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Ghost Forests in the Sea: The Use of Marine Protected Areas to Restore Biodiversity to Kelp Forest Ecosystems in Southern California

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Executive Summary

The kelp forests of California are an important habitat for many species of economically important fish and invertebrates. There has been an alarming downward trend for many of these species over the last two decades to the extent that the kelp forests resemble ghost towns. It is becoming increasingly apparent that these so-called "ghost-forests" are in need of protection. In response to this downward trend in marine populations off California, the state legislature passed the Marine Life Protection Act in 1999. This Act mandates the establishment of a network of marine reserves to reverse these declines. Unfortunately, political pressure based on the dearth of focused science has impeded implementation of the law.

The goal of our study was to develop a much-needed framework for the collection, analysis, and synthesis of the scientific, historical, and social data necessary for the design of effective kelp forest reserves in California. It is important to recognize that kelp forest ecosystems differ dramatically along the entire state, especially southern California due to the diversity of environments, both biological and physical in which the giant kelp lives. This study represents a model approach, that we believe is the most effective and rigorous to date, that can be applied to other kelp forests within Southern California. The diversity of kelp forest types means that each forest under consideration for reserve status merits individual consideration with regard to the emergent issues under development here and elsewhere. Here we offer an example of such a study and we propose a model framework that should apply to all kelp ecosystems.

Because the La Jolla kelp ecosystem embodies a representative array of kelp habitats, user conflicts, and societal needs, it represents an excellent case study. Additionally, there is a long-standing reserve located in and adjacent to the northern edge of the kelp forest. This reserve, the San Diego-La Jolla Ecological Reserve (SDLJER) was established in 1971 and protects the northern tip of the La Jolla kelp forest, the head of the La Jolla Submarine Canyon, and an adjacent sandy shelf. We set out to determine how effective this reserve has been for kelp forest animals and to determine the causes for its successes and failures. In addition we attempted to determine if a more ecologically meaningful, and therefore effective reserve is needed, and if so, determine its desired location and size.

Our study was multi-faceted and included the collection of biological and physical data within the La Jolla Kelp Forest and La Jolla Submarine Canyon, an attempt to organize an army of trained diving volunteers to help with the biological survey, sifting through archival materials for historical biological data and natural history, and interviewing the public regarding their knowledge of the San Diego-La Jolla Reserve and the need for marine reserves in general.

The entire La Jolla kelp forest, which is approximately 8 km long and 1.5 km wide, was mapped using sonar and surveyed by scuba divers to determine the distribution of habitats and the animals associated with those habitats. Our results indicate that the Reserve has been effective for some species that do not venture far during their lifetimes.

Of the fishes, these include Vermillion Rockfish and Sheephead, and for invertebrates a reserve effect was only unambiguous for Green Abalone. We also found that the oceanographic climates differ between the northern and southern halves of the La Jolla kelp forest, and the most diverse habitats were located in the southern half of the forest. Discussions with stakeholders and observations on the use of the kelp forest by fishers indicate that the northern half of the bed is most valued by stakeholders due to the presence of pelagic fish and the high recruitment of urchins. Taking into consideration the ecological finding that the southern half of the forest encompasses the most diverse habitat for non-migratory species, and that there would be greater opposition to the establishment of a reserve in the northern half of the forest, we recommend that a 'no-take' reserve be established in the southern half of the kelp forest from Northern Pacific Beach to Wind'n'Sea.

We also recommend the application of our reserve research method to other critical kelp habitats in Southern California for the establishment of other kelp forest reserves as part of the implementation of the MLPA. The southern Channel Islands are urgently in need of study. The northern Channel Islands have been the subject of intense political struggles, and are very different habitats than the southern islands with the western areas bathed by cold, nutrient rich waters while the eastern habitats of the northern islands are bathed by warmer waters, but waters that still have a coastal influence including sedimentation. The northern islands also enjoy a richly endowed research program at UCSB. There is still a pressing need to employ these rigorous methods to a true oceanographic island such as Catalina Island. The east side of Catalina Island has an almost tropical oceanographic regime with clear, relatively warm nutrient poor water. In addition, it is one of the most important marine recreation areas in the state. For marine enthusiasts the clear protected waters of eastern Catalina Island represent the most important marine playground for southern California. The west side of the island has colder, richer water. Catalina Island has not figured in the controversies surrounding the northern Channel Islands, but it does have a small very active reserve research program that is, in many ways, comparable to this one.

Our results, which are specific to the kelp forest in La Jolla, form the basis for a general set of criteria for the development of marine reserves in kelp forests throughout Southern California. In no particular order, these criteria include:

(1) Kelp forest reserves should be established in areas that have the most persistent stands of kelp. Kelp forests are spatially dynamic and many smaller beds are ephemeral, disappearing for long periods of time after a disturbance such as El Nino or episodes of urchin grazing. Further, the persistence of kelp stands within large forests is spatially variable (as in La Jolla), and the areas with the most persistent stands of kelp represent the most important habitat to protect.
(2) Areas having the kelp habitat subtype that supports the greatest diversity of animals should be protected. This information is only available as a result of extensive surveys of habitat parameters such as bottom type, relief, and algae, with spatially concomitant estimates of animal abundance.

(3) A reserve must include edge habitats over a large extent of their spatial scale. These include the edge of the kelp forest, the edges of bottom types, and the edges of large reefs. Many important ecological processes occur at these edges and many animals aggregate there.

(4) Reserves must be spatially scaled to protect the entire home range of the species that are targeted for protection within the reserve. Kelp forest reserves can only protect animals that are essentially non-migratory and are specifically associated with kelp forest habitat. The home ranges of these animals vary among species and among individuals for some species. Larger kelp forests have the potential to protect a larger set of species than small forests because large forests encompass the home ranges of more species. The set of species targeted for protection within a kelp forest is therefore set by the size of the forest.

(5) The spatial pattern of ocean climate (temperature and wave energy) and the water masses that a kelp forest is exposed to should be determined. Ocean climate can vary over scales as small as a kilometer and can have profound effects on the growth and persistence of kelp as well as the distribution of animals within or near the forest.

(6) The circulation within and around the edges of the kelp bed should be studied to determine the ability of a reserve to retain larvae and to seed nearby habitats. One of the most important functions of a reserve is to seed nearby habitat with larvae so that the reproductive output of large protected animals within the reserve can be exported to areas outside the reserve for the enhancement of fishery resources. Also, oceanic and migratory fish congregate near kelp projections on the outside edge of the beds where currents are highest. These areas are highly valued by sportsfishers who will fight the establishment of reserves in these areas.

Background and Motivation

Coastal ecosystems around the world are increasingly threatened by fishing. Technological advances which enable the increasingly efficient and destructive harvest of the oceans, and the dramatic increase in human population have set the stage for perhaps the most rapid decline and profound change these ecosystems have ever experienced. The most telling statistic for the accelerating downward trend is that of catch for many coastal fisheries around the world. These trends have occurred even though great effort has been made to manage these fisheries. These downward trends also raise serious questions about the utility of traditional fisheries management in which the focus is typically a single species or stock. Scientists and managers increasingly advocate the value of ecosystem-based management. That is, the focus of management should be the interactive sets of species that live together in a common habitat should be managed as a unit rather than the failed approach of managing individual species. The missing component for almost all ecosystems, especially California coastal systems, is examples of relatively pristine systems that can be used for an understanding of management objectives. This is one of several arguments for the implementation of a network of marine reserves.

Perhaps the most pressing need for totally protected marine reserves is the need to protect spawning aggregations of animals that reproduce by discharging gametes into the water. The dilution of these gametes means individuals more than 3-5 meters from each other are reproductively sterile. Fishery management has focused on minimal size of the individuals, utterly oblivious to the fact that for populations to persist, aggregations of mature individuals is essential and that the protection of such aggregations is the most important management tool, yet it is one that is almost never used. Not only is this true for sedentary organisms like abalones, sea cucumbers, and sea urchins, but it is also true of motile individuals that have spawning aggregations. Some species have mated pairs or harems, and they are less dependent on reserves, but most of the animals in the kelp forest do depend on aggregate spawning. The only conceivable way of insuring this level of reproduction is to protect the aggregations of large animals (fecundity tends to increase exponentially with size of the individuals), and by whatever definition one uses, such protection implies an area in which seed stock and breeding grounds are protected from killing.

Another advantage to establishment of marine reserves involves what is termed “spill-over”, or the fact that fishing can be enhanced when fish recruit and grow in the reserves and eventually move out where they can be captured. Theoretically, the reserves would then supply animals to areas outside the reserves through the migration of juveniles and adults (spillover), and through the export of larvae. Successful reserves must be designed to ensure that the species of interest are exposed to appropriate conditions including the local ocean climate (e.g., temperature, currents, and exposure to waves), the distribution and suitability of specific habitats on spatial scales ranging from meters to hundreds of kilometers, and the dynamics of non-harvested species that can have profound effects on their ecosystem.

Regardless of the utility of marine reserves as a fishery management tool, reserves are the only way to insure, restore and maintain fully functioning ecosystems in a relatively pristine state so that future generations can appreciate them, and so that ecologists can understand how these systems work and how they evolved. The design of these so-called 'heritage reserves' also requires scientifically gathered information so that areas supporting the most diverse and resilient ecosystem can be identified for protection.

