south.

As the SONGS kelp project plan evolved and matured from 1991 through 1999, the project participants also agreed that it would be most advantageous to build the entire 150-acre kelp mitigation artificial reef at one location [5]. Splitting it into smaller components at various locations could result in less satisfactory or at least unexplainable kelp performance results, because:

1) Site-to-site differences might mask or overwhelm the critical design variables that are being tested in Phase One of the project, especially if the Phase One modules were too small and spread out to properly represent the build-out phase reef.
2) Past studies have shown that more fish are attracted to small artificial reef modules than are seen on larger natural reefs; and graze more persistently and "unnaturally" on the recruiting kelp at these smaller artificial modules [13,14].
3) Relying on small, scattered reefs would negate the benefits that large reefs are likely to have, including self-sustaining kelp recruitment. This seems especially relevant since long-distance advection of kelp spores is limited [18,19]. Specifically, data on kelp spore dispersal indicate that, on average, >90% settle within 1.5 m of the parent plant. Successful colonization of more distant sites requires massive dispersal events of clouds of spores from large beds [18, 20].

D. San Clemente Kelp Experimental Reef

The initial phase of the San Clemente Kelp Artificial Reef was constructed in September 1999 along 4 km of beach frontage between the City Pier and San Mateo Point in San Clemente, California (Fig. 1). Based on the siting and design issues described above, and in response to public and agency comments in the environmental review (EIR) stage of the project, a low-relief reef using a mono-layer of hard substrate was developed [5,6]. This first phase of the project also tests three densities (17%, 34%, and 67% bottom coverage) of two different kinds of materials (quarry rock and broken concrete). The assessment of the sites, the design work, and the project environmental evaluation has cost more than $1 million. The construction of this 22.4-acre experimental reef cost $2.5 million.

The final design of the experimental kelp reef called for a mono-layer of scattered rock to be placed on a seafloor with a thin veneer of sand covering bedrock or other existing hard substrate. Therefore, it was critical to obtain accurate geophysical and geological characterization of the potential reef sites, to ensure that a mono-layer of scattered material will not, over time, sink into the seafloor or be silted over.

A further possible benefit of reef placement on a sand veneer was observed at some previous artificial reefs and is being studied here. As a reef subsides onto sub-bottom hard substrate, it exposes some of this pre-existing substrate around the new reef material in a scour-hole. Therefore, the reef derives further benefit from the additional hard substrate in the exposed depression around the reef [12].

The 22.4-acre initial phase reef is considered an experiment designed to determine and refine the best construction methods, material types, and material densities (percent bottom cover) for the future build-out phase. The success of the 22.4-acre experimental reef will influence the final 150-acre mitigation reef.

II. METHODOLOGY

This section describes the instrumentation and methodology used to obtain bathymetric, substrate, and sub-bottom profile data for the San Clemente Artificial Kelp Reef site selection study and for input into reef design. These geophysical and seafloor geological surveys were conducted in two major phases between 1991 and 1997, with final construction verification surveys performed just before, during, and after reef construction in 1999.

A. Survey Vessel and Navigation

The survey was conducted using a 26’ Farrallon survey boat. The boat was equipped with DGPS, RADAR, fathometer, side-scan sonar, sub-bottom profiler, data acquisition and navigation hardware and software, and with a lifting hoist for deployment of instrumentation.

Navigation and positioning were accomplished with a Differential Global Positioning System (DGPS). The DGPS is an all-weather, radio-based satellite navigation system that consists of a Leica Professional GPS Model MX600, Hydro-Pro Navigation software, and differential correction signal receiver. The differential signals come from Coast Guard beacons established for GPS correction. The system provides accuracy of +/- 1 m in the horizontal.

The survey parameters (i.e., area coordinates, survey lines, and spacing between lines) were entered into the Hydro-Pro Navigation software creating a “pre-plot.” With this pre-plot, it is possible to ensure that adequate survey line coverage has been obtained. The navigation system records the shot point number, x/y position (east and north), date, time, and position information at each selected time interval. For this survey, a sample rate of 15 seconds was used. Positioning and time data were automatically stored on a computer hard drive, and digital back-up storage was used. In addition, a real-time Helmsman Correct Course Steering Display helped to keep the vessel on the pre-plotted survey lines. Simultaneously with the collection of positioning data, an event mark was sent to an analog recorder (EPC thermal printer), which is annotated with shot point number, time, and date.

