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A Public-Access GIS-Based Model of Potential Species Habitat Distribution for the Santa Barbara Channel and the Channel Islands National Marine Sanctuary

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Signature Page

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. It is a three quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Abstract

The Marine Sanctuary Group (MSG) Project demonstrated the efficacy of a Geographic Information System (GIS) to create a useable ecological habitat characterization of the Santa Barbara Channel and, specifically, the Channel Islands National Marine Sanctuary (CINMS). A habitat characterization would be helpful in managing the CINMS; however, to date, habitat characterization studies made of the region lack a spatial component. To address this, we used a GIS model that integrated four physical environmental parameters, bathymetry, substrate type, sea surface temperature, and wave exposure, to determine potential species habitat distributions in the Sanctuary. In order to disseminate the resulting information in a manner that would facilitate participation of all users and stakeholders in the resource management of the CINMS, we served the model, the data, and the results on the World Wide Web.

We used a GIS system to access, store, retrieve, and analyze data as well as an interface for coupling the GIS model with the Internet and publishing the results on the Web. The model's outputs are the results of two interpolation techniques: Thiessen and Kriging. Each technique produced species habitat distribution maps with properties, limitations, and caveats unique to the modeling technique used as well as the data inputs. The output of both models were integrated with an Internet-capable mapping software with built-in GIS functionality: ESRI's ArcIMS^{TM}. A website containing a detailed description of the project and its components was then built around ArcIMS.

Executive Summary

Unique oceanographic conditions, diverse habitats, and an assortment of cold and warm water flora and fauna characterize the Channel Islands National Marine Sanctuary (CINMS). Unfortunately, development, resource extraction, pollution, poor management, and other pressures are threatening the region. In 1998, the CINMS began a management plan review, incorporating recommendations from federal, state and local agencies, community stakeholders, and interest groups. The CINMS staff and the concerned community identified the need for a comprehensive ecological site characterization to provide basic knowledge and to promote public stewardship of the Sanctuary.

The Marine Sanctuary Group (MSG) Project was proposed to synthesize available biological and physical data in order to provide baseline information about the distribution of marine habitats within the Sanctuary. The MSG Project is expected to promote an ecosystem understanding of the CINMS, and provide an interactive medium for public stewardship of Sanctuary resources.

Phase I of the project involved the research and selection of an appropriate system of marine habitat classification. We decided to use a habitat classification system based on four abiotic parameters: substrate, depth, temperature, and wave exposure. Many species in the CINMS depend on the presence of Kelp for habitat. For these species, we included Kelp as a fifth parameter in determining potential habitat distribution. Phase II consisted of collecting pertinent available data, identifying gaps in the data, and developing and acquiring additional data. Substrate, depth and temperature data were obtained from various government agencies and the University of California. Minimal processing was done on the depth and temperature data. However, we had to interpolate the substrate data using Kriging and Thiessen techniques in order to create a useable input for our model. For the wave exposure parameter, we determined areas of high wave exposure from publicly available wave height, period and direction data. All datasets were then systematically formatted and/or processed for use in the third phase. In Phase III, an integrated Geographic Information System (GIS) database was created. Using this system, a habitat model was developed and tested against observed biological data. Our model had distinct outputs resulting from the two interpolation techniques. The precision and accuracy of the model outputs are also highly dependent upon the quality of the data we used for our input parameters, specifically the substrate data. Phase IV of the project involved the production of an Internet-based system of information dissemination that fosters public participation in Sanctuary resource management. The mapping software we used to integrate the GIS with the Internet is still in its developmental stages and is therefore limited in the kind of spatial querying we hoped it could do. However, because the web-based GIS system is publicly accessible, it can be an effective tool for stakeholders and resource managers to exchange information and ideas. It also facilitates public participation in resource management through several features that allow users to comment on and even edit model outputs through commercially available web-browsers.

Background

The National Marine Sanctuaries Program (NMSP)

It was only after the devastating Santa Barbara Oil Spill of 1969, that the general public exerted enough pressure on Congress to enact a series of environmental laws aimed at preventing toxic oceanic dumping and protecting marine animals. One of the results is the Marine Protection, Research and Sanctuaries Act of 1972. Title III of the Act gave the Secretary of Commerce the authorization to designate and manage areas of the marine environment with nationally significant aesthetic, ecological, historical, or recreational value as national marine sanctuaries. This led to the implementation of the National Marine Sanctuary Program (NMSP), which is administered by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) and is under the jurisdiction of the Department of Commerce (DOC) (www.csc.noaa.gov, 2000).

The mission of the NMSP is to conserve, protect, and enhance the biodiversity, ecological integrity and cultural legacy of the nation's system of marine sanctuaries. Today there are thirteen national marine sanctuaries that protect over 18,000 miles of ocean, lakes and coast. The NMSP is devoted to protecting marine resources while accommodating all acceptable forms of public and private use of those resources. The NMSP is also maintains a monitoring program of the different marine environments to increase the public's understanding of marine ecosystems and assess the impacts of human activities (www.sanctuaries.nos.noaa.gov, 2000).

The Channel Islands National Marine Sanctuary (CINMS)

President Jimmy Carter designated the Channel Islands National Marine Sanctuary (CINMS) on September 22, 1980. Located 22 nautical miles (25 miles) off the shores of Santa Barbara, California, the CINMS rests primarily within the Santa Barbara Channel region. Specifically, the Sanctuary encompasses the waters surrounding San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands, extending from the mean high tide line to six nautical miles offshore. The region is characterized by a series of underwater basins and ridges and a complex counter-clockwise current system of warm and cold waters commonly referred to in the literature as the Santa Barbara Gyre. Additionally, intense seasonal upwelling makes this region an area rich in marine resources. The unique features of the CINMS make it a suitable habitat for various species of plants and animals, including a wide array of invertebrates, marine mammals, seabirds, fishes, and grasses.

Ocean Circulation in the CINMS

Ocean processes play a significant role in the marine Sanctuary. In fact, it is the unique circulation patterns of the Santa Barbara Channel (SBC) that make the presence of a diverse array of species in the CINMS possible. Observations suggest that "currents in the channel are a superposition of a larger-than-SBC scale flow and a cyclonic circulation which is specific to the channel interior" (Harms and Winant, 1998). These currents have spatial and temporal trends. According to Harms and Winant, there are several characteristic current patterns in the Santa Barbara Channel. During the spring months, surface currents tend to flow equatorward; it reverses from summer to winter. Additionally, these trends can be reversed for short periods of time, on the order of several days. For the most part, the SBC circulation is dominated by an inflow of cold nutrient rich waters upwelling off the Pt. Conception coast and entering the western end of the channel. This leads to a cold water mass occupying the western half of the channel. Similarly, warm water coming from the south (Southern California Countercurrent, or SCC) and entering the eastern end of the channel leads to a warm water mass occupying the eastern region of the channel. The strengths of the water mass inflows determine how far into the channel the warm and cold water masses intrude. Typically, a transition zone of mixed water lies between the cold and warm water masses and occupies the center of the channel. These patterns are also directly affected by wind stress patterns in the region (usually northwesterly winds). When typical wind patterns are disrupted, a massive inflow of warm water enters the eastern end of the channel and makes its way through the entire extent of the channel. This particular pattern is often associated with El Nino-Southern Oscillation events.

Biological Characteristics of the CINMS

Numerous species have unique distributional boundaries that often coincide with oceanographic conditions and characteristics. These boundaries define biophysical regions called bioprovinces. Because of the unique ocean patterns in the SBC, the CINMS straddles three provinces: depending on the prevailing SBC circulation, the waters of San Miguel, and most of Santa Rosa are characterized as a cold temperate (Oregonian Province) bioprovince; the waters off Santa Barbara Island, Anacapa Island, and the eastern half of Santa Cruz Island are characterized as warm temperate (Californian Province); in between, there is a "Transition" Province which has properties resulting from the mixture of cold and warm water masses. Thus, CINMS species are often grouped into two primary faunal regimes: those species associated with cold water masses and those species associated with warm water masses. These regimes often shift depending on the strength of upwelling in the Pt. Arguello-Pt. Conception area as well as the strength of the SCC (McGinnis, 2001).