Marine Life Protection Act

The California legislature passed the Marine Life Protection Act (MLPA) in 1999 which requires the California Department of Fish and Game (CDF&G) to establish a network of marine reserves in state waters to

> "Protect habitat and ecosystems, conserve biological diversity, provide a sanctuary for fish and other sea life, enhance recreational and educational opportunities, provide a reference point against which scientists can measure changes elsewhere in the marine environment, and help rebuild depleted fisheries…"

The Act was drafted out of concern for coastal ecosystems and fisheries statewide.

Unfortunately, implementation of the Act, which should have gone into effect last year (2002), appears stalled because (1) the Act was passed with no money appropriated to design and establish the network of marine reserves, (2) the lack of scientific information to adequately design a network of reserves, and (3) the vocal opposition of sports and commercial fishing groups. The primary opposition to the MLPA is based on the belief that reserves are not effective and there is a lack of adequate scientific information on where to site the reserves. The first argument is refuted by a large and growing scientific literature showing that diversity, size, abundance, and fecundity is much larger in reserves than in nearby unprotected areas, and that spillover and larval export from reserves enhance fished stocks outside reserves in many cases. The latter argument is more legitimate as there is a lack of information on habitats and habitat-connectedness at the level of detail that is required to optimally design a large network of reserves in State waters.

The Ghost Forest Project

Kelp forests are one of the most important habitats in need of protection, and one in which many species of invertebrates and fish have been depleted throughout the coastal waters of Southern and Central California. These areas are defined by the presence of Giant Kelp (*Macrocystis pyrifera*) that provides habitat and food to a diverse assemblage of species. Presently, there are only a handful of reserves in kelp forests, and none of these encompasses an entire forest. The MLPA specifically identified kelp forests as a representative habitat that should be included in the reserve network. As part of the "Ghost Forest Project", we collected crucial data and developed an information gathering and analysis system that (1) should serve as a model for the establishment of marine reserves in kelp forests in California, (2) provides an exhaustive amount of information on the locations of habitat and the animals associated with those habitats throughout the second largest kelp forest in the state, (3) is the most comprehensive survey of a kelp forest system to date, and therefore represents a crucially-needed baseline by which to gauge human disturbance into the future, (4) gauges the effectiveness of an existing small reserve that includes a small fraction of that forest, (5) provides data necessary to redesign the old reserve or design a new reserve that would better represent the kelp forest ecosystem, (6) identifies important nursery (sink) habitats of several harvestable species, (7) identifies important larval source habitats within the kelp forest.

Project Research

We chose to study the La Jolla kelp forest as a case study because it represents an array of kelp habitats, user conflicts, and societal needs. In addition, our work is extremely labor intensive so our initial effort in this type of research needs to be done near our institution to minimize logistic needs. Finally, and most importantly, there is a long-standing reserve located in and adjacent to the northern edge of the kelp forest. This reserve, the San Diego-La Jolla Ecological Reserve (SDLJER) was established in 1971 and protects the northern tip of the La Jolla kelp forest, the head of the La Jolla Submarine Canyon, and an adjacent sandy shelf (Fig.1).The reserve was established in 1971 by the City of San Diego in cooperation with the California Department of Fish and Game as a 'no-take' marine reserve where no extraction is allowed. The reserve is centered on the La Jolla Submarine Canyon but also protects approximately 1500 square meters of kelp at its southern margin. The original goals of the reserve are not clear, but it is thought that it was established to protect abalone in the rocky shallows at its southern end and the head of the submarine canyon where rockfish populations once flourished, and where the squid fishery had destroyed important rockfish nursery habitat. The area of kelp forest that is protected by the reserve is less than 1% of the entire La Jolla kelp forest, but nonetheless, represents one of the largest kelp reserves in the state and therefore warranted study to determine its effectiveness. Further, the La Jolla forest, due to its large size, should be part of a network of marine reserves, and surveys of the bed were needed to identify important areas or habitats that should be protected.

We conducted the following projects:

(1) Comprehensive surveys (counts) of conspicuous algae, invertebrates, and fishes were conducted throughout the entire kelp forest (see Fig. 2) along temporary transects to determine the distribution of habitats within the kelp forest and the distribution and abundance of select conspicuous animals. Thirty-three species of invertebrates and twenty-seven species of fish were counted.

(2) Multivariate analysis of survey data to determine habitat types both inside and outside the reserve to facilitate statistical comparisons of species harvested in similar habitats. The most accurate inside v. outside comparisons are those that compare densities of animals in the same types of habitat.

(3) Surveys of Green Abalone habitat for comparisons of abalone densities and breeding aggregations inside and outside the reserve were conducted to gauge the effectiveness of the Reserve for Green Abalone. All abalone reproduce by broadcasting eggs or sperm into the water. Abalone must be close together

(within a meter or so) for a large proportion of eggs to be fertilized. Green Abalone inhabit waters from near the surface to depths typically not greater than ~7 meters which is inshore of the inner edge of the kelp forest. Therefore these surveys had to be conducted independently of the random transects conducted inside the kelp forest.

(4) Comparisons of urchin size frequencies within the Reserve with areas outside the reserve to further gauge the effect of the Reserve on urchin sizes.

(5) Surveys of rockfish in the head of the La Jolla Submarine Canyon (LJSC; inside the Reserve) with the unprotected but otherwise similar Scripps Submarine Canyon (SSC) located ~3 km north of the LJSC. These surveys were conducted at depths ranging from 50 to 100 meters using a Remotely Operated Vehicle (ROV; Seabotix LBV150) equipped with a video camera owned and loaned by Brock Rosenthal.

(6) Important nursery habitat types were identified for harvestable gastropods (marine snails including abalone) and urchins by placing larval/juvenile collectors (cobble covered with crustose coralline algae in plastic mesh bags) in different types of habitat. The resulting habitat affinities could then be used to extrapolate important nursery areas inside the forest using the habitat data.

(7) An attempt to establish a network of diving volunteers who could help survey sites into the future.

(8) Discussions were held with local commercial urchin harvesters, recreational spear fishers, vessel and kayak sports fishers to help determine what areas of the kelp forest they utilized most and to solicit their help in monitoring these areas. Preliminary discussions were conducted with the urchin fishermen to set up an experiment to determine the effects of urchin harvesting on kelps and associated animals by establishing a voluntarily closed area.

(9) As part of an ongoing effort, we are gathering as much archived biological data and historical notes regarding kelp forests and their associated animals that are still available. We are also researching the history of marine resources in Southern California. This work is being conducted so that we can understand the history of depletion along our coastline and determine how our estimates of present species abundances compare with abundances in the past.

(10) Surveys of San Diegans were conducted to understand their knowledge and opinions of marine reserves in general, and their knowledge of the San Diego-La Jolla Ecological Reserve. The enforcement of the present Reserve is only possible with public participation since resources to enforce the Reserve are severely limited. This requires public knowledge and support of the Reserve.

Study Personnel

This work was possible only with the efforts of many people most of whom volunteered their time. These include:

Divers: Leen Geelen, Cleridy Lennert-Cody, Kim Whiteside, Noelle Barger, Eddie Kisfaludy, Melissa Carter, Andrea DeMent, Margot Stiles and Ed Parnell.
Historical Data: Ed Parnell and Tonya Huff.
Research Program Development: Ed Parnell, Paul Dayton, and Cleridy Lennert-Cody
Data Analysis: Ed Parnell and Cleridy Lennert-Cody.
Synthesis and Writing: Ed Parnell and Paul Dayton.
Public Surveys: Laura Stanley, Kim Whiteside, Andrea Dement, Noelle Barger, and Ed Parnell
ROV: Brock Rosenthal (Ocean Innovations, San Diego) and Ed Parnell. Brock kindly loaned us the use of his ROV and provided technical assistance in the field.

RESULTS

Habitat

The multivariate analysis of habitat data revealed five basic habitat types within the kelp forest (Table1). The underlying habitat classifications were based on cluster analysis of sixteen different variables including substrate type, vertical relief, and algal group (i.e., both physical and biological parameters). Please note that common names were used for species that have them throughout this report, otherwise scientific names were used. A table of common names and their corresponding scientific names is provided in the appendix.

Table 1. Description of habitat types including characterization of substrate and vertical relief, and dominant algal groups. "High" designates that the characteristic substrate or algae was highest in that cluster. "Moderate" designates that the cluster was within ~75% of the cluster that had the highest value for that characteristic.