After surveying, the actual paths of the boat, or “vessel track,” were plotted from the data stored on the disk. This is called the “post-plot.” These plots were then used to map the collected data (Fig. 2).

B. Fathometer

A survey-grade digital fathometer (Ocean Data Bathy-50 MF) with a 200 kHz transceiver was used for these studies. The depth data were stored digitally and output to a paper recorder.

At the beginning and end of each survey day, a calibration was performed utilizing the “bar check” method as described in the Hydrographic Manual, U.S. Department of Commerce Publication 20-2. This calibration was then utilized to calculate water depth (which varies with the temperature/density of seawater).

The depth data were corrected for tidal height. The data were then plotted, edited, gridded, and contoured using Golden Software’s Surfer

C. Side-Scan Sonar

Side-scan sonar is used for identification and delineation of seafloor characteristics. Side-scan sonar provides sound reflection images of the seafloor. The reflection of sound from objects is related to the reflecting capacity of a given surface and the angles of that surface.

A Klein Mode 595 Side-Scan Sonar System with a 500 kHz operating frequency was utilized for this study. The system consists of a graphic recorder with a digital processor and a tow fish with dual transducers. A graphic recorder produces a continuous permanent record of seafloor characteristics. The system differentiates between bottom types based upon differences in reflectivity.

The surveys for the San Clemente reef siting study used a 75-meter line spacing grid pattern providing approximately 300% overlap. Boat speed was 4 knots, and the sonar fish was towed at a height above the seafloor where optimum detailing of seafloor characteristics could be achieved. Fig. 3 is an example of a side-scan sonar record showing areas of reef outcropping amidst expanses of sediment-covered seafloor.

D. Sub-Bottom Profiler

Sub-bottom profiling equipment allows for the determination of sediment thickness, the interpretation of geological structures, and the detection of objects buried below the seafloor. The EcoSystems 3.5-kHz system utilizes a 3000-watt transceiver that provides communication with the towed transducer (fish) containing four MASSA T15 transducers. The fish was towed at 2.0-meter depth. In order to acquire

Fig. 2. Survey vessel track plot for the San Clemente area. The open circle in the lower part of the track plot is the San Mateo Kelp Bed.

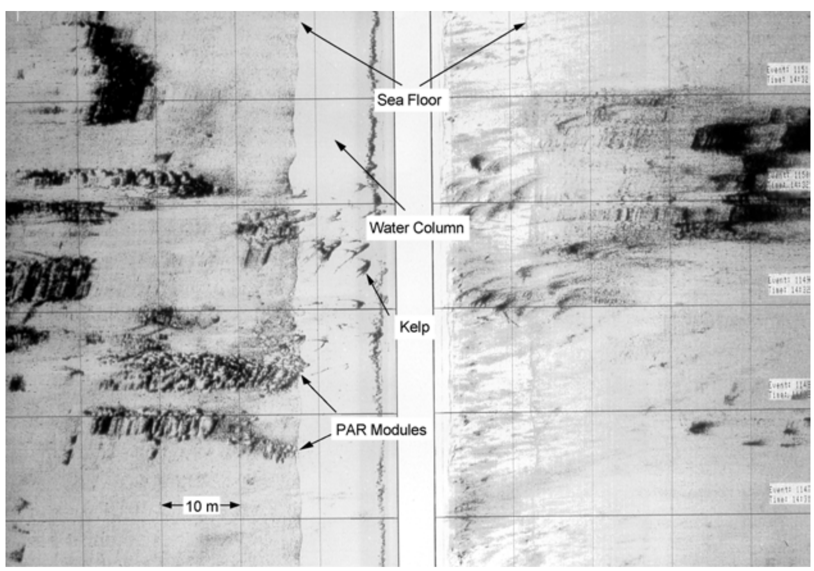

Fig. 3. Record from side-scan sonar system, defining hard substrate outcropping on sediment-covered seafloor.

proper penetration and resolution in different types of underwater strata, frequency selection is of primary importance. A system operating at a frequency of 3.5 kHz provides penetration in unconsolidated sediments of up to approximately 20 meters.