Consumptive Uses of the CINMS

Because of the species richness in the CINMS, it has been viewed as a valuable resource in the region. The main consumptive industries that utilize the CINMS are recreation, fishing, and related industries. The fishing industry has, by far, the greatest socioeconomic and biological impacts on the Sanctuary. The combined economic value of the top five commercial fisheries grossed an estimated $118 million dollars between 1988 and 1999 from Sanctuary landings alone (McGinnis, 2001). Recreation, primarily sport fishing, is also a presence in the CINMS. This sector includes firms that charter boats and provide fishing supplies to recreational fishermen.

Ecotourism and recreational activities (including scuba diving, snorkeling, and ocean kayaking) within the Sanctuary boundaries are also important and do generate substantial income to the local economy. However, for the most part, they are nonconsumptive in nature.

CINMS Objectives

In light of the numerous uses of the CINMS, managing the Sanctuary's resources is a difficult task. Sound management is necessary to reduce various potential threats present in the area. These threats include, but are not limited to, the possibility of oil spills from nearby oil and gas development facilities; vehicle pollution (noise, chemical, garbage) from busy shipping lanes; non-point source pollution (anthropogenic chemicals and waste) flushed from the region’s watershed; and overexploitation of stocks by commercial and recreational fishing. The CINMS staff has been given the responsibility of protecting biological and physical resources while accommodating multiple uses. The staff also conducts scientific research and runs educational programs to increase the public understanding of the Sanctuary's resources and to facilitate sustainable management practices.

Since 1980, four main goals provide the basis for the major program areas for Sanctuary management. The highest priority goal is to enhance protection of the resources and marine environment of the CINMS. Objectives aimed at achieving this goal include:

1. Establishing mechanisms for coordination between all federal and state agencies concerned with the CINMS promoting public awareness through educational programs.
2. Developing effective programs to enforce Sanctuary regulations.
3. Reducing threats to the Sanctuary through contingency and emergency response planning.

The second goal involves research activities within the Sanctuary that are directed toward resolving management concerns and increasing understanding of the Sanctuary environment and resources. The CINMS' research program establishes a framework and procedures for administering studies that are responsive to management concerns.

Developing interpretative programs aimed at increasing public awareness and understanding of the Sanctuary is the third goal of the management plan. CINMS aims to accomplish this by enhancing public access to relevant information about the Sanctuary's resources, encouraging feedback on the effectiveness of interpretive programs, and collaborating with other organizations to provide complementary interpretive services.

The final Sanctuary goal is to encourage commercial and recreational use of the Sanctuary that is compatible with the protection of its significant resources (www.cinms.nos.noaa.gov, 2000).

CINMS Management Plan Revision

The CINMS is currently engaged in a five-year management plan review process. Management plans are the site-specific documents that the NMSP uses as "blueprints" to manage individual sanctuaries. These plans set priorities, contain regulations, present existing programs and projects, and guide the development of future activities. Public participation in the management plan review proceedings has been a key component of the process. Many in the proceedings have suggested that an ecological site characterization of the CINMS is a necessary tool for the effective management of its resources. An ecological site characterization would be helpful in managing the CINMS; however, to date, site characterization studies made of the region lack a spatial component.

Ecological Characterization

Ecological characterizations of geographic areas have been used as intensive descriptions of ecosystems since the 1970s. Characterizations assume that by assembling information about ecosystems, ideally prior to the onset of anthropogenic activities (i.e., resource extracting), public and private agencies will be able manage these areas effectively and efficiently. Typically, the gathered information includes thorough descriptions of physical and biological systems (i.e., species distributions, geologic maps, etc.). To date, ecological site characterizations have been significant tools for land and ecosystem management.

Habitat classification is an integral component of ecological site characterizations. Current habitat classifications are based on hierarchical structures: specific habitat types are described in terms of specific physical and biological factors and are then nested within larger, more general habitat types. This system fails to describe habitat features that are non-hierarchical such as the depth and temperature of species' habitats. Additionally, although hierarchical habitat classification provide great detail about habitat characteristics, the resulting system of classification tends to be a cumbersome and complex list of labels nestled within labels, making it difficult for the general public to comprehend.

Currently, the dissemination of ecological characterization results to the public is limited. The results of characterization studies are usually published for narrow distribution and, almost always, in the form of scientific papers. This approach excludes people without a scientific background. Consequently, the general public involved or who want to be involved in the decision-making processes and management of protected natural resources are restricted by the lack adequate information.

Ecological Characterization Projects and the Internet

Ecological characterizations have been performed on different environmental systems and management units from rivers, bays, and estuaries to watersheds and landscapes. Each characterization is unique in its approach and methodology, but the common emphasis is centered on understanding the local ecosystem. Recently, characterizations are being published in digital format via the World Wide Web, providing an accessible public interface. This form of communication can provide valuable scientific information to the concerned community. Access to scientific information about resource distribution will provide the opportunity for the public to learn about local resources. An educated or a knowledgeable community, in turn, can become more effective participants in state and federal management of an area's resources.

GIS as a Management Tool

A Geographic Information System (GIS) is a computer system for organizing, visualizing, and analyzing spatial data. It can manipulate and combine data from various sources including digital images as well as tables of geographically referenced information. These capabilities can be especially useful when applied toward resource management.

GIS systems can solve certain problems faced by decision makers and agencies that deal with resource management. These managers often rely on geographic datasets obtained from other agencies, each with its own particular data format, projection, and resolution, which are therefore difficult to integrate. A GIS system allows users to reformat, reproject, combine, and overlay datasets from a variety of sources. Decision makers also have problems that stem from poor data management. Numerous agencies often have data or jurisdictions that overlap. A GIS system is an effective way to coordinate efforts as well as manage spatial data. The querying function of a GIS system allows users to easily sort and identify specific data points. Additionally, GIS systems not only provide spatial information, but can also be linked to databases that are not strictly geographic. Thus, a GIS can provide pointers to documents and reports associated with a particular location or attribute. Because of these capabilities, an integrated GIS can enhance the decision-making process.

Coupling GIS and the Internet

The ability of a GIS system to integrate disparate, but spatially related, datasets is useful in creating an ecological site characterization of the CINMS. However, the results of the site characterization need to be distributed not only to resource managers, but also to various stakeholders including the general public in order to facilitate effective and inclusive resource management. One way to do this is by publishing the results through an easily accessible medium such as the Internet.

A few efforts have been made to publish GIS-based ecological characterizations on the Internet. The ecological characterization of Otter Island, South Carolina, was the first attempt at such a digital publication (www.csc.noaa.gov/otter/htmls/mainmenu.htm, 2000). The Otter Island project constructed a web site that provided an ecosystem description, resource management scenarios, and an interactive web-enabled Geographic Information System (GIS) that displayed spatial information. The construction of the web-GIS was an ambitious endeavor that required substantial investments in capital and labor. Time and money are the limiting factors for most public agencies that routinely operate on thin budgets.

The Monterey Bay National Marine Sanctuary (MBNMS) Site Characterization project was the first national marine Sanctuary to complete a comprehensive site characterization that was also published digitally via the World Wide Web. The web site consisted of a thorough description of the MBNMS physical setting, biological communities and assemblages, human influences, and an extensive bibliographic database (www.mbnms.nos.noaa.gov/sitechar/index.html, 2000). The MBNMS staff is currently working on the second phase of the project that will describe the archaeological, cultural and historical resources of the region. One drawback of the MBNMS project is the lack of spatial information. The lack of a spatial component limits the user's ability to interact with the information contained within the website.

Project Objectives

The Marine Sanctuary Group Project had three objectives:

1. Decide upon a habitat classification system that would be useful to resource managers of the Channel Islands National Marine Sanctuary.
2. Determine a method for querying the classification system in order to extract potential species distributions.
3. Create a system for efficient information dissemination to management agencies, scientists, stakeholders, as well as the general public.