Habitat	**Substrate**	**Algae**
Turf Reefs	High: reefs Moderate: sand, depth variability, sharp vertical relief, ledges, crevices, overhangs	High: Feather Boa Kelp, Forked Kelp, Bladder Leaf Kelp, red turfs, articulated corallines Moderate: Tangle Kelp
Red Urchin Reefs	High: bedrock, rock, depth variability, sharp vertical relief, overhangs Moderate: reefs, crevices	High: *Agarum fimbriatum*, Flattened Acid Leaf Kelp, brown turfs
Cobble Flats	High: cobble, sand	Moderate: Walking Kelp
Kelp	High: crevice Moderate: bedrock, bedrock dusted with sand, bedrock with lots of sand cover, reefs, ledges	High: Giant Kelp, crustose corallines
Red Algal Understory	High: bedrock dusted with sand, bedrock with lots of sand cover, ledges	High: Walking Kelp, Tangle Kelp Moderate: Flattened Acid Leaf Kelp, articulated corallines

Habitat Associations for Invertebrates and Fish

There were strong patterns of habitat associations for several invertebrates and fish (see Table 2).

Table 2. Habitat associations for fish and invertebrates. "Most abundant" designates invertebrates and fish that were highest in that cluster. "Common" designates that the cluster was within ~75% of the cluster that had the highest value for those fish and invertebrates.

Habitat	Invertebrates	Fish
Turf Reefs	Most Abundant: Pink Abalone, Wart-Neck Piddocks, sublegal lobsters, Brown Gorgonian, total lobsters Common: Purple Urchins, Wavy Turbans, legal lobsters, octopus, total piddocks	Most abundant: Kelp bass, Opaleye, Garibaldi, Rock Wrasse Common: female Sheephead, total Sheephead, Black Perch
Red Urchin Reefs	Most abundant: Red Urchins, cucumbers, Giant Spined Star, Bat Stars, legal lobster, California Golden Gorgonian, Fragile Rainbow Star, total gorgonians, Rock Scallops Common: Purple Urchins, Wavy Turbans, sublegal lobsters, Brown Gorgonians, Ornate Tube Worm, octopus, Giant Keyhole Limpets, total lobster, total gorgonians, Kellet's Whelks	Most abundant: female Sheephead, total Sheephead, total rockfish, Sculpin, Blacksmith, Kelp Rockfish, Black Perch Common: male Sheephead, Garibaldi, Lingcod
Cobble Flats	Most abundant: octopus Common: Ornate Tube Worm	Most abundant: Senoritas
Kelp	Most abundant: Purple Urchins, Blood Star, Kellet's Whelks, Scaleside Piddock, Ornate Tube Worm, Red Abalone, Giant Keyhole Limpets, total piddocks Common: Red Urchins, Warty Sea Cucumbers, Giant Spined Star, Wavy Turbans, Fragile Rainbow Star, Rock Scallops	Most abundant: male Sheephead, Barred Sand Bass, Cabezon, Lingcod Common: total Sheephead, total rockfish, Sculpin, Black Perch
Understory	Most abundant: Wavy Turbans Common: Purple Urchins, Fragile Rainbow Star	Most abundant: female Sheephead, total Sheephead, Cabezon, Senoritas, Black Perch

Reserve v. Non-Reserve Comparisons

Statistical tests compared the densities of economically important species inside the Reserve with comparable areas outside the Reserve to gauge the effectiveness of the Reserve. Comparison tests were run for male Sheephead, female Sheephead, Red Urchins, Warty Sea Cucumbers, Kellet's Whelks, Purple Urchins, Kelp Bass, Barred Sand Bass, Lobster, Wavy Turbans, and Total Rockfish. Comparisons were not possible for Abalone, Giant Keyhole Limpets, or Rock Scallops because too few were observed. Significant differences between reserve and non-reserve densities were observed for Sheephead, Red Urchins, Warty Sea Cucumbers, and Kellet's Whelks. Densities for these species were greater in the reserve than outside the reserve indicating that the reserve afforded some protection to these species.

Fish sizes were estimated for female Sheephead, male Sheephead, Kelp Bass and Barred Sand Bass. No significant differences were observed for the species between reserve and non-reserve areas.

Red Urchins and Purple Urchins were collected exhaustively from meter squares and measured. Urchins were collected from three different areas, (1) inside the Reserve, (2) outside the Reserve but in habitat similar to the Reserve (these were all in the northern half of the forest), and (3) the southern half of the bed. Over 1000 urchins were collected for each category and all were collected at depths from 12-17 meters. Two effects were observed. The first was a Reserve effect. Red Urchins (the species harvested by urchin harvestors) were significantly larger inside the Reserve than outside. This was not observed for Purple Urchins, which are not harvested. Second, there is significantly more recruitment for both species in the northern half of the forest; these data corroborate the claims by representatives of the urchin divers.

Biodiversity

The area with the highest diversity (Hill's N1 diversity, Hill 1973) of fish and invertebrates was at the southern edge of the forest (Fig. 3). Moderately high diversity was observed in seven other areas of the forest having spatial scales of 800-1200 meters. Relatively low diversity was observed in the kelp forest within the Reserve.

Green Abalone

Comparisons of densities and aggregations of Green Abalone between the reserve and an area having similar habitat outside the reserve showed that Green Abalone are found in higher densities inside the reserve (1.6 ± 0.05 abalone/100 meters of search path) than outside (0.2 ± 0.01 abalone/100 meters of search path, and that abalone were significantly more aggregated inside the reserve (3.4 abalone/aggregation) than outside (1.2 abalone/aggregation). These results are preliminary results and work is ongoing using a different sampling method (adaptive cluster sampling), which will allow the estimation of absolute abundance rather than relative density. Two more control areas outside the Reserve will be added so that the Reserve can be compared to a total of three areas outside the Reserve. The reason for adding two more control areas is to cover a wider range of habitats making the inside v. outside comparisons more meaningful.

ROV

Preliminary quantitative surveys of the LJSC (reserve) and SSC (non-reserve) show that the abundances of Vermilion Rockfish inside are greater than outside the Reserve by at least a factor of 10-100. Further, the few that were observed in the SSC appeared significantly smaller than those in LJSC. Calico Rockfish were occasionally observed inside the reserve but none were observed outside.

Gastropod and Urchin Nurseries

The gastropod and urchin juvenile collectors were placed in different areas of the forest having different types of habitat. Preliminary results suggest that important nursery areas for urchins include the outer half of the bed in areas with heavy cover of articulated coralline algae and vertical relief ("Turf Reefs", "Red Urchin Reefs" and "Kelp" habitats). On the other hand, the "Turf Reef" habitat appears to be the main nursery for the economically important gastropods (mainly Red and Green Abalones and Wavy Turbans).

Public Outreach

The main public outreach component of the study was to develop a core of diving volunteers that would monitor specific dive sites for fish and invertebrates through time. Several meetings and training sessions were held involving more than 100 divers. We invested several hundred hours on this and we equipped the divers with sampling equipment such as transect reels, meter sticks, and slates. After several months of fits and starts, it was evident that the level of cooperation and interest were not great enough to warrant continuing the program. We found that the main problem was that we asked the divers to collect data that requires a great deal of effort and is laborious. Considering that we were asking them to take time out from their recreational activities while diving to measure and count things was overly ambitious. A drastically scaled-back monitoring program might have met with moderate success had we spent lots of time on organization and motivation. However, the data that would have been collected in such a scaled-back program would not have been very useful. Further, we found that the time we spent organizing, training, and motivating was much greater than it took to go collect the data properly ourselves. The downside is that future monitoring will not occur now that the project has been completed. A group of dedicated volunteers could have continued an extremely important monitoring program into the future tracking changes if more reserves are established in the La Jolla kelp forest.

Several meetings with vessel sport fishers, spear fishers, kayak fishers, and commercial urchin divers were also held so that we could learn their opinions on reserves and determine where most of their extractive activities were taking place in the La Jolla kelp forest. Vessel sports fishers, spear fishers, and commercial urchin divers are nearly unanimously opposed to reserves and were not shy about expressing their opinions. Kayak fishers appeared to value reserves more but were concerned about access to and the closure of their favorite sites located near the outside of the kelp bed immediately NW of Pt. La Jolla.

Public Surveys

While still preliminary, surveys of the general public have revealed that there is overwhelming public support for marine reserves (>90%), most surveyed believe there are much more coastal waters set aside as reserves than is the case, and a general lack of knowledge about the rules and boundaries of the San Diego-La Jolla Ecological Reserve even by people who were interviewed on the beaches where the Reserve is located.

DISCUSSION

History of Human Impacts on Coastal Habitats in Southern California

People have impacted the coastal ecosystems since the ice ages, and there is evidence of these Holocene (the time since the ice ages ended) people along the sides of the submerged coastlines of San Diego County. While we have written about these prehistoric impacts, we limited our focus here to the impacts of Europeans, and then focused mainly on the last 100 years when the fishing impacts were most dramatic.

The popular history of European impacts on the ecosystems of San Diego's coastlines and embayments began in the early 1800s, the most popular was Richard Henry Dana's classic, "Two Years Before the Mast". Since that pre-gold-rush era, the watershed that drains into coastal San Diego has undergone tremendous change, and the ever-accelerating pace of population growth has resulted in dramatic changes to the wildlife of San Diego's waters. As part of our project, we have researched the history of San Diego and the scientific literature to piece together an understanding of the history of change to the marine and estuarine biota brought about by humans during this period. Obviously it is very important to understand conditions at the beginning of this period of early expansion, and to understand the trajectory of our coastal ecosystems. This allows us to put the present pace of ecosystem change in perspective, and to develop ways to properly gauge and hopefully reverse the effects of our impacts. Besides fishing, the human activities with the most dramatic effects have been the re-engineering of the San Diego River basin, the dredging of San Diego and Mission Bays, development near and encroachment upon several estuaries throughout the County, the runoff and improper discharge of poorly treated waste and storm waters, and the improper storage and dumping of hazardous materials in or close to these waters. Some of these problems, such as sewage discharge, have been effectively mitigated, but efforts to mitigate the negative effects of other activities, such as fishing, have thus far met with little success.