The 3.5-kHz system is towed by the survey vessel while data are simultaneously collected and merged with navigation information from the DGPS navigation system. The data are then available for further processing, such as conversion to sediment thickness and transformation into contour maps using “Surfer” software. Fig. 4 shows the analog data from the 3.5kHz profiler and depicts uptilted, truncated layers covered by a very thin layer of modern shelf sediments.

D. Diver Ground-Truthing

Ground-truthing for sub-bottom hard substrate reflectors, as evidenced in the 3.5-kHz data, requires the use of probes that are inserted into the seafloor. The probing data are used primarily to measure and verify the sediment thickness. Both hydraulic and pneumatic probing equipment are used, according to the types of sediments encountered, to provide the best possible penetration. Penetration is limited to the depth of refusal of the probing equipment. The jet probe is driven by a water pump on the dive boat, and divers manipulate the probe at the seafloor. The divers carefully insert the probe into the sediments and observe the material washing up as well as the resistance encountered during probing. From these observations, sub-sea bedding depths and overburden sediment types can be established and compared to the sonar data. Diver observations of seafloor biological conditions are also noted on each dive. Divers visually examined approximately 2% of each study area to qualitatively describe the seafloor characteristics in terms of mud, fine sediments, shell hash, sand, and gravel/cobble cover.

III. SURVEY RESULTS

The initial 1991-1993 site study assessed six areas between South Laguna Beach and Leucadia. These sites were chosen because they were not near river mouths, outfall pipes, or areas of known sensitive biotic communities and/or major sediment deposition. Further, these areas were near existing natural kelp reefs, as further prescribed by the permit conditions [17].

A. Bathymetry

The bathymetry of the six initially chosen study areas, South Laguna, Dana Point, San Clemente, San Onofre, Carlsbad, and Leucadia, were plotted as part of the initial 1991-1993 reef siting study and re-surveyed in 1997. The 1997 bathymetry for the San Clemente study area is plotted in Fig. 5. The area of potential kelp reef placement, between 11 and 15 meters, is shown. The area for this location is approximately 400 acres in a long slender rectangle of about 4 km by 0.8 k, about 0.8 k off the San Clemente beach between the City Pier to the north and San Mateo Point to the south.

B. Side-Scan Sonar

The side-scan sonar results at the six preliminary study sites were plotted to determine seafloor characteristics. Exposed cobble/boulder hard substrate was mapped as well as existing kelp growth. Fig. 5 shows hard substrate for the San Clemente study area. These results were overlaid with the bathymetry results to further characterize the areas for potential reef placement.

C. Sub-Bottom Profiler

Sub-bottom profiling at the six stations further refined the potential for artificial reef placement. Accurate sub-bottom profile data were critical because of the key constraint placed on the project: no artificial reef rock placement on areas that have more than 0.5 meters of sand overburden on existing sub-bottom hard substrate. These results indicated that only the San Clemente area had 150 acres or more in potential area for the placement of the mitigation reef. Neither the northerly site, South Laguna, nor the southerly sites, South San Mateo, San Onofre, or Carlsbad, had appropriate amounts of thin sand veneer areas to support a contiguous 150-acre or larger mono-layer artificial reef. Further assessment of sites in the San Onofre area, at and around Carlsbad, and furthest south, at Mission Beach, were performed in 1998-1999. These more recent studies came to the same conclusion as the earlier work: No site, other than San Clemente, has adequate area to place a single, contiguous artificial reef of 150 acres.

D. Diver Ground-Truthing

The diver jet-probing work done at each of the sites provided ground-truthing insight into the sub-bottom depths and type of hard substrate below the sand veneers. These results were incorporated into a final decision matrix for comparing the six sites (Table 1).