Study Area

The habitat classification system was applied to a region encompassing the Santa Barbara Channel (SBC) and, most importantly, the CINMS. The exact extent of the study area is shown in Figure 1:

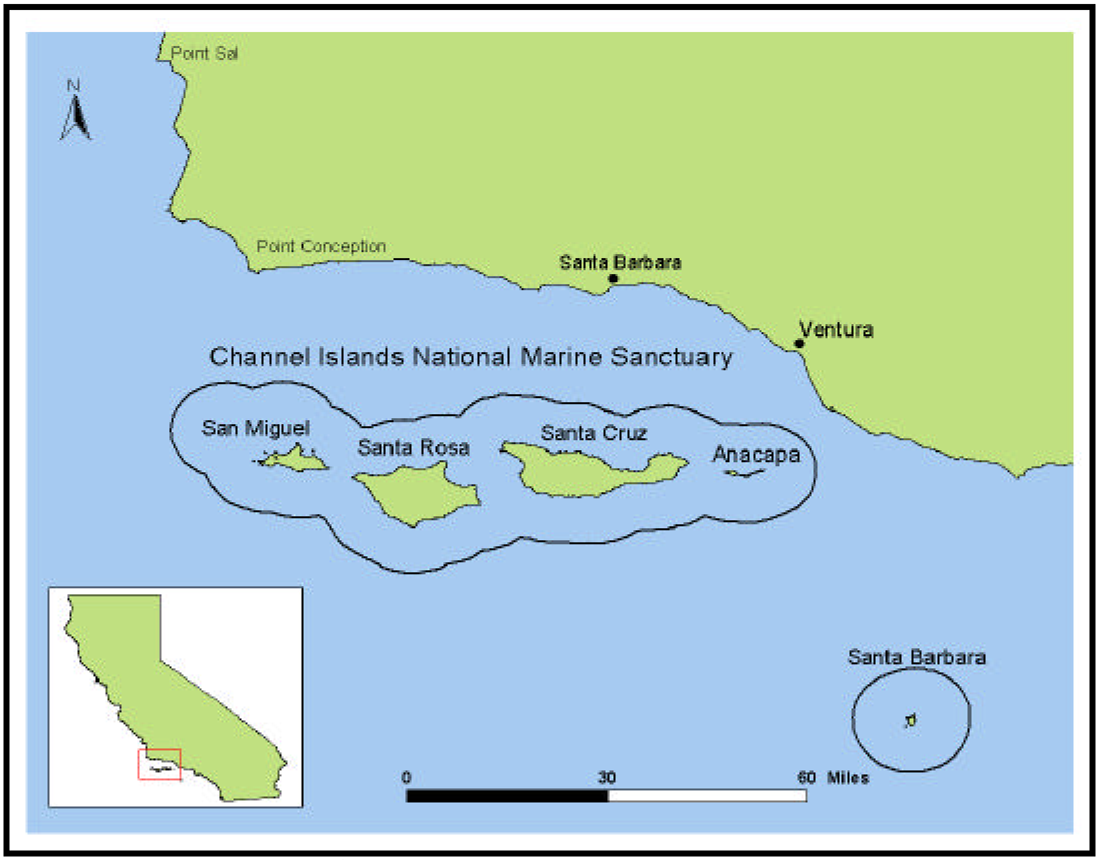


Figure 1. Extent of study area.

Species Selection

To create a GIS model of potential species habitat distribution, a set of species must first be selected. The habitat requirements of the species must be converted to the model input parameters. Data on the observed distribution of species can serve as controls against which the model outputs can be tested.

Although not meant to be an exhaustive list of existing species in the region, the individual species in the project's Species List were chosen because they represent the range of plant, invertebrate, and vertebrate marine species in the Santa Barbara Channel. Additionally, those in the Species List were selected based upon a set of criteria that appropriates and modifies parts of a species selection matrix used by the CINMS in its Five Year Management Plan Review process (see Table 1).

Category	Description of Criteria
ERS	Species of economic and/or recreational importance
KS	Keystone species
ES	Species listed, proposed, or candidates under the Endangered Species Act
DS	Species which have exhibited long-term or rapid declines in harvest

Table 1. Selection criteria for "Project Species List"

The species in Category ERS are or were at one time commercially harvested. Species such as Purple Sea Urchin and Market Squid comprise major fisheries in the Santa Barbara Channel region and therefore have great economic significance. Other species in the same category, such as Quillback rockfish, also have recreational significance because of their sport value.

The species in Category KS are considered "keystone" species. By definition, keystone species are those "species whose removal may engender dramatic changes in the structure and functioning of its biological community" (De Leo and Levin, 1997). Species under this category, such as Giant Kelp, are important constituents of their respective ecosystems. In the case of Giant Kelp, which serves as habitat for numerous other species, changes in its distribution will affect profound changes in the distribution of the species dependent upon it.

The species in Category ES are species on the brink of irreversible population decline and/or extinction. Thus, they are proposed, candidates, or listed under the auspices of the Endangered Species Act of 1973 (see http://endangered.fws.gov, 2001). Both Black and White Abalone fall under this category.

The species in Category DS are those species that at one time may have been common in the region but have since undergone drastic and observable population declines. Reasons for population loss range from disease and loss of habitat to overexploitation and human intervention. The Southern Sea Otter and the some rockfishes such as Bocaccio and Copper fall under this category.

Below is the project's Species List followed by a detailed description of each species.

ALGAE	**SCIENTIFIC NAME**	**CATEGORY**
Giant Kelp	*Macrocystis pyrifera*	ERS, KS
INVERTEBRATES	**SCIENTIFIC NAME**	**CATEGORY**
Abalone		
Black Abalone	*Haliotis cracherodii*	ERS, ES, DS
White Abalone	*Haliotis sorenseni*	ERS, ES, DS
California Spiny Lobster	*Panulirus interruptus*	ERS
Sea Urchins		
Red Sea Urchin	*Strongylocentrotus franciscanus*	ERS
Purple Sea Urchin	*Strongylocentrotus purpuratus*	ERS
Market Squid	*Loligo opalescens*	ERS
VERTEBRATES	**SCIENTIFIC NAME**	**CATEGORY**
California Halibut	*Paralichthys californicus*	ERS
Giant Sea Bass	*Stereolepis gigas*	ERS, DS
Rockfish		
Copper	*Sebastes caurinus*	ERS, ES, DS
Cowcod	*Sebastes levis*	ERS, DS
Bocaccio	*Sebastes paucispinis*	ERS, ES, DS
Quillback	*Sebastes maliger*	ERS
Sheephead	*Semicossyphus pulcher*	ERS, DS
Southern Sea Otter	*Enhydra lutris nereis*	KS, ES, DS

Table 2. Project Species List

ALGAE

Giant Kelp (*Macrocystis pyrifera*)

Giant kelp is a species of marine algae found along the Pacific coast of North America from central California to Baja California. Giant kelp prefers depths less than 40 m, temperatures less than 20°C, hard substrate such as rocky bottoms, and bottom light intensities above 1% that of the surface (Foster, M. and D. Schiel, 1985).

Macrocystis also requires ocean temperatures above 5°C, which is the lethal temperature for the gametophytes. The upper temperature limit may actually be a result of decreased nutrients, especially nitrogen, noted in warmer waters (Bushing, 1994). Nutrient levels are low in the summer and fall in southern California, especially above the thermocline and during periods when warm water masses move into the region from the south. In southern California the giant kelp canopies commonly deteriorate during these seasons, when inorganic nitrogen is low (Bushing, 1994).

Although it begins life as a microscopic spore at the ocean floor, this species may grow to lengths of 60 m with its upper fronds forming a dense canopy at the surface. The spores grow into tiny male or female plants called gametophytes. These plants produce eggs and sperm, which fertilize and grow to form the large visible plants (sporophytes). The adult sporophytes release many new spores to start the process over again. The minimum amount of time needed to complete the *Macrocystis* life cycle is believed to be 12 to 14 months although in the environment, grazing by animals and shading by other plants would affect this rate of development (Bushing, 1994).