In the meantime, the negative effects of coastal fishing activities were becoming abundantly clear. By the turn of the century, government biologists were writing about the demise of the abalones as the result of poorly managed hardhat diving (see Rogers-

Bennett et al, 2002). Intensive barge fishing, in which commercial and recreational fishers were transported to old sailing hulks anchored offshore, serially depleted nearshore waters beginning in the 1920's. Hardest hit were the largest and most important fish at the top of the marine food chain. These fish included Black Seabass (some of which weighed over 600 lbs) and Broomtail Grouper, both of which are now only rarely seen. Later, the availability of SCUBA in the 50's and the post-WWII population boom began a second wave of exploitation that led to the further devastation of these species as well as Red Urchins, abalone, large lobster, and many other species of invertebrates and fish. It is now very rare to see lobster weighing more than 1 pound (the typical weight at legal size), while it was quite common to see eight-pounders in the 60's. All species of abalone are in such bad shape that it is now illegal to take them south of San Francisco. The impacts of the first two waves of devastation are now being supplemented by a new third wave of exploitation which began in the late 80's in the form of the live fish fishery in which live fish are trapped and brought directly to restaurants for patrons to pick out their meal while it is still swimming. This third wave has led to the serious depletion of many species of fish including the California Sheephead, an important species that regulates the sea urchins that eat kelp. In the background behind these waves of exploitation, has been the phenomenon of targeting ever smaller animals, or fishing down the food chain. This phenomenon is indicative of a collapsing food chain and serious change to an ecosystem.

For our historical search, we tracked down the scientific literature and data pertaining to the abundances of animals through time. These data then provided a comparison for our present observations. We found that fishery-independent data only become available in the 1950's. We also discovered that fish populations were so depleted by the 1950's that these early data do not represent a true baseline of pristine conditions, but rather a baseline that is well shifted toward depletion. Fishing conditions were so bad by the by the 50's that fishermen were greatly concerned and pushing for an understanding of the problem. Many blamed the fish depletion on the harvest of kelp, which had become a major industry by then. Thus began the Institute for Marine Resources (IMR) a major research institute at the Scripps Institution of Oceanography initially charged with studying the state of California's marine resources. Data from projects administered by the IMR and other projects have led us to the conclusion that many harvested species of animals are presently in much lower abundances than even in the 1950's when fishermen were already complaining.

We have also researched the archives and interviewed old divers to obtain even anecdotal information on the abundances and sizes of the fish in local waters fifty years ago. Connie Limbaugh kept good notes, but the early divers were not very quantitative. Unfortunately, even the anecdotal information was predicated with assertions that the fish were heavily depleted before the early divers began spearing fish, and by the 1960s the densities that Jay Quast (one of the first diving quantitative scientists) recorded represented the modern pattern of small fish. More recently, diving surveys conducted in the San Diego-La Jolla Ecological Reserve in the mid-seventies by Bert Kobayashi who used more modern methods, yielded the first data that is directly comparable to our data. These data reveal a further pattern of depletion, even in the Reserve, as lobsters, Sheephead, and Kelp Bass were about ten times more abundant than they are now, and Pink Abalone and Green Abalone were more than one-hundred times as abundant.

The general conclusion that must be drawn from our historical analysis is that stocks of harvestable marine fish and invertebrates were already depleted by the 1950's due to fishing, and this trend has not only continued but has accelerated through today. The degree of exploitation is such that San Diego's coastal ecosystems are vastly different from those observed by fishermen even a generation ago.

Habitat Patterns

The most striking habitat pattern that emerged from our study is the difference in habitat types between the northern and southern halves of the forest (Fig. 2). The "Turf Reef" habitat, which is the main habitat found in the Reserve, is very common in the northern half but is rare in the southern half. "Turf Reef" habitat represents reefy, sandy areas with lots of turf and understory algae. The "Understory" habitat, indicative of areas having an abundance of understory algae, displays a similar spatial pattern to that of "Turf Reefs". The "Kelp" habitat, representing typical giant kelp habitat, is more abundant in the southern half. The "Red Urchin Reef" habitat, indicative of high vertical relief and very little understory and canopy algae, is nearly equally abundant in the north and the south. However, this habitat appears to be more common on the outside edge of the bed in the north while it is more common on the inner margins of the bed in the south.

There are three possible mechanisms underlying the observed distribution of habitats. First, is the underlying pattern of substrate type (e.g., sand, bedrock, or rock) and vertical relief (e.g., reefs, overhangs, or ledges). The distribution of all of these features, with the exception of sand and cobble, are not different between the north and the south. Sand is more abundant in the north while cobble is more abundant in the south. However, these two substrates are similar in that kelps are generally absent on both substrates, and neither substrate has vertical relief associated with it. Therefore, the difference in habitat types between the north and the south is not due to differences in substrate or relief. The second possible cause is the slope of the seafloor where the kelp forest exists. However, the bathymetric map presented in Figure 1 clearly shows that the kelp forest in La Jolla consists of two broad shelves, one each in the north and south, separated by a gully near the central portion of the forest. Therefore, habitat differences based on bathymetry can be ruled out because bottom profiles are similar between the two halves of the forest. The third possible cause is differences in the ocean climate between the northern and southern halves of the forest. We can explore this cause using biological and temperature data.

The biological patterns that implicate ocean climate as an important cause of habitat patterns in La Jolla include the patterns of giant kelp persistence (Fig. 1) and the distribution of animals that are known indicators of local ocean climate. Because of its reliance on nutrients, the giant kelp is an important indicator of the oceanic influence on a kelp forest. The pattern of giant kelp persistence in the La Jolla forest is very different between the northern and southern halves, with giant kelp being much more persistent in the south. Time-series of kelp abundance in La Jolla show that the northern half of the forest disappears during periods of warm water and large storm waves, both of which are stressful to giant kelp, and which occur during the more intense El Nino's. The distributions of animals indicative of hydrologic conditions, the gorgonians in the genus *Muricea*, and the tube-building worm, *Diopatra ornata* (Ornate Tube Worm), are also very different between the two halves (Figs. 4 and 5, respectively). Gorgonians are suspension feeders dependant on a continuous supply of plankton; they are known to thrive in areas with vigorous water circulation and are more abundant in the northern areas. On the other hand, Ornate Tube Worms, which live in an exposed tube, are vulnerable to vigorous water movement and are more abundant in the calmer areas in the south.

Temperature data from sensors placed on the bottom throughout the bed during our study reveal a difference in the temperature climate between the northern and southern parts of the forest. The northern half is subjected to more frequent warming events than the southern half. Taken together, the biological and temperature data strongly indicate that the oceanographic climate is different between the northern and southern halves of the forest. The picture that emerges is that the northern half is subjected to warmer and more energetic conditions than the southern half. Both of these conditions are stressful to giant kelp and explain why kelp is more persistent in the southern half. These different conditions are adequate to account for the different habitats and have important implications, which will be discussed later, for the design of a Reserve in La Jolla.

<u>Effectiveness of Present Reserve</u>

Despite the small size of the rocky bottom inside the SDLJER, it appears to have afforded some protection to species that are known not to venture far as adults (i.e., small home ranges). These include Red Urchins, Warty Sea Cucumbers, Kellet's Whelks and Sheephead, all of whose densities were higher inside the Reserve than in comparable habitat outside. The most striking difference was for that of Red Urchins ($p<0.001$), which are heavily fished throughout the kelp forest. Adding support to this conclusion is the fact that no reserve effect was observed for the Purple Urchin that is not fished. The reserve effect for Sheephead was also quite significant ($p=0.009$). However, it is curious that there were no differences in size for Sheephead inside and outside the Reserve. In almost all cases where there are higher densities of fish inside reserves, size is also higher inside reserves. The only way to help explain our results for Sheephead is to conduct a tagging study to determine the movements of Sheephead inside and near the Reserve. The significant differences for Warty Sea Cucumbers ($p=0.032$) and Kellet's Whelks ($p=0.05$) are not as definitive as those observed for Red Urchins and Sheephead. The results of the Green Abalone study, while still preliminary, are nonetheless striking in that the relative densities and aggregation sizes were so large inside the Reserve relative to the outside. If this pattern holds for the data that we are presently collecting, then the Reserve has greatly protected Green Abalone. The same is true for Vermillion Rockfish in the LJSC.