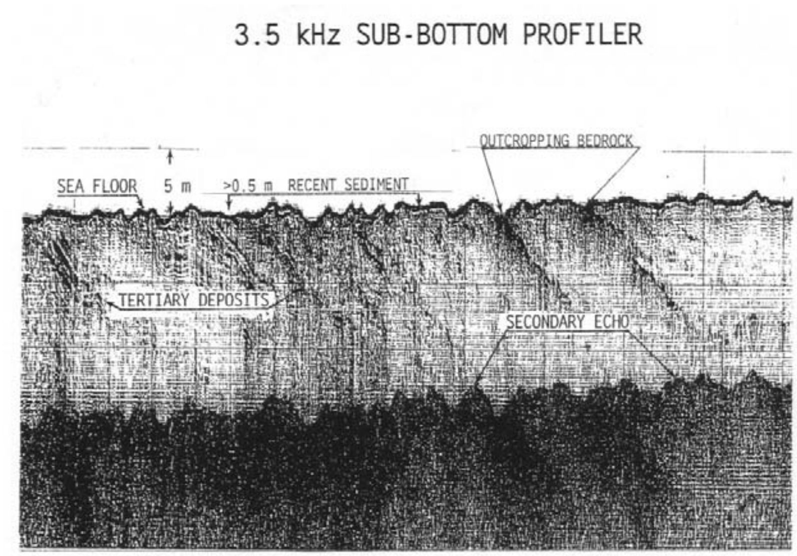

Fig. 4. Sub-bottom 3.5 kHz profiler data showing an example of one type of the San Clemente area seafloor.

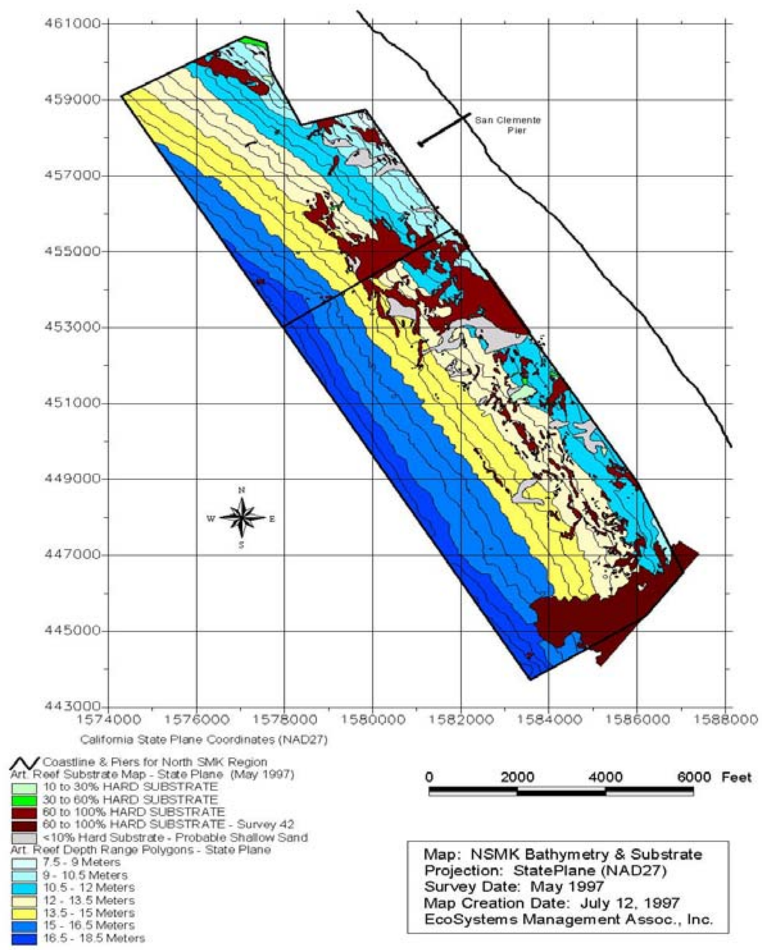

Fig. 5. San Clemente Artificial Reef area bathymetry (in meters) and substrate types (in % exposed hard substrate).

Table 1. The final ranking of the potential sites for development of the artificial reef for kelp.