The average kelp plant is capable of releasing trillions of spores a year. Few, if any, of the billions of spores produced by a single mature *Macrocystis* kelp plant ever make it to adult gametophytes due to burial by sand or mud, competition for limited space with other plant or animal species, the lack of light at the ocean floor due to absorption by the water or shading by kelp and other plant species, nutrient limitation, and the effects of animals which graze on the plants. Only 1 in 100,000 young kelp plants need to mature to reestablish the kelp beds. As the fertilized eggs develop into sporophytes, they must avoid shading and overgrowth by other organisms, grazing by small echinoids, gastropods, micro-crustacea and the bat star (*Patiria*); as well as being buried and abraded by sediments (Bushing, 1994).

Studies suggest kelp fronds may grow at rates of 1-2 feet per day. Although giant kelp plants are perennial, the individual fronds only survive for about 6-9 months

(Neushul, 1981). Fronds of mature kelp plants become senile and deteriorate about 6 months after they are produced. Mature fronds continually develop, then die and break away in a process known as sloughing, giving way to the new fronds developing from the holdfast. The individual fronds survive for about 6 months, while individual blades may last only about 4 months (Bushing, 1994).

Macrocystis plays an important role in the marine environment by providing food and habitat for a wide range of marine invertebrates and fishes in southern California. Forests of giant kelp may support millions of individual organisms and more than 1,000 species of marine plants and animals (Foster, M. and D. Schiel, 1985).

The presence or absence of *Macrocystis* is not essential for the spawning of any sport fish species. However, kelp beds do provide shelter for the larvae and juveniles of several species such as the kelp topsmelt (Bushing, 1994). There is a great abundance and diversity of life associated with the structurally complex and high productive *Macrocystis* kelp.

Giant kelp has been harvested for years as a food supplement because it contains iodine, potassium, other minerals, vitamins and carbohydrates. Algin is used as an emulsifier to bind oily and watery fluids together and is used for this purpose to prevent salad dressings from separating. It is also a suspender to keep pigment particles mixed with the carrier as in paints, cosmetics and pharmaceuticals. Algin aids in controlling viscosity and makes ice cream smoother and cake icings stiffer. It is used to smooth and thicken more than 300 preparations from ice cream to paints, sauces and toothpaste (Neushul, 1981).

INVERTEBRATES

Black Abalone (*Haliotis cracherodii)*

These abalones are members of a large class (Gastropoda) of molluscs having one-piece shells. They belong to the family Haliotidae and the genus *Haliotis*, which means sea ear, referring to the flattened shape of the shell.

Black abalone live higher in the intertidal zone than any other California species. They range from the mid-intertidal zone to a depth of about 20 m; however, few of the animals live below 10 m. They are most abundant at depths of 2 to 3m below mean low tide in areas of high turbulence, strong surge, and suitable crevice refuge (Ault, 1985). Specimens larger than 90 mm tend to be sedentary and live under and on the sides of large rocks and in crevices. Smaller (<90 mm) black abalone live primarily under boulders and in crevices. They move about more than the larger animals, presumably in search of food (Ault, 1985).

The thermal optima for the black abalone are between 14 and 18°C. The optimal temperature for egg fertilization is apparently 15°C (Ault, 1985). Black abalone eggs develop normally within a temperature range of 10-23°C, but optimum larval growth is at 13.5-20°C. At 18°C, larvae settle in about 5 days. Larval growth is temperature dependent; only larvae reared between 14 and 18°C reached the advanced post-larval stages. Black abalone feed at temperatures of 7 to 22°C, but maximum feeding is between 13 and 18°C. Growth was fastest at temperatures between 15 and 20°C and was only slightly less at 12.5°C (Ault, 1985).

The shell of the black abalone is relatively deep and oval, with an average shell length of about 115 mm, and a maximum of 215 mm (Ault, 1985). The shell exterior is dark blue, black, or greenish black, usually smooth, and supports few or no encrusting organisms. Its round respiratory apertures, which are flush with the shell surface, are about 3 mm in diameter. Usually five to nine of these pores are open at any one time, but in specimens from Baja California and Guadalupe Island, 11 to 14 pores may be open. The interior shell pigmentation is cream to silver pearl with pink and green iridescence. A columellar muscle scar is lacking. The outer edge of the shell protrudes over a nacreous surface forming a narrow, dark blue-black rim. The epipodium (dorsal rim of the foot) is smooth and black. Its upper edge is scalloped and bears short, slender tentacles that sometimes protrude slightly beyond the edge of the shell (Ault, 1985).

The black abalone feeds mostly on brown algae, and to a lesser extent on red algae. Densities are often high in locations with abundant algal drift kelps. The smaller abalones (less than 20 mm long) graze on diatom films and coralline algae, but larger ones subsist on fragments of algae brought in by waves and currents. To some extent, shell color varies with the diet. Under laboratory conditions black abalone have shown a preference for the brown alga Egregia, but Macrocystis produced the most rapid growth (Haaker, 1994).

The black abalone fishery in California, with a maximum harvest of 800 tons in 1973 (Haaker, 1994), was closed statewide in 1997. The principal cause of this decline is due to both overfishing and the onset of a disease in southern California in 1986. The cause of this disease is unknown but has been attributed to a pathogen (Lafferty and Kuris, 1993).

White Abalone (*Haliotis sorenseni)*

White abalones are marine gastropods belonging to the family Haliotidae and genus Haliotis, and are characterized by a flattened spiral shell (Haaker, 1986).

Historically, white abalone ranged from Point Conception, California, U.S.A., to Punta Abreojos, Baja California, Mexico. As its name suggests, the shell of Haliotis sorenseni is white—the adult body is characterized by a mottled orange tan epipodium. White abalones are the deepest-living of the west coast Haliotis species (Hobday and Tegner, 2000), usually reported at subtidal depths of between 20-60m and historically most "abundant" between 25-30m (Cox, 1960; Tutschulte, 1976). At these depths, white abalones are found in open low relief rock or boulder habitat surrounded by sand (Tutschulte, 1976; Davis et al., 1996).

White abalone may be limited to depths where algae grow, a function of light levels and substrate availability, because they are reported to feed less on drift algae and more on attached brown algae (Tutschulte, 1976). Temperature effects on larvae and juvenile survival could also influence the upper and lower limits of white abalone depth distribution. Leighton (1972) found that white abalone larval survival is reduced at lower temperatures. Tutschulte (1976) speculated that white abalone might have been restricted to depths below 25 m by predation from sea otters when sea otter and white abalone latitudinal ranges overlapped or from competition with pink abalone and predation by octopuses.

Abalone have separate sexes and are broadcast spawners, releasing millions of eggs or sperm during a spawning event. Fertilized eggs hatch and develop into free-swimming larvae, spending from 5 to 14 days as non-feeding zooplankton before development into the adult form. After metamorphosis, they settle onto hard rocky substrates in intertidal and subtidal areas.

Young abalones seek cover in rocky crevices, under rocks, and deep crevices, feeding on benthic diatoms, bacterial films, and single-celled algae found on coralline algal substrate (Cox, 1962). As abalones grow and become less vulnerable to predation at about 75-100 mm in length, they emerge from secluded habitat to more open, visible locations where their principal food source, attached or drifting algae, is more available (Cox 1962). Abalones lead a relatively sedentary lifestyle. Although juveniles may move tens of meters per day, adult abalone have extremely limited movements as they increase in size (Cox, 1962).

Maximum shell length recorded for white abalone in California and Mexico is 20-25 cm and 17 cm respectively. However, "average" observed size is about 13-20 cm, and animals that are less than 10 cm are rare (Cox, 1960). White abalone grow slowly, reaching sexual maturity at a size of between 88 and 134mm in approximately 4 to 6 years and spawn in the winter, between February and April (Tutschutle, 1976). White abalones appear to have irregular recruitment, and a maximum lifespan of 35 to 40 years (Tutschutle, 1976).

Using a research submersible vessel, deep-reef surveys for white abalone were conducted near Santa Barbara, Anacapa, and Santa Cruz Islands, and on Osborn Bank in 1996 and 1997 (Davis et al., 1998). After searching 77,070m^2 of rocky reef between 27 and 67m depth, only nine live white abalones were found. Assuming that population densities of white abalone estimated from these surveys (i.e., 0.000167 white abalone/m^2, plus or minus 0.0001) were representative of white abalone densities throughout their entire range and that the total available habitat within the species range is 966 ha (2,386 acres), Davis et al. (1998) estimated that fewer than 1,000 white abalone existed in 1996/1997.