Summarizing the results of the inside v. outside comparisons, we found unambiguous reserve effects for Red Urchins, Sheephead, Vermillion Rockfish, and Green Abalone. All of these species have small home ranges relative to the size of the Reserve. For other economically important species with larger home ranges, such as lobster, kelp bass, barred sand bass, and wavy turbans, no reserve effect was observed, which strongly indicates that the Reserve is not large enough to protect these species from exploitation. This study has also shown that reserves in Southern California can be locally effective at protecting some species. These effects however, are limited to the Reserve, as spillover and larval export are not likely to be important from such a small area. For a reserve in Southern California to be effective as a fishery management tool and as a source of significant spillover and larval export it must be much larger than the present reserve in La Jolla.

Considerations for Future San Diego County Reserves

The species effectively protected in the small San Diego-La Jolla Ecological Reserve include those whose home ranges are similar to or less than the size of the Reserve. Thus, virtually all migratory species would receive little benefit from any reserve unless they can derive benefit from protection of spawning aggregations. Accordingly, most migratory species are not effected by marine reserves and their conservation depends upon much improved traditional management.

On the other hand, there are many species with sufficiently restricted home ranges that reserves would be expected to function as predicted. Such species include Sheephead, Cabezon, Sculpin, Lingcod, many species of rockfish, large lobster, Red Urchins, cucumbers, and all economically important gastropods and bivalves (principally abalone, Wavy Turbans, Kellet's Whelks, octopus and Rock Scallops). Kelp Bass and Barred Sand Bass may also be afforded some degree of protection since home ranges vary among individuals of these species with some venturing for miles while others remain within a few thousand meters of their natal area. Since the La Jolla kelp forest is so large relative to most other kelp forests in Southern California, a marine reserve in La Jolla has the capacity to afford protection to more species. Therefore, a marine reserve in La Jolla is likely to be more effective than other rocky areas in Southern California.

Lobsters (*Panuliris interruptus*) warrant special consideration because they typically migrate from onshore to offshore seasonally. These animals, with exceptions, move offshore in winter and migrate into shallower water during the spring. Therefore, any reserve in La Jolla should include a section of coastline from the shallows all the way to the limit of State waters (3 nautical miles). Combining the considerations of home ranges for the species that could be protected by a reserve in La Jolla and that of lobster migration, **a reserve in La Jolla should extend over at least a few kilometers of shoreline and extend offshore to the edge of State waters**. This is a fairly large area and inspection of the bathymetry off La Jolla leads to the conclusion that the most obvious areas that satisfy these criteria would be either the northern or southern half of the kelp forest. The border between these two areas is where the kelp is narrowest off Wind'n'Sea.

From an ecological perspective, both the northern and southern halves have advantages for establishing a marine reserve within them. However, there are more advantages for the establishment of a reserve in the southern half. These include, (1) the most persistent stand of giant kelp which provides habitat for many species and indicates lower environmental stress and variability than the northern half, (2) contains the most high-diversity habitat ("Kelp" habitat), (3) the area with the most male Sheephead (Fig. 6) and Lingcod (Fig. 7), and (4) cooler and therefore more consistent nutrient availability for giant kelp. The only possible ecological disadvantage for establishing a reserve in the south instead of the north is that currents in the upper few meters of the water column are typically driven southward and shoreward by the prevailing NW afternoon sea breeze. This means that larvae in the upper parts of the water column are more likely to be lost from the southern part of the bed than the northern part. However, kelp has a dampening effect on currents and subsurface currents are commonly observed going northward. Circulation in this area has not been well studied and the design of a reserve off La Jolla would be enhanced with a better understanding of the currents so that the trajectories of larvae emanating from different parts of the bed can be estimated.

From a political perspective, the meetings and discussions held with the stakeholders made it clear that a reserve in the southern half of the bed would be more acceptable than one in the northern half. The commercial passenger fishing vessels, private boat fishers, spear fishers, kayak fishers, and commercial urchin divers all prefer the northern half of the bed. The favorite fishing spot for pelagic and migratory fish is at the very northwest tip of the bed off Point La Jolla. Urchin fishermen claim that the best urchin recruitment is also to the northwest. Therefore, locating a reserve in the northern half would meet with very stiff political opposition.

To summarize, our recommendations for the placement of a marine reserve off La Jolla are for a reserve to be established in the southern half of the bed from Northern Pacific Beach (Law Street) to Wind'n'Sea (Palomar Avenue). This area is the most diverse of the entire kelp forest, is the area with the most persistent kelp habitat, is less exposed to disturbance, and would be politically more acceptable than a reserve in the north. The present boundaries of the SDLJER should be maintained as the kelp habitat protects the now very rare green abalones and it includes a large number of unique soft bottom habitats not discussed in this paper. The present reserve also protects a very important canyon habitat, which is home for a stock of rockfish at the head of the submarine canyon.

Future Research Towards the Development of a Network of Marine Reserves in Southern Calfornia

In this paper, we have presented a set of arguments on how best to design a reserve in the La Jolla kelp forest based on the best available scientific and social knowledge. We believe that this level of rigor is novel, especially in southern California. This habitat, while rich and interesting, is not necessarily representative of the wide diversity of kelp habitats in southern California. Similar studies of other kelp forests throughout southern California are needed to define an effective network of marine reserves in these waters. However, these studies need to go one step further such that oceanographic circulation is also studied so that the dynamics of larval exchange between reserves can be better understood.

Mainland kelp forests tend to be impacted by coastal runoff and pollution from non-point sources, and these need study. But most urgently in need of study are the southern Channel Islands. The northern Channel Islands have been the subject of intense political struggles, and have very different habitats than the southern islands because the western areas are bathed by cold and nutrient rich oceanographic climates while the eastern habitats of the northern islands are in warmer waters, but waters that still have a coastal influence including sedimentation. The northern islands also enjoy a richly endowed research program at UCSB. Because of the intense political pressures, there is still a pressing need to employ rigorous methods to a true oceanic island such as Catalina Island. The east side of Catalina Island has an almost tropical oceanographic regime with clear, relatively warm nutrient poor water. The west side of the island has colder, richer water. Catalina Island has not figured in the controversies surrounding the northern Channel Islands, but it does have a small very active reserve research program that is, in many ways, comparable to this one.

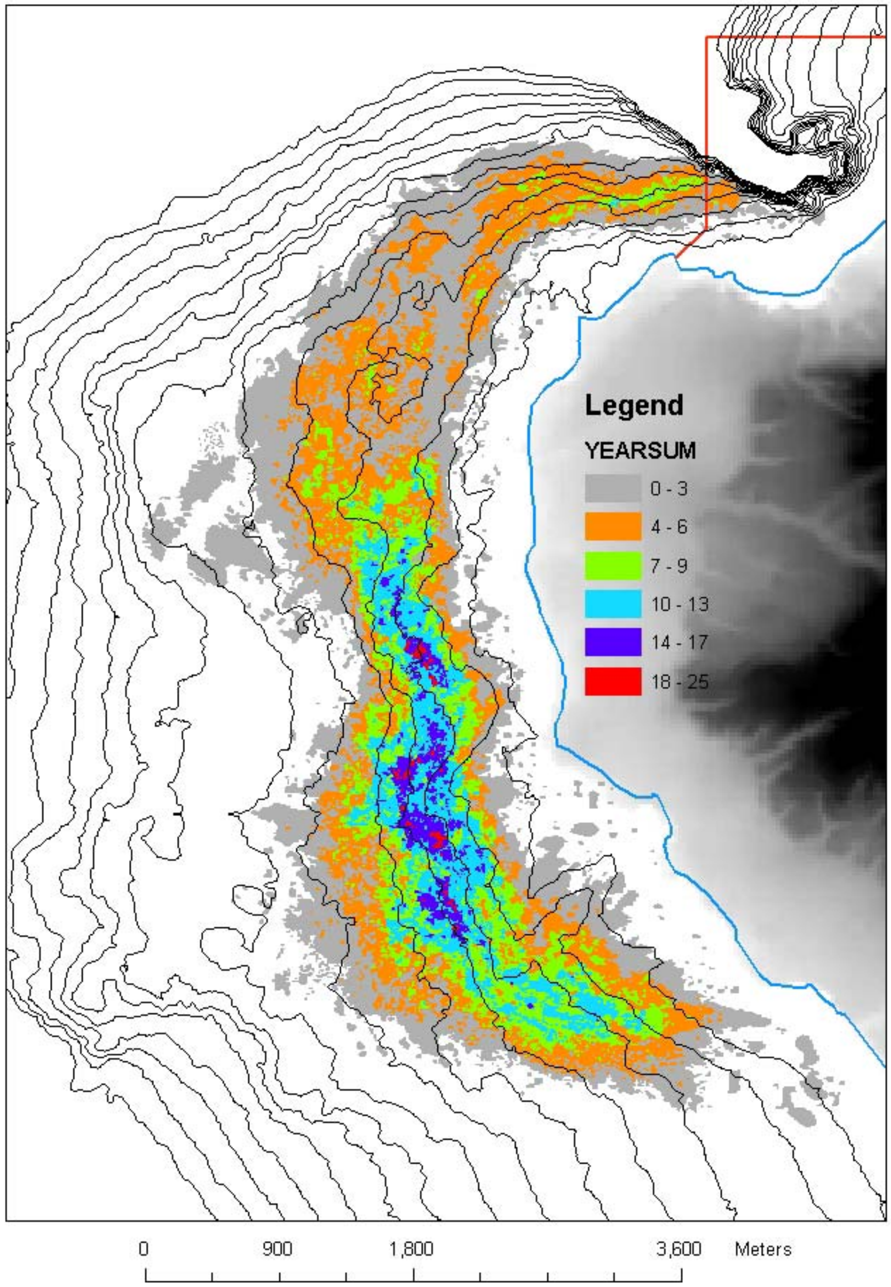

Figure 1. Map of the La Jolla Kelp Forest. The boundaries of the San Diego/La Jolla Ecological Reserve are shown at the top in red and the shoreline is blue. Kelp persistence from 1967-1999 is displayed on the map (see legend for color pertaining to the number of years that kelp was observed at that site). Kelp persistence data courtesy of Larry Deysher (Ocean Imaging Inc.).