Site	Final Ranking or Overriding Factor	Stage in Study When Assessed	Approximate Area in Acres	Other Significant Factors
Sites of adequate size and near impact site:				
San Clemente – Pier and South	Preferred site (#1)	1991-93; 1997-99	356	Preferred site – thin sand veneer and near existing kelp beds.
San Clemente – North of Pier	Deep sand	1991-93; 1997-99	163	Fishermen prefer this site for reef, yet site has high turbidity.
San Clemente – Nearest Dana Point	Deep sand, near river mouth	1991-93; 1997-99	180	High turbidity, finer sand, deep sand, and near a sewer outfall and river mouth.
San Clemente – Deepwater area, further offshore	Too deep for kelp bed	1998-1999	300+	Fishermen interested in this site, yet too deep for kelp and in an area of deep sand.
Sites too small, but maybe combined:				
South Carlsbad	Near river mouth, abandoned in EIR	1997-99	64	Adjacent to Batiquitos Lagoon and sewer outfall.
North Carlsbad	Maybe combined, abandoned in EIR	1991-93; 1997-99	30	Appropriate sand veneer. Small area, especially for kelp.
Leucadia	Maybe combined, abandoned in EIR	1991-93; 1997-99	25	Appropriate sand veneer. Small area, especially for kelp.
Encinitas	Maybe combined, abandoned in EIR	1997-99	25	Appropriate sand veneer. Small area, especially for kelp.
Laguna	Fine sediments, rejected pre-EIR	1991-93	34	Small area, near turbidity sources and near sewage outfall, and no nearby kelp.
Sites no longer considered:				
Mission Beach	Dismissed by resource agencies: too far away	1997-99	85	No exposed hard substrate nearby, deep sand, and far from SONGS, yet adjacent to small artificial reef with kelp.
South of San Onofre	Not allowed: U.S. Marine Base	1991-93; 1997-99	218	On Marine Corps Base (not allowed) and in deep sand area.
South of San Mateo	Not allowed: U.S. Marine Base	1991-93; 1997-99	168	On Marine Corps Base (not allowed) and near creek mouths.

E. Combined Ranking of the Potential Sites

The six sites initially surveyed in 1991 (South Laguna, Dana Point, San Clemente, San Onofre, Carlsbad, and Leucadia) were further sub-divided and re-evaluated as nine sites in 1993 (from north to south): South Laguna, North San Clemente, Mid San Clemente, South San Clemente, South San Mateo Point, South San Onofre, North Carlsbad, South Carlsbad, and Leucadia. These nine sites were given a combined ranking based on all of the CCC-permit siting and geological study criteria, which included [21]:

1) area available, based on bathymetry for kelp-appropriate depths: between 11 and 16 m;
2) area available, based on side-scan for avoiding exposed hard substrate;
3) area available, based on sub-bottom sonar, to find shallow sand veneer with more desirable sub-bottom foundation materials;
4) possible additional area, based on acceptance of slightly thicker sand veneer;
5) assessment, based on diver probes, of percent fine and coarse materials in the exposed veneer and makeup of the hard sub-bottom;
6) apparent wave exposure/disturbance;
7) runoff from adjacent streams or anthropogenic disturbances; and
8) proximity to existing kelp beds.

The 1993 ranking [21] was: 1) South San Clemente, 2) South San Onofre, 3) Mid San Clemente, 4) South San Mateo, 5) North San Clemente, 6) South Laguna, and 7) the two Carlsbad sites. The Leucadia site was dropped from the evaluation for being too far from the point of impact at SONGS.

In the 1997-1998 re-evaluation [22], the sites were again ranked in support of the Draft Environmental Impact Report (EIR). The primary criterion for siting the project artificial reef was that a site could accommodate the full 150-acre kelp mitigation reef on a sand bottom of less than 0.5 m of veneer over a hard sub-bottom. The draft EIR needed to describe and assess alternatives to a preferred project. As a result, the 1997-98 assessment included one new northern site: Salt Creek; and six new southern sites: Encinitas, Cardiff, Solana Beach, Del Mar, Torrey Pines, and Mission Beach. San Clemente was also evaluated from the San Clemente Pier to San Mateo Point. The ranking of the six best sites were (the acres available are in parenthesis): 1) San Clemente, from the Pier to San Mateo Point (356 acres), 2) Leucadia (25 acres), 3) Encinitas (25 acres), 4) North Carlsbad (30 acres), 5) South Carlsbad (64 acres), and 6) Mission Beach (85 acres) [22]. Other sites did not fit criteria and were eliminated.