California Spiny Lobster (*Panulirus interruptus)*

Spiny lobsters are decapod crustaceans of the family Palinuridae, which contains 49 species worldwide. Spiny lobsters are found in the coastal waters of the Pacific Southwest, from Monterety Bay to Magdalena Bay, Mexico (Duffy, 1973). Spiny lobsters are typically found on rocky and sandy substrates at depths from 10 to 60m (Gotshall, 1994).

The animal is called "spiny" because of the strong, forward- curving spines projecting from the hard shell covering its body. On the seafloor, sharp-pointed legs enable the animal to move about freely. A lobster may also swim rapidly backward by flapping its powerful tail. The fifth pair of legs of the female bears a claw or spur-like growth, which is used to clean the eggs she may carry and to scratch the sperm packet (Herrnkind, W. F. 1975).

Adults spawn primarily from May through July, with mating taking place in water depths from 15 to 30m. Females then move inshore to deposit their eggs, which develop in 9 to 10 weeks (Shaw, 1986). Annual growth rates range from 4.8 to 1.3mm for females and 5.6 to 1.5mm for males (Odemar et al. 1975).

Feeding habits of lobsters change as they grow and mature. As larvae, they feed on plankton, although the specific taxonomic groups are unknown. Juvenile lobsters commonly consume mollusks, sponges, hydroids, polychaetes, crustaceans, and sea urchins. Mature animals are omnivorous and primarily scavengers. They feed at night by combing through algae, digging in soft sediments, or feeding on attached organisms (Shaw, 1986).

The primary predators for lobsters are octopuses, sheephead, cabezon, kelp bass, sharks, and eels (Shaw, 1986).

The spiny lobster supports a valuable commercial and sport fishery in regions where they are commonly found. In the early 70’s lobster abundance declined sharply as the fishery increased. Local stocks declined and the fishery spread to more distant grounds (Odemar et al. 1975).

Red Sea Urchin (*Strongylocentratus franciscanus)*

The red sea urchin is a large echinoderm, and prominent member of the nearshore marine ecosystem and is found on rocky or gravel substrate from the sub-tropical to sub-Arctic waters of the eastern Pacific. It is the largest known species of sea urchin in the world achieving test diameters up to 180 mm (Kozloff 1983). They prefer rocky substrates, especially ledges and crevices located near or in kelp beds and other brown algae in areas. They are generally associated with areas of moderate to swift currents from low tide to 100 m subtidal depth, with most concentrated abundance around 5-10 m subtidal (Bernard 1977).

Red urchins are broadcast spawners with two distinct sexes. Gamitogenesis and spawning are annual. Gamitogenesis occurs from September through March and spawning commences in March and lasts until approximately September (Bernard 1977).

Red urchins are omnivorous, but primarily subsist on algae, feeding on phytoplankton during larval stages, and then standing drift algae after settlement (Rowley 1990). Where urchin densities are high, and drift algae is insufficient, urchins may over-graze standing algae leading to barrens. Under some circumstances they are known to prey on barnacles, abalone, and a variety of other invertebrate species (Rowley 1990).

Growth has been strongly correlated with food availability, gonad maturity, and first reproduction occurring typically within the first three to five years (Rowley 1990). Where food supplies are scarce, urchins may respond by re-absorbing skeletal and gonad nutrient stores; the result can be urchins that appear to be empty. Urchins have also been observed to shrink when food is scarce (Pfister and Bradbury 1996).

The only known major predators of adult red urchins are sea otters (*Enhydra lutris*). Other species known to prey on red urchins include the sunflower star (*Pycnopodia helianthoides)* and wolf eels (*Anarrhichyhts ocellatus*), but neither seems to specialize on them (Kozloff 1983). Estimates of maximum life span vary, and range from 10 to more than 100 years (Rowley 1990).

Red sea urchins are harvested for their roe (gonads), which is extracted at processing plants for shipment to fresh markets. Unlike red sea urchins, green sea urchins are shipped whole and alive to Japan. The gonads are sold there as "uni." Divers using short aluminum rakes remove sea urchins from the ocean floor.

Purple Sea Urchin (*Strongylocentrotus purpuratus)*

The purple sea urchin is an echinoderm, which has relatively short spines, and is usually light purple or lavender in color. The purple urchin is the common intertidal sea urchin of exposed and semi-protected rocky areas on the west coast of North America from Baja, California, to Sitka, Alaska (Mottet, 1976). The purple sea urchin is well adapted to pounding surf where it usually lives in crevices or holes. Purple urchins are typically found from intertidal to depths of 38m (Kalvass, 92).

One of the major factors in the ability of the sea urchin to live in diverse coastal regions is their ability to live on almost any food. If seaweed is plentiful, the sea urchins will be grazers. If they live where no seaweed can grow, they can scavenge on dead animals or drifting algae; or if the opportunity arises, they may prey on other animals (Mottet, 1976). In the absence of such food, the urchins may still persist even in areas that seem completely barren. Here the urchins scrape rocks and ingest sand, and live off the associated microorganisms such as diatoms, radiolarians, and other protozoa. They may even be able to live on the organic matter that is discharged in sewage (Mottet, 1976).

Sea urchins are preyed upon by a number of animals including lobsters, crabs, starfish, sea anemones, flat fish, sculpins, sea gulls, and sea otters. In most areas, predation is not an important factor in controlling the numbers of sea urchins. This is because the major predators (sea otters) have been greatly reduced in number by man (Mottet, 1976).

A fishery for purple sea urchins developed in the early 1990's as landings for red sea urchins declined, and harvest restrictions for red sea urchins expanded (Dewees, 1991). The harvest of purple sea urchins is currently not regulated, with the exception that a red sea urchin permit is required by Fish and Game in order to harvest them.

Market Squid *(Loligo opalescens)*

Market squid are small short-lived mollusks reaching a maximum length of 30cm (Roper & Sweeney, 1984). Market squid range from the southern tip of Baja California to southeastern Alaska, but are most abundant from Punta Eugenio to Monterey Bay. Squid are pelagic and can be found from the surface to depths of at least 800m (Jefferts, 1983).

Spawning squid concentrate in dense schools near spawning grounds, but habitat requirements for spawning are not well understood. Spawning occurs over a wide depth range, but the extent and significance of spawning in deep water is unknown (Roper & Sweeney, 1984). Known major spawning areas are shallow semi-protected nearshore areas with sandy or mud bottoms adjacent to submarine canyons where fishing occurs. In these locations eggs are deposited between 5 and 55m, and most commonly between 20 and 35m (Jefferts, 1983).

At an age of 1 to 2 years, sexually maturing adults migrate seasonally to nearshore waters, form dense schools, mate, lay their eggs, and then die. Spawning can occur throughout the year, but the major activity takes place in the spring and early summer. Temperature of the water appears to have a significant influence on the timing and duration of spawning. Females will lay 20-30 egg capsules, anchor them to the substrate or previously laid capsules, forming dense clumps or layering the bottom. 200-300 eggs are common per capsule in California. The eggs will hatch as miniature adults in 30-90 days, depending on the temperature of the water. The juvenile market squid are then dispersed by currents, possibly to deeper offshore waters (Morejon et al. 1978).

Squid feed on copepods as juveniles gradually switching to euphausids, other small crustaceans, small fish, and other squid as they grow (Karpov an Cailliet, 1978).

Market squid are consumed by a variety of predators including lingcod, sea lions, sea otters, and cormorants (Morejon et al. 1978). Few organisms eat squid eggs, although bat stars and sea urchins have been observed doing so (Jefferts, 1983).

For over 100 years market squid has been harvested off the California coast from Monterey to San Pedro. The squid fishery has evolved into one of the largest fisheries in volume and economic value in California. In 1996, the squid harvest reached an all time high of over 80,272 metric tons (Vojkovich 1998).