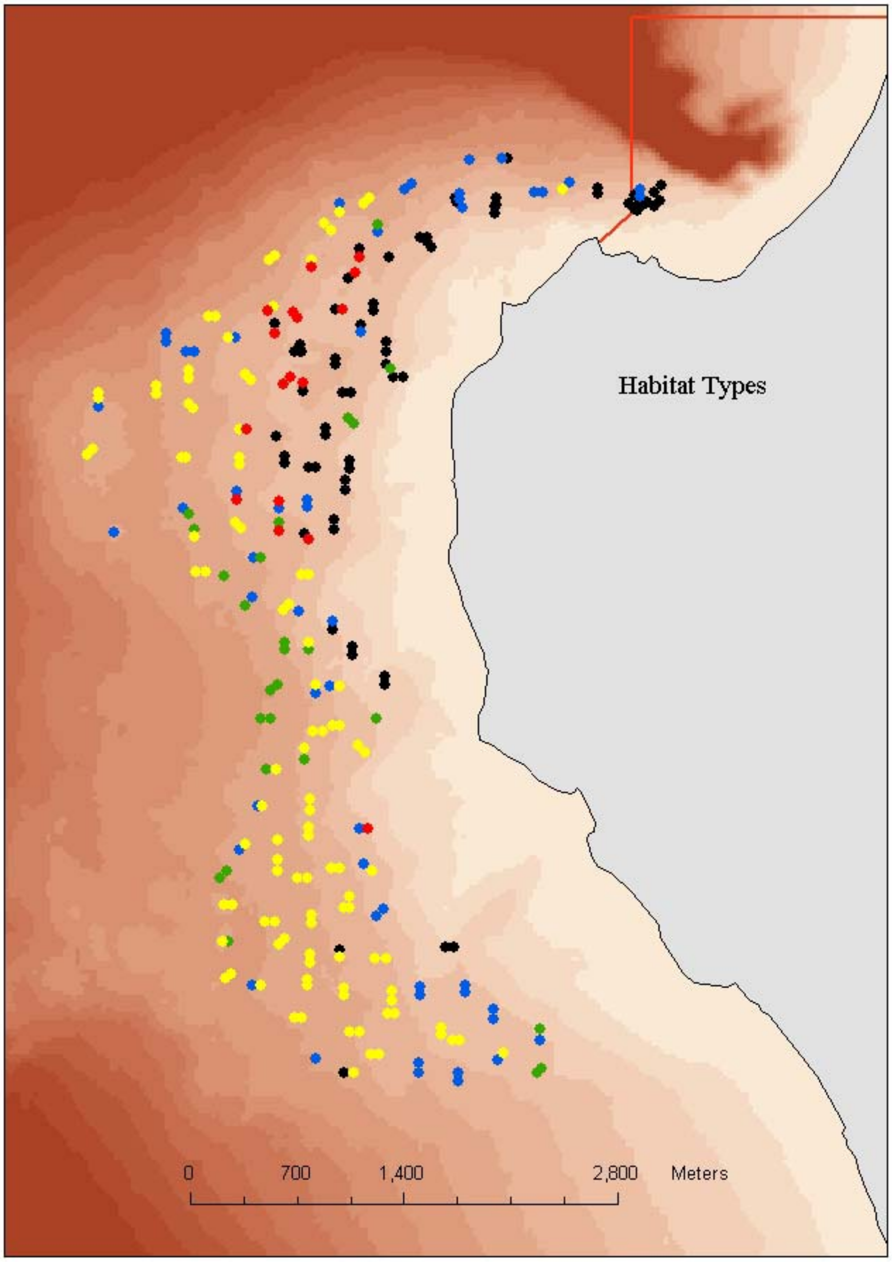

Figure 2. Map of the La Jolla Kelp Forest showing location of random transect surveys. Colors indicate habitat type for each transect. There are 5 different habitat types (see Tables 1 and 2 for descriptions of habitat types and animal affinities for each habitat). Color codes for habitat types: Black="Turf Reefs", Blue="Red Urchin Reefs", Green="Cobble Flats", Yellow="Kelp", Red="Understory".

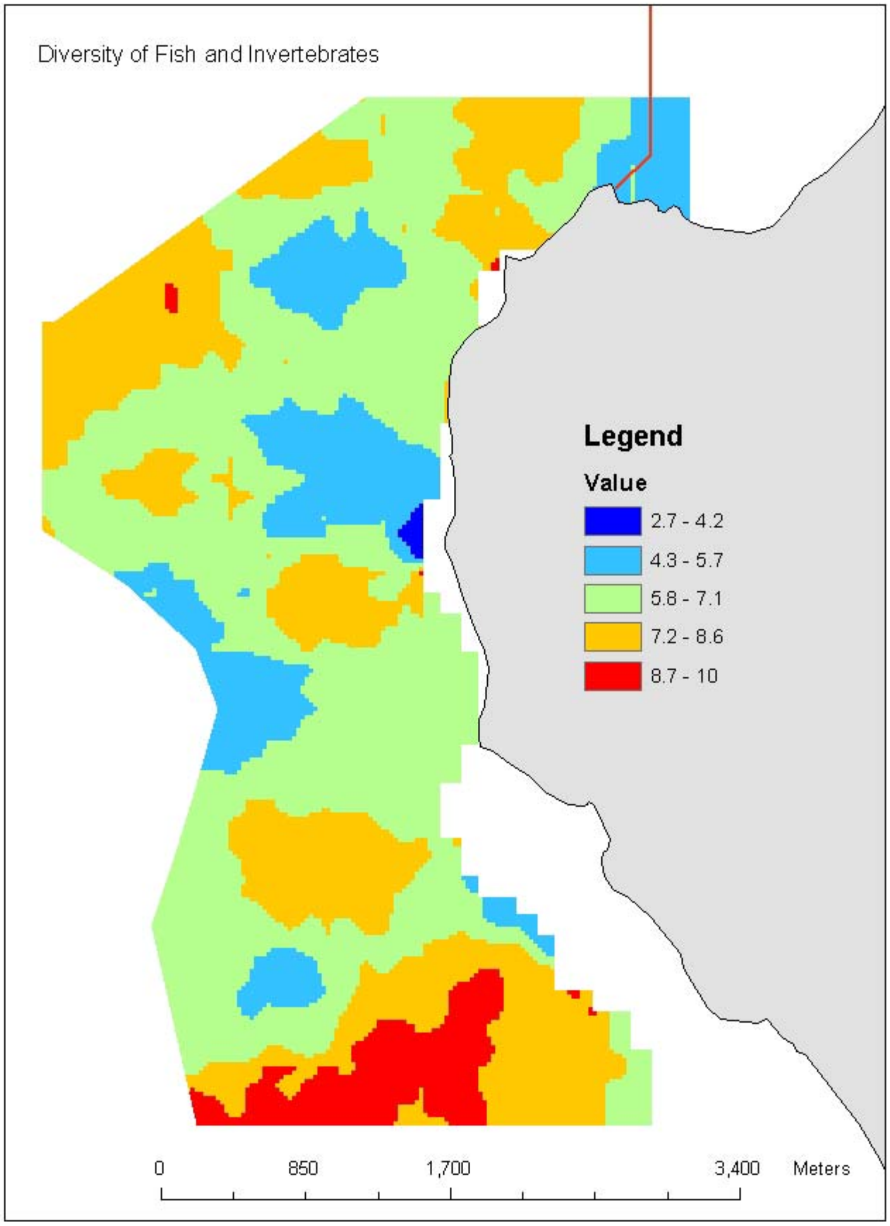

Figure 3. Map of the La Jolla Kelp Forest showing spatial patterns of fish and invertebrate diversity (Hill's N1 diversity index). Hill's N1 index is a measure of the number of abundant species (see legend for color representation of index).