Public comments concerning site selection in the Final EIR of 1998-1999 project environmental evaluation process necessitated that the San Clemente area be further evaluated. Special emphasis was placed on areas: 1) to the north of the San Clemente Pier, and 2) to the seaward side of the preferred Pier-to-San Mateo area. These two areas were evaluated, and they ranked low for two reasons: 1) deeper sand, and 2) deeper sand plus water too deep to support kelp, respectively.

Table 1 summarizes the final, 1999 EIR, reef-siting evaluation results and includes the potential sites with acreages approaching or exceeding the 150 acres needed to build the mitigation reef. This assessment was done as part of the final EIR process. It divides San Clemente into four sub-areas, and looks only at the sites deemed promising in earlier studies that are closer to being in the "in-place, in-kind" mitigation. This final evaluation also includes Mission Beach for two reasons: 1) It is the area with the only persistent kelp bed growing on an artificial reef in southern California [6], and 2) It has enough area to build at least a significant portion of the mitigation reef. The ranking draws from all previous assessments: The initial studies of 1991-1993 [21], the follow-up studies of 1997-1998 [22], and the thinking that went into the 1999 EIR [5]. The San Clemente (Pier to San Mateo Point) site prevailed as the highest ranked site and the most conducive to single-site total mitigation reef success.

IV. DISCUSSION OF PREFERRED SITE SELECTION

The preferred site, San Clemente from the City Pier south to San Mateo Point, was fully characterized, combining the geological parameters, to allow for effective reef module placement. The 22.4-acre experimental kelp reef was designed to allow for study of various bottom coverage densities - 17%, 34%, and 67% - and for comparison between quarry rock and broken concrete material [5,6]. All of the siting data that were collected in the geophysical and geologic surveys were incorporated into ARC/INFO GIS coverages. In this manner, the data layers could be combined, and intersections of the desired unions could be graphically displayed and areas calculated.

The geophysical surveys included substrate type (from side-scan sonar surveys), bathymetry, and sediment thickness. The geotechnical data are from sediment thickness determined by jet probes. ARC/INFO polygon coverages were created for substrate, sediment thickness, and water depth, and for an additional coverage containing a union of all three of these physical parameters. Maps were produced in ArcView using various combinations of coverages.

The final GIS figure (Fig. 6) combines the data from the substrate, sediment thickness, and bathymetry surveys and displays them as a GIS overlay of suitability for reef development. The criteria for suitability were >90% sand on the seafloor, between 12 and 15 meters of water depth, and less than 0.5 meters of sediment thickness. There are approximately 350 acres that qualify as suitable for reef placement in this study area. This is the area that was directed to the California State Lands Commission for a Lease of State Submerged Lands for this project. A buffer zone was also asked for and obtained from State Lands, such that the final lease zone granted is 850 acres. The Phase One reef, the San Clemente Kelp Experimental Artificial Reef, was designed as 56 specific 0.4-acre modules, grouped in seven blocks of 8, totaling 22.4-acres [6].

V. CONCLUSION

The geophysical and nearshore geologic characterization work that was performed for the San Clemente Artificial Reef Project allowed the reef to be properly sited and effectively designed. The critical siting specification, dictated by the resource agencies and advising scientists, resulted in placement of the reef on a sandy seafloor with no more than 0.5 m of sand veneer over a stable sub-bottom hard substrate. The critical design specification, that the reef be no more than one layer of rock high off the seafloor, necessitated very accurate sub-bottom geophysical monitoring. If the physical monitoring had not been accurate, the entire reef could have sunk into the sediment at a cost of $2.5 million. The requirement to fully mitigate the impact of operating a coastal nuclear power plant on adjacent kelp forest communities would have been unfulfilled. The San Clemente Kelp Experimental Artificial Reef, built in September 1999, was expected to grow kelp at a density of at least 4 adult plants per 100 square meters throughout its 22.4-acre extent. Kelp did establish on the reef within months of the reef's construction. After 3.5 years of existence, the reef still consistently has kelp at a density at least twice as great as the intended performance standard for kelp mitigation. As of mid-2003, there has been no problem with reef material inundation by sediments or from the sinking of reef material into the seafloor.