VERTEBRATES

California Halibut (*Paralichthys californicus)*

A cold-water fish, the halibut belongs to the flounder group, and has the characteristic flat body, with both eyes on the same side of the head. California halibut occur from Magdalena Bay, Baja California, to the Quillayute River, British Columbia (Gilbert and Scofield, 1898, and www.dfg.ca.gov, 2001). This species lives mostly on sandy and mud bottoms, commonly beyond surf line, and also in bays and estuaries. They are typically found at depths ranging from intertidal nearshore to 183m depth (Eschmeyer, 1983).

The body of the California Halibut is oblong and compressed. The head is small and the mouth large. Although a member of the left-eyed flounder family, about 40 percent of California Halibut have their eyes on the right side. The color is dark brown to black on the eyed side and white on the blind side. Their numerous teeth, very large mouth and a high arch in the middle of the "top" side above the pectoral fin make them easily distinguishable from other flatfish (www.dfg.ca.gov, 2001).

Males first mature when 2 or 3 years of age, but females do not mature until age 4 or 5. A 5 year old fish may be anywhere from 11 to 17 inches long. These fish may live as long as 30 years (Frey, 1971). Spawning takes place in relatively shallow water during the months of April through July (www.dfg.ca.gov, 2001).

California halibut feed almost exclusively upon anchovies and similar small fishes (www.dfg.ca.gov, 2001).

This species is one of the most desirable of commercial and sport fish in California (Frey, 1971). They are usually caught with trammel nets, and marketed as fresh fillet (Eschmeyer, 1873).

Giant Sea Bass (*Stereolepis gigas)*

The Giant Sea Bass is a member of the class Osteichthyes and the class Percichthyidae. It is closely related to the Black Sea Bass. It is the largest, native marine bony fish in California. Adults live in rocky areas and kelp beds, and also spend time closer to the sand. Giant Sea Bass live mostly along the Californian coast. Although they have been seen north of California, it is very rare. They mostly range from Humboldt Bay, California to the Gulf of California in Mexico (Caldwell, 1988). They are typically found from 5 to 46m over rocky substrate (Gotshall, 1989, and Eschmeyer, 1983).

The body of the adult giant sea bass is elongate with dorsal spines that fit into a groove on the back. The head is robust, and the mouth is large. Giant sea bass are usually reddish brown to dark brown in color on all but their stomachs and, at times, many have dark spots on their sides. Coloring on juveniles is distinct with the body being sandy red with white and dark patches spread along the sides (www.dfg.ca.gov, 2001).

Spawning season for this fish is between July and September. Some females start to mature at seven to eight years and all are by the time they reach 11 years old. Maturity takes place when the female reaches 50 to 60 pounds. The largest females can produce enormous amounts of eggs. Ovaries in a 320-pound female contained over 60 million eggs. When the fish are ready to spawn, they form spawning aggregations. They remain together for 1 to 2 months while they lay their eggs and sperm. Larger eggs are about 0.004 inches in diameter (Caldwell, 1988).

During the maturing time of a Giant Sea Bass's life, they move from sandy bottom water, to hard and flat-bottomed water in deeper water. They eat animals such as crabs, small lobsters, squid, anchovies, sardines, and bonito. Sea lions are major predators and as they grow, fast-swimming sharks become another (Caldwell, 1988).

Copper Rockfish (*Sebastes caurinus*)

Copper rockfish are found from the Gulf of Alaska southward to central Baja California (Love, 1991). Adult copper rockfish occur in nearshore waters, reportedly from the surface to 183m (Stein & Hassler, 1989). Juvenile copper rockfish tend to live in shallower water, up to about 6m (Love, 1991). Copper rockfish are common in rocky areas or on rock-gravel bottoms in shallow water, but are never observed on an exclusively sand bottom (Stein & Hassler, 1989). They are found on natural rocky reefs, artificial reefs, and rock piles; typically found directly on the bottom, closely associated with reefs or vegetation (Mathews, 1990).

Copper rockfish are considered habitat generalists (Mathews, 1990). Juveniles are closely associated initially with the surface and mid-depth Macrocyctis kelp beds (Stein & Hassler, 1989). Copper rockfish inhabit low relief reefs during the summer, coincident with the densest kelp cover; but in fall and winter, when algal cover is reduced, low relief reefs appear quite barren. Copper rockfish do not seem to defend their territories. They assess habitat quality on the presence of structure, protective cover, mates, and food, not on presence of predators (Mathews, 1990).

Copper rockfish also avoid warm water by living in deeper depths off southern California (usually below 55m) than farther north. Conversely, off British Columbia, they are found in quite shallow water, mostly less than 18m (Love, 1991).

The body of the copper rockfish is moderately deep and compressed. The head is large with a slightly curved upper profile; the mouth is large and the lower jaw projects slightly. The color is copper brown to orange tinged with pink. The back two-thirds of the sides are a clear, light pink area; the belly is white (www.dfg.ca.gov, 2001).

Off central California, male copper rockfish may be sexually mature at 3 years of age (30 cm); all are mature by 7 years (40cm). All females are mature off central California by 8 years (41cm) (Stein & Hassler, 1989).

Copper rockfish spawn once per year. Egg production ranges from 15,000 eggs in a 24-cm female to 640,000 in one 47 cm long (Stein & Hassler, 1989). Young are pelagic as larvae and measure 5-6 mm in length at birth; they remain pelagic until 40-50 mm SL. Copper rockfish are slow growing and live to 55 years. They can grow to 57 cm in length. Growth rates are highest during the summer, coinciding with high feeding rates and upwelling (Stein & Hassler, 1989).

Copper rockfish are opportunistic carnivores. Crustaceans, followed by fish and mollusks, are the most important food groups of the copper rockfish in terms of volume, number, and frequency of occurrence. In Humboldt Bay, juvenile Dungeness crabs were the most important individual food item in terms of volume and frequency of occurrence (Prince & Gotshall, 1976). Generally, copper rockfish rely less on reef associated food organisms as their age (size) increases. Copper rockfish feed during the day and at night. Copper rockfish 1-3 years old eat juvenile Dungeness crab and anchovies; with fish increasing and crustaceans decreasing as the fish grow (Stein & Hassler, 1989).

Copper rockfish are moderately important in the recreational catch from southern California northward to at least southeastern Alaska; adults are commonly taken by party and private vessels and young are occasionally taken from piers, jetties and rocky shores (Love, 1991). Copper rockfish are part of the commercial catch off California, taken primarily by hook and line and gill nets (Love, 1991).

Cowcod (*Sebastes levis*)

Cowcod occur from Ranger Bank and Guadalupe Island, Baja California to Usal, Mendocino County, California (Miller, 1972). Cowcod range from 21 to 366m (Miller, 1972) and are considered to be transitional between a mid-water pelagic and benthic species. Adults are commonly found at depths of 180-235m and juveniles are most often found in 30-149 m of water (Love, 1990).

Adult cowcod is primarily found over high relief rocky areas (Allen, 1982). They are generally solitary, but occasionally aggregate (Love, 1990). Juveniles occur over sandy bottom and solitary ones have been observed resting within a few centimeters of soft-bottom areas where gravel or other low relief was found (Allen, 1982). Although the cowcod is generally not migratory, it may move to some extent to follow food (MacGregor, 1986).

The body and head of the cowcod are somewhat compressed, although head is very large, with a large mouth, and a projecting lower jaw. Adults are uniform pale pink to orange in color. Young fish have four dark vertical bands on their sides, which gradually fade into dusky blotches as they increase in size. Their heads are large and spined, the dorsal fins are deeply notched, and there is an unusually wide space between the eye and the upper jaw. These three characteristics help to distinguish cowcod from other reddish colored rockfish (www.dfg.ca.gov, 2001). Cowcod grow to 94cm (Allen, 1982). The length at 50% maturity for both sexes occurs at 43-44cm in the southern California Bight (Love, 1990).

Cowcod are ovoviviparous, and large females may produce up to three broods per season (Love, 1990). Spawning peaks in January in the Southern California Bight

(MacGregor, 1986). A 45.5-cm female may produce up to 181,000 young per brood, and an 80-cm female may give birth to nearly two million young (Love, 1990).