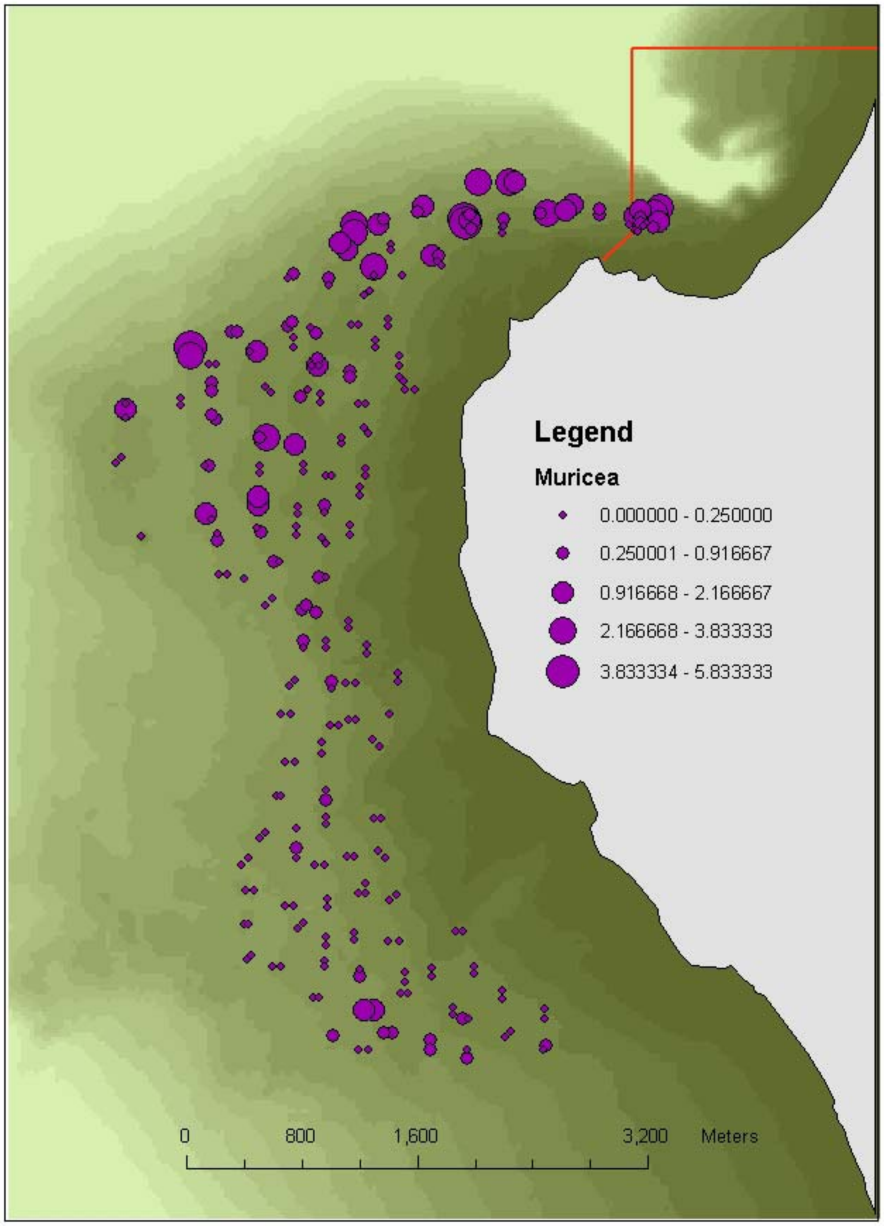

Figure 4. Distribution pattern for gorgonians (*Muricea* spp.) in the La Jolla Kelp Forest. Gorgonians thrive best in areas with greater water motion. The distribution above indicates that the northern part of the forest is subjected to greater water motion than the southern half.

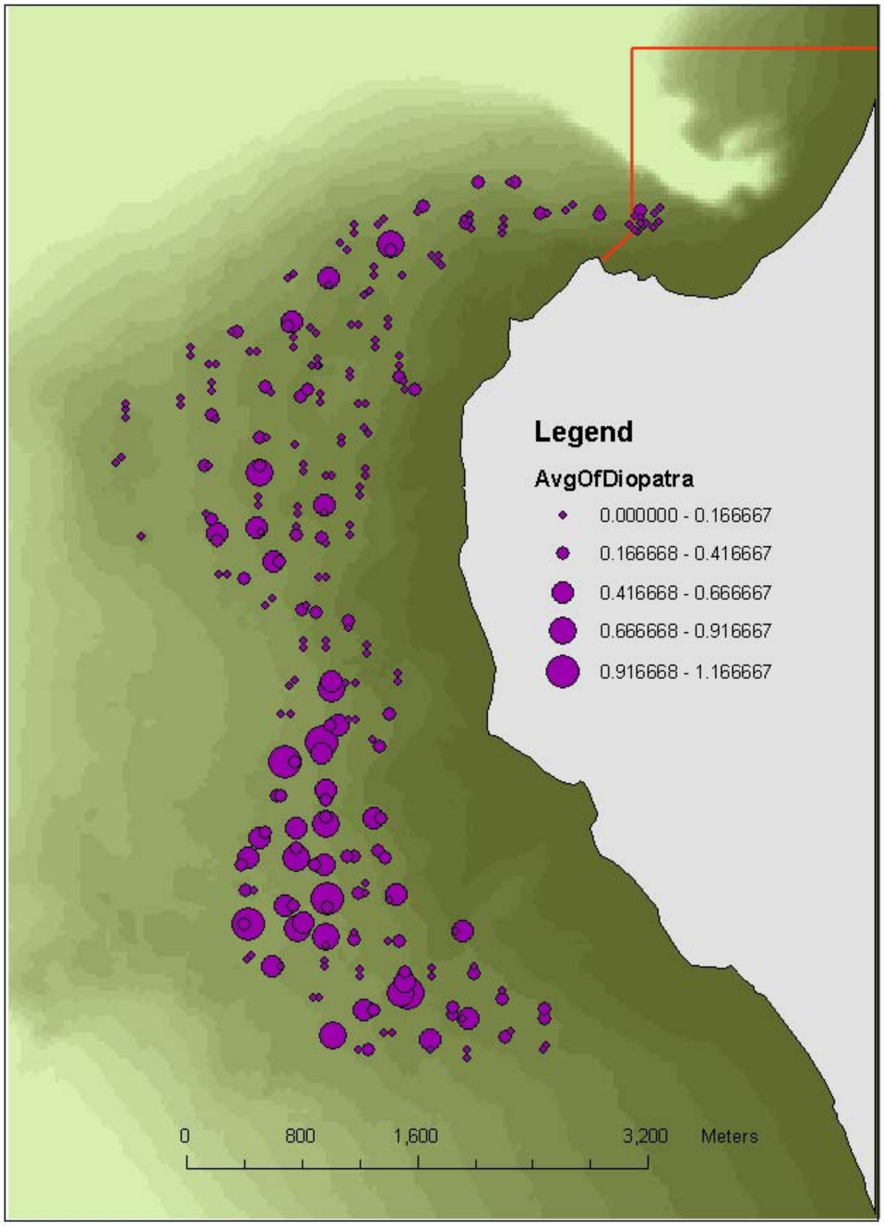

Figure 5. The distribution of *Diopatra ornata* (a tube-building worm) in the La Jolla Kelp Forest. D. ornata lives in an exposed tube. It is therefore vulnerable to vigorous water circulation and is indicative of areas that are relatively protected from water motion due to surge and currents.