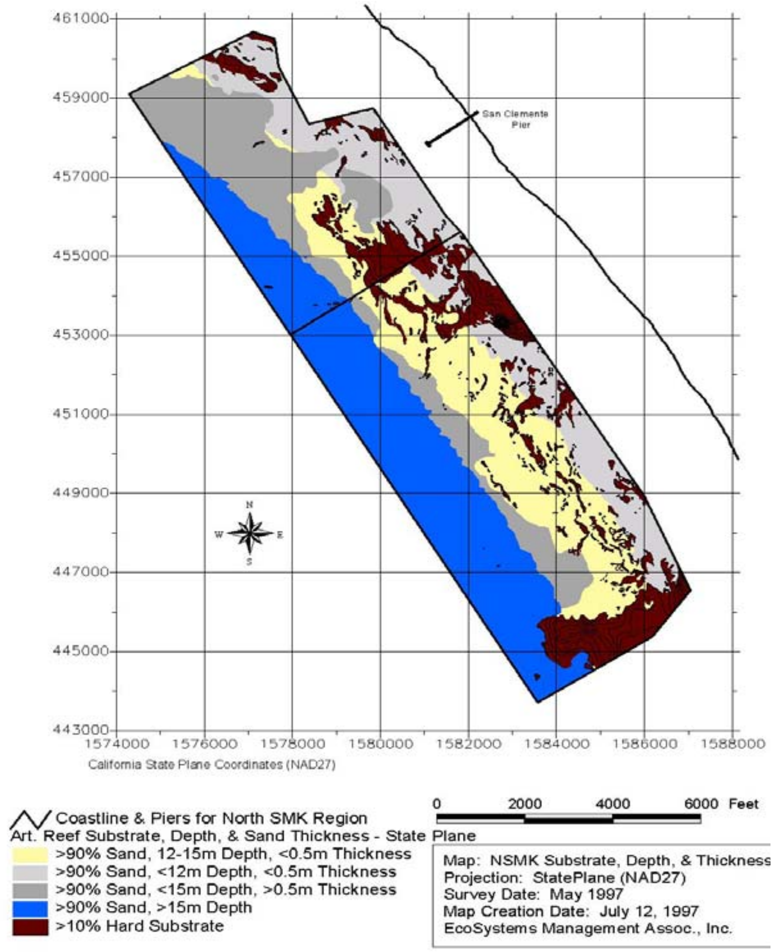

Fig. 6. San Clemente Artificial Reef area sand cover depths showing suitable kelp reef habitat (sand depth from 0 to 0.5 m-the light area) representing 356 acres.

ACKNOWLEDGMENTS

The authors wish to express our thanks to Drs. Jake Patton, Larry Deysher, Tom Dean, Andy Jahn, Steve Schroeter, John Dixon and Dan Reed for their valuable biological insights and input over the life of this project. We also express our appreciation to Kyle Marshall for his outstanding field and instrumentation work. We dedicate this paper to the late Mr. Karel Zabloudil, the President of EcoSystems Management and the lead scientist when this work was being performed.

REFERENCES

[1] Ambrose, R.F., “Mitigation of the effects of a coastal power plant on a kelp forest community: Rationale and requirements of an artificial reef,” *Bull. Mar. Sci.*, vol. 55, pp.694-708, 1994.

[2] Cheney, D., G. Oestman, G. Volkhardt, and J. Getz, “Creation of rocky intertidal and shallow subtidal reefs to mitigate for the construction of a large marina in Puget Sound,” Washington, U.S.A. *Bull. Mar. Sci.,* vol. 55, pp.772-783, 1994.

[3] Garrison, T., “*Essentials of Oceanography*. 3rd ed.,” Pacific Grove, CA, Brooks/Cole, p.370, 2003.

[4] North, W.J., “The biology of giant kelp (*Macrocystis*) in California,” *Nova Hedwigia,* supplement to vol. 32, pp.1-97, 1971.

[5] Resource Insights, “*Final Program Environmental Impact Report for the Construction and Management of an Artificial Reef in the Pacific Ocean Near San Clemente, California,”* prepared for the California State Lands Commission, p.320, May 1999.