Juveniles eat shrimp and crabs and adults eat fish, octopus, and squid (Allen, 1982).

Cowcod have considerable commercial importance and are prized by sport fishers (Love, 1990). Because of its large size, the cowcod is one of the most sought after rockfishes in southern California (www.dfg.ca.gov, 2001).

Bocaccio (*Sebastes paucispinis*)

Bocaccio are found in the Gulf of Alaska off Krozoff and Kodiak Islands, south as far as Sacramento Reef, Baja California (Miller & Lea, 1972). In survey catches, bocaccio were found to be most common at 100-150 m over the outer continental shelf; nearly all were between 50 and 300 m (Allen & Smith, 1988).

Larvae and small juveniles are commonly found in the upper 100 m of the water column, often far from shore (MBC, 1987). They are most often found in shallow coastal waters over rocky bottoms associated with algae (Sakuma & Ralston, 1995). Postpelagic newly settled larvae in central California are first observed associated with the giant kelp canopy, but are also seen throughout the water column. Adults are commonly found in eelgrass beds, or congregated around floating kelp beds (Sakuma & Ralston, 1995).

Warm temperatures are preferred by larvae, with highest larval densities in water 12° C or higher (Sakuma & Ralston, 1995). Bocaccio reportedly occur in typical marine waters with salinities of 31 to 34ppt., temperatures of 6 to 15.5° C, and dissolved oxygen concentrations of 1.0 to 7.0ppt. (MBC, 1987).

The body of the bocaccio is elongate and compressed. The head is pointed, the mouth large, and the lower jaw greatly protruding. The color varies from shades of brown to reddish and extends down over the belly. Young fish are generally light bronze with speckling over the sides and back. As they mature, their color generally becomes darker and the speckling gradually disappears (www.dfg.ca.gov, 2001).

Adult bocaccio may move more than 2km per day and they are known to be transient around oil platforms around Santa Barbara, California; large aggregations may remain near a platform for months and then disappear suddenly (MBC, 1987). Also, large adults disappear from traditional commercial fishing grounds during winter spawning and reappear in the spring (MBC, 1987).

Parturition occurs during October to March off southern California (MBC, 1987). In California, bocaccio may become pregnant in October, give birth in November, and prepare immediately for a second brood to be born in March (Hart, 1973). Two or more broods may be born in a year in California (Love, 1990). The spawning season is not well known in northern waters.

Bocaccio move into shallow waters during their first year of life, then move into deeper water with increased size and age (Hart, 1973). Males mature at 3 to 7 years with 50% mature in 4 to 5 years. Females mature at 3 to 8 years with 50% mature in 4 to 6 years (MBC, 1987). Although age-at-size calculations were not given, a 38.1-cm female may give birth to 20,000 young, while a 77.5-cm specimen may give birth to 2.3 million young (Hart, 1973). Mature eggs measure about 0.55 mm in diameter. Eggs develop for 40-50 days in the ovary, hatch, and yolkless larvae are released about one week later at 4-6 mm (Hart, 1973). Larvae remain pelagic for up to 150 days (Sakuma & Ralston, 1995). Metamorphosis to a semi-demersal juvenile stage occurs near 30 mm TL (Hart, 1973).

Larval bocaccio often eat diatoms, dinoflagellates, tintinnids, and cladocerans (Sumida & Moser, 1984). Copepods and euphausiids of all life stages (adults, nauplii and egg masses) are common prey for juveniles. Adults eat small fishes associated with kelp beds, including other species of rockfishes, and occasionally small amounts of shellfish (Sumida & Moser, 1984). Bocaccio probably locate prey by sight and feed mostly at night (MBC, 1987). Bocaccio directly compete with chilipepper, widow, yellowtail, and shortbelly rockfishes for both food and habitat resources (Rielly, 1992).

Sharks, salmon, other rockfishes, lingcod and albacore, as well as sea lions, porpoises, and whales all prey on this species (MBC, 1987).

Bocaccio are caught primarily in mid-water trawls. Bocaccio are a recreationally sought-after species by anglers from jetties, piers and boats. They are important to the party boat fishery off California (MBC, 1987).

Quillback Rockfish (*Sebastes maliger*)

Quillback rockfish are found from the northern Channel Islands in southern California to the Gulf of Alaska (Mller & Lea, 1972). The are common in the Strait of Georgia, San Juan Islands, and Puget Sound and from southeastern Alaska to northern California (Love, 1991). Quillback rockfish are a common, shallow-water benthic species (Mathews, 1990). They are taken from subtidal depths to 275m (Love, 1991), but they occur mainly from 41-60m (Love, 1991).

Quillback rockfish are solitary reef-dwellers, living close to or on the bottom (Love, 1991). Quillback rockfish live among rocks or sometimes on coarse sand or pebbles next to reefs, particularly in areas with a lot of flat-bladed kelp (Love, 1991). They are either found perched on rock or kelp or wedged into crevices and holes, and are rarely seen out in the open or unstructured areas of reefs (Mathews, 1990). Adults tend to associate with high-relief substrate and young-of-the-year tend to associate with low-relief substrate. Young-of-the-year tend to be on the most complex areas of low-relief reefs (West et. al, 1994) and use eelgrass/sand habitat as temporary habitat (Mathews, 1990). Young settle at 18-25 mm TL to shallow, vegetated habitats such as beds of kelp and eelgrass (West et. al, 1994). Densities on low-relief reefs and sand/eelgrass increased during the summer coincident with peak plant cover (Mathews, 1990).

Quillback rockfish only inhabit low relief reefs during the summer and only return from displacements in the summer coincident with peak algal cover. They move from artificial reefs to low relief reefs during the summer and return to artificial reefs in the fall when kelp disappears on low relief reefs. Returns to original reefs when artificially displaced indicate site fidelity. Quillback rockfish are not territorial of their home range. They may use navigation or olfactory cues to relocate home sites. They maintain small home ranges during the day, night, and high currents (Mathews, 1990). Female quillback rockfish probably move to other habitat to release larvae because no pregnant individuals were observed in several survey studies (Mathews, 1990).

Quillback rockfish can grow to 61cm, and can live to be 32 years old but almost certainly live longer (Love, 1991). Growth rates differ along its range; off southeastern Alaska a 12-year-old is approximately 31 cm, and 50% of quillback rockfish mature at 31 cm; whereas off California a 12-year-old would only be 18 cm, and 50% mature at 23 cm (Love, 1991).

Quillback rockfish consume a wide range of prey taxa, but are more dietary generalists than other rockfish species. They feed primarily during mid-day and are inactive, sheltering in holes and crevices during the night (Murie, 1995). Quillback rockfish principally prey upon brachyuran crabs, gammarid amphipods, euphausiids, and calanoid copepods (Mathews, 1990).

Quillback rockfish are important in the sport and commercial fisheries (Murie, 1995). From Oregon to southeastern Alaska quillback rockfish are an important part of the inshore sport fishery and are taken by party and private vessels and divers (Love, 1991).

California Sheephead (*Semicossyphus pulcher*)

The California sheephead is a member of the wrasse family, typically growing to approximately 91cm, and ranging from Monterey Bay in central California, to Isla Guadalupe and Gulf of California. They are generally found on rocky substrate and kelp beds from the intertidal zone to 85m (Eschmeyer et al., 1983).

This species of wrasse are hermaphroditic. When sexually mature they are females, but after a few years almost all will become males for the remainder of their lives (Gotshall, 1989). Juveniles are distinct from adults not only in size but in color, they are almost entirely gold or salmon colored with a white stripe along the side (www.dfg.ca.gov, 2001). Juveniles also have two prominent black spots on the dorsal fin and the anal fin.

At about one year, juveniles are 3 to 4 inches long and have faded to dull pink. At 2 years they are 6 to 8 inches long, have lost all spots, and have changed in appearance (www.dfg.ca.gov, 2001).