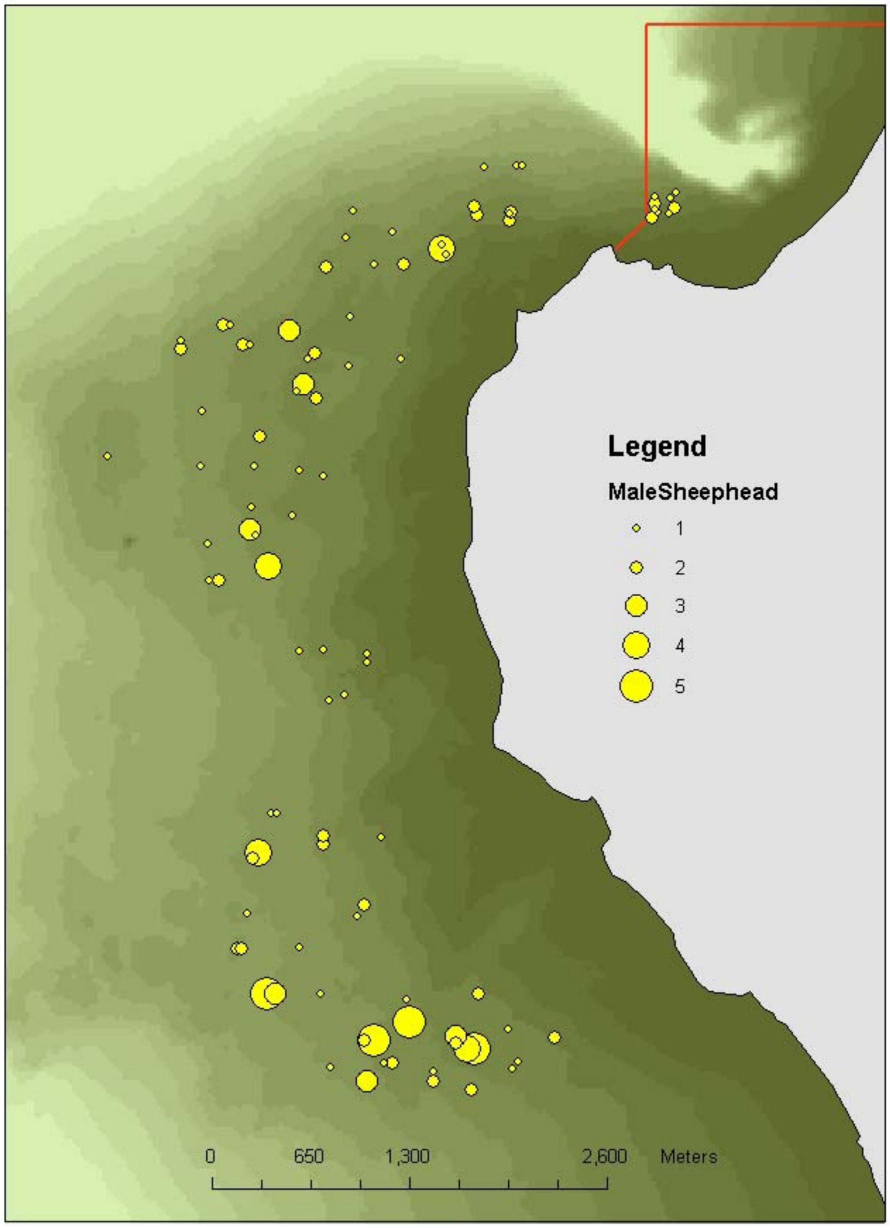

Figure 6. The distribution of Male Sheephead in the La Jolla kelp forest. Circles represent the number of animals counted along a thirty meter transect (see legend).

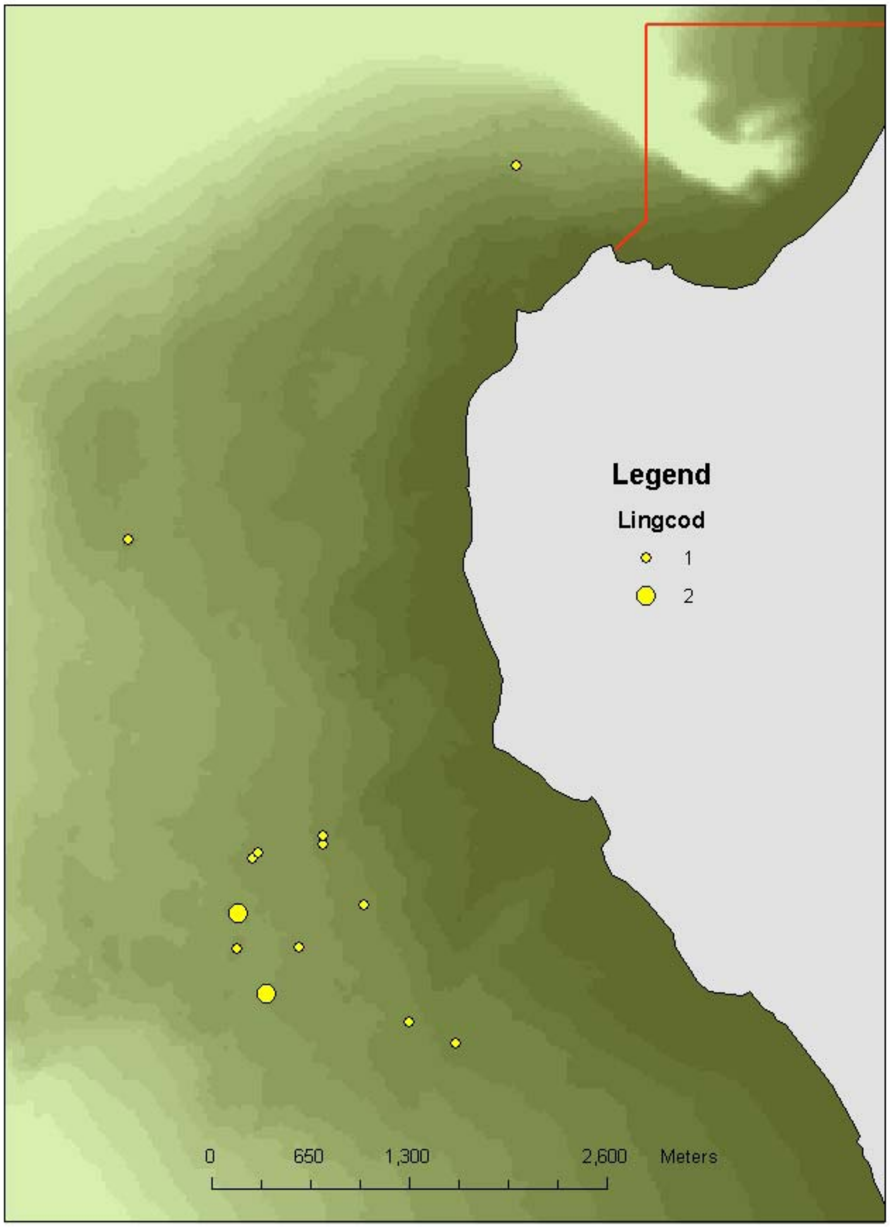

Figure 7. The distribution of Lingcod in the La Jolla kelp forest. Circles represent the number of animals counted along a thirty-meter transect (see legend).

APPENDIX 1. Table of Species Names

Table A1. Common names and corresponding scientific names.

Common Name	Species Name
Invertebrates	
Blood Star	*Henricia leviuscula*
Brown Gorgonian	*Muricea fruticosa*
California Golden Gorgonian	*Muricea californica*
Fragile Rainbow Star	*Astrometis sertulifera*
Giant Keyhole Limpet	*Megathura crenulata*
Giant Spined Star	*Pisaster giganteus*
Green Abalone	*Haliotis fulgens*
Kellet's Whelks	*Kelletia kelletii*
Ornate Tube Worm	*Diopatra ornata*
Pink Abalone	*Haliotis corrugata*
Purple Urchins	*Strongylocentrotus purpuratus*
Red Urchins	*Strongylocentrotus franciscanus*
Rock Scallops	*Crassedoma giganteus*
Scaleside Piddock	*Paralophas californica*
Spiny Lobsters	*Panulirus interruptus*
Wart Neck Piddock	*Chaceia ovoidea*
Warty Sea Cucumbers	*Parastichopus parvimensis*
Kelps	
Bladder Leaf Kelp	*Cystoseira osmundacea*
Feather Boa Kelp	*Egregia menziesii*
Flattened Acid Leaf Kelp	*Desmerestia ligulata*
Forked Kelp	*Eisenia arborea*
Giant Kelp	*Macrocystis pyrifera*
Tangle Kelp	*Laminaria farlowii*
Walking Kelp	*Pterygophora californica*
Fish	
Barred Sand Bass	*Paralabrax nebulifer*
Black Perch	*Embiotoca jacksoni*
Black Seabass	*Stereolepis gigas*
Blacksmith	*Chromis punctipinnis*
Broomtail Grouper	*Myctoperca xenarcha*
Brown Rockfish	*Sebastes auriculatus*
Cabezon	*Scorpaenichthys marmoratus*
Calico Rockfish	*Sebastes dalli*
California Moray	*Gymnothorax mordax*
Copper Rockfish	*Sebastes caurinus*
Garibaldi	*Hypsypops rubicunda*
Gopher Rockfish	*Sebastes carnatus*
Kelp Bass	*Paralabrax clathratus*
Kelp Rockfish	*Sebastes atrovirens*
Lingcod	*Ophiodon elongatus*
Olive Rockfish	*Sebastes serranoides*
Opaleye	*Girella nigricans*
Rock Wrasse	*Halichoeres semicinctus*
Sculpin	*Scorpaena guttata*
Senoritas	*Oxyjulis californica*
Sheephead	*Semicossyphus pulcher*
Treefish	*Sebastes serriceps*
Vermillion Rockfish	*Sebastes miniatus*

APPENDIX 2. (References)

Hill, MO (1973). Diversity and evenness: A unifying notation and its consequences. Ecology 54:427-432.

Rogers-Bennett, L, Haaker, PL, Huff, TO, Dayton, PK (2002). Estimating baseline abundances of abalone in California for restoration. CALCOFI Rep. 43:97-111.

R/CZ-177
The San Diego-La Jolla Ecological Reserve: Implications for the Design and Management of Marine Reserves

Appendix 3

Publications/Presentations
Parnell, P.E. 2003. Patterns of Habitat and Abundance in the La Jolla Kelp Forest. Southern California Academy of Sciences, 102(S2):38.

Parnell, P.E. 2003. The La Jolla Kelp Forest: In the footsteps of Connie Limbaugh, Jay Quast, Wheeler North, and Jimmy Stewart. Ecology Seminar, Scripps Institution of Oceanography.

To be given May 14 this year at the annual meeting of the Southern California Acad. of Sciences:
ParnellL, P.E. Recommendations for a Reserve in the La Jolla Kelp Forest Based on Spatial Patterns of Habitat, Diversity, and Oceanographic Climate.

Collaborating Institution
USC Wrigley Institute, Catalina Island

Award
UCSD Faculty Research Lecture Award to Paul Dayton.
April 22, 2004: The Loss of Nature and the Nature of the Loss: Impacts of Specialization.