[6] Deysher, L.E., T.A. Dean, R.S. Grove, and A. Jahn, "Design considerations for an artificial reef to grow giant kelp (*Macrocystis pyrifera*) in Southern California," *ICES Journal of Marine Science*, vol. 59, pp.S201-S207, 2002.

[7] Turner, C.H., E.E. Ebert, and R.R. Given, "Man-made reef ecology," Calif. Dept. of Fish and Game, *MRR Fish Bull,* vol. 146, p.221, 1969.

[8] Grove, R.S., "Artificial reefs as a resource management option for siting coastal power stations in Southern California," *Mar. Fish, Rev*. vol. 44, pp.24-27, 1982.

[9] Grant, J.J., K.C. Wilson, A. Grover, and H.A. Togstad, "Early development of Pendleton Artificial Reef," *Mar. Fish, Rev*. vol. 44, pp.53-60, 1982.

[10] Lewis, R.D. and K.K. McKee, "*A guide to the artificial reefs of Southern California,"* California Department of Fish and Game, Sacramento, California, p.73, 1989.

[11] Wilson, K.C., "An overview of the California Department of Fish and Game artificial reef plan for sport fish enhancement. In: *Recent Advances in Aquatic Habitat Technology,"* Proceedings, Japan-U.S. Symposium on Artificial Habitats for Fisheries. Editors: M. Nakamura, R.S. Grove, and C.J. Sonu, Southern California Edison, Rosemead, CA, pp.49-55, 1991.

[12] Wilson, K.C. and J.J. Grant, "*Results of the Pendleton Artificial Reef Project and Siting and Design Considerations for a Kelp Mitigation Reef,"* Report by the California Department of Fish and Game to Southern California Edison, Long Beach, California, p.45, 1987.

[13] Carter, J.W., W.N. Jessee, M.S. Foster and A.L. Carpenter, "Management of artificial reefs designed to support natural communities," *Bull. Mar. Sci.,* vol. 37, pp.114-128, 1985.

[14] Patton, M.L., C.F. Valle, and R.S. Grove, "Effects of bottom relief and fish grazing on the density of the giant kelp, *Macrocystis* sp.," *Bull. Mar. Sci,.* vol. 55, pp.631-644, 1994.

[15] Curtis, M., and W. J. North, "The kelp beds of San Diego and Orange counties," report to the San Diego Regional Water Quality Control Board and the San Diego Kelp Consortium by MBC, p.72, 2002.

[16] Sheng, Y.P., "*Physical Characteristics and Engineering at Reef Sites: Artificial Reef Evaluation with Application to Natural Marine Habitats,"* Edited by W. Seaman, Jr. New York: CRC Press, pp.51-94, 2000.

[17] Resource Insights, "*Final Program Environmental Impact Report for the Construction and Management of an Artificial Reef in the Pacific Ocean Near San Clemente, California,"* California Coastal Commission, Permit 6-81-330-A, B, Condition C: Kelp Reef Mitigation, prepared for the California State Lands Commission, pp.30-38, May 1999.

[18] Anderson, E.K., and W.J. North, "In situ studies of spore production and dispersal in the giant kelp *Macrocystis pyrifera," Proceedings of the International Seaweed Symposium,* vol. 5. pp.3-86, 1966.

[19] Reed, D.C., A.W. Ebeling, T.W. Anderson, and M. Anghera, "Differential reproductive responses to fluctuating resources in two seaweeds with different reproductive strategies," *Ecology,* vol. 77, pp.300-316, 1996.

[20] Reed, D.C., D.R. Laur, and A.W. Ebeling, "Variation in algal dispersal and recruitment: The importance of episodic events," *Ecological Monographs*, vol. 58, pp.321-335, 1988.

[21] EcoSystems Management Associates, Inc., Ecometrics, and Science Explorations, "Survey of potential sites for the construction of an artificial reef," report submitted to Southern California Edison, p.83, 1993.

[22] Elwany, H. and L. Deysher, "Review of site selection process for Southern California Edison's mitigation reef," Submitted to Resource Insights by Coastal Environments, CE Ref. No. 98-4, p.42, 17 March 1998.