Most females transform to males at a length of about 12 inches at 7 to 8 years of age. Sex changes come between spawning seasons. At Catalina Island, spawning occurs from July to September (Love, 1991). Young about 0.5 inch long occur in late May through late December The sex change is accompanied by a marked change in appearance. Younger fish (females) are a uniform pinkish red with a white lower jaw. As they age and become males, the head and rear third of the body turns black, the midsection of the body remains red and the lower jaw remains white. In all stages of their development, sheephead have unusually large teeth (www.dfg.ca.gov, 2001).

Crabs, mussels, various sized snails, squid, sea urchins, sand dollars, and sea cucumbers are typical food items. The large canine-like teeth are used to pry food from rocks. A special plate in the throat crushes shells into small pieces for easy digestion (www.dfg.ca.gov, 2001).

Sheephead are targeted by the live-fish fishery since they are found near-shore, and easily kept alive (Love & Johnson, 1998). Statewide the landings for sheephead jumped in 1989 from 16,203 tons to 194,942 tons in 1995. Over harvesting of sheephead is especially problematic since these fish are sequential hermaphrodites and the fishery takes only small females that may be pre-reproductive (Tegner & Dayton, 2001).

Southern Sea Otter (*Enyhdra lutris nereis)*

The sea otter is a marine mammal that lives in coastal waters in the central and North Pacific Ocean. It is the smallest marine mammal in North America. Sea otters inhabit a narrow zone of shallow, littoral water along the central California coast. The majority of otters remain within approximately 1-2km of shore, inshore of the outer kelp edge, which generally corresponds to the 18.3m depth curve. Some individuals, however, may be found further offshore to the 37m-depth curve (Wild, 1974). Foraging activity is generally restricted to water depths of 25 meters or less (Estes, 1983),

In California, sea otters are primarily associated with subtidal habitats characterized by rocky, crevice substrate, although they are also found in sandy substrate areas. A rocky substrate supports a rich and diverse assemblage of plants and animals, including prey frequently consumed by sea otters, such as sea urchins, abalones and crabs. Sea otter density within most of the range (with the exception of the northern and southern population fronts) is related to substrate type; rocky bottom habitats support an average density of five otters per square km, whereas sandy bottom areas support an average density of 0.8 otters per square km (Anon, 1976). Although California sea otters may inhabit areas devoid of canopy-forming kelp and rest in open water, the presence of kelp beds is preferred.

Sea otters prefer the temperate climate. They are foragers who seek their food on the bottom of rocky and soft-sediment subtidal habitats in coastal waters (Van Blaricom & Estes 1988). They also make their home among the kelp forests. Sea otters, in fact, help the kelp forests by eating the dominant herbivore in the region, sea urchins. The original habitat of the sea otter ranged from the coasts of Washington and Oregon, and down to the coast of California and Baja California (www.seaotters.org, 2001).

Sea Otters are typically about four feet long and weigh an average of 65 pounds for males and 45 pounds for females. They have strong canines and strong molars to tear and crush their food. Their lung capacity is 2.5 times that of land mammals of the same size. They have good eyesight and use their whiskers to sense vibrations in the water. They are known for the use of rocks as hammers and anvils to help open the shells of mollusks (Kenyon, 1969).

Unlike most other marine mammals, sea otters have very little subcutaneous fat to provide thermal protection and reserve energy, and therefore depend on an entrapped air layer maintained within their dense, water-resistant underfur. This provides an insulating barrier against the cold as well as buoyancy (Kenyon, 1969).

The California sea otter's diet is almost exclusively of a variety of nearshore macro invertebrates (Estes, 1974). Prey availability varies with location and length of time an area has been occupied by sea otters, which in part determines dietary composition. In recently reoccupied habitats of central California, the diet consists principally of abalones, rock crabs and sea urchins (Wild, 1974).

Below is a summation of selected abiotic and biotic habitat requirements for the species of interest.

Species	Depth (meters)	Substrate	Biological Province	Wave Exposure	Kelp as Habitat
Giant Kelp	0-40	Rock	OR/CA	Low-Med-High	N/A
Black Abalone	0-10 Prefer 2-3	Rock	OR/CA	Low-Med-High	No
White Abalone	20-60 Prefer 25-30	Rock	OR/CA	Low-Med-High	No
California Spiny Lobster	10-60	Rock/Gravel/ Sand	OR/CA	Low-Med	No
Red Sea Urchin	0-100 Prefer 5-10	Rock/Gravel	OR/CA	Low-Med-High	Yes
Purple Sea Urchin	0-38	Rock/Gravel	OR/CA	Low-Med-High	Yes
Market Squid	0-800 Spawn 20-35	All Mud/Sand	OR/CA	Low-Med	No
California Halibut	0-183	Mud/Sand	OR/CA	N/A	No
Giant Sea Bass	5-46	Rock/Gravel/ Sand	OR/CA	N/A	Yes
Copper Rockfish	0-183	Rock/Gravel	OR/CA	N/A	Yes
Cowcod Rockfish	21-366 Prefer 180-235	Rock/Gravel	OR/CA	N/A	Yes
Bocaccio Rockfish	50-300 Prefer 100-150	Rock/Gravel	OR/CA	N/A	Yes
Quillback Rockfish	0-275 Prefer 41-60	Rock/Gravel	OR	N/A	Yes
Sheephead	0-85	Rock/Gravel	OR/CA	N/A	Yes
Southern Sea Otter	0-37 Prefer 0-18	All Prefer Rock	OR/CA	Low-Med-High Prefer Low-Med	Prefer Kelp

Table 3. Selected species abiotic and biotic habitat requirements

Methods

GIS Habitat Model

The GIS habitat model was built in four phases: planning, data collection and processing, habitat model construction, and information dissemination. ArcView (ESRI, 2001) was the GIS package used, since most data collected was in ArcView "shapefile" format.

Phase I: Planning

The planning phase began with the selection of a habitat classification scheme appropriate for the CINMS. The limiting factor of any habitat classification system is the availability of information, which varies for each species or specific habitat type. Thus, the level of habitat categorization will be determined by the quality of information accessible. A habitat classification scheme should also be determined objectively and have a systematic but intuitively understandable structure (Mumby et al., 1999).

Any system that the CINMS staff develops or adopts must incorporate many species with very different life forms, habitat needs, and relationships. The ecological relationships among species and between species and their habitats can provide the basis for a classification scheme. As part of the management plan review process, the CINMS staff is considering adopting the Essential Fish Habitat (EFH) scheme devised by the National Marine Fisheries Service (NMFS) (Airamie, personal communication).

The NMFS developed the EFH classification system to identify and protect important marine and anadromous fish habitats. As mandated by the Magnuson-Stevens Fishery Conservation and Management Act of 1996, the NMFS, federal agencies, and regional fishery management councils are required to delineate "essential fish habitat." The Act defines EFH as "those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity" (i.e. waters and substrates occupied by a species during its life cycle).

According to the EFH classification scheme, habitat can be characterized by physical parameters such as substrate, depth, slope, sea temperature, and wave exposure. The EFH scheme groups species of interest into communities if they require similar physical and biological conditions during their life cycle. An EFH community can be further divided to specie-specific habitat by explicitly specifying the suitable ranges of sea temperature, wave exposure, depth, and substrate. These physical parameters can be used to delineate essential fish habitats and be incorporated into a GIS, which can be updated and managed. In addition, the modified EFH scheme will be easy to understand. Given the units of categorization that are relatively familiar to everyone (depth, substrate, temperature, and wave exposure), the public will be able to participate in the proactive management of marine resources since they will be able identify critical habitats to be conserved.

Phase II: Data Collection and Processing

The EFH scheme uses the physical parameters of substrate, depth, sea temperature, and wave exposure to delineate species' habitats. The data collection and processing phase focused on collecting data from available sources and processing them into a usable GIS format.

Depth Data

Ben Waltenberger of the CINMS provided Santa Barbara Channel bathymetry and topography data. The data was delivered in Arc/INFO (ESRI, ©2001) GRID format with a resolution of 60 meters, in a Geographic projection (Appendix A). Ben Waltenberger originally created the bathymetry grid under the direction of Dr. Leal Mertes of the UCSB Department of Geography. Integrating USGS Digital Line Graphs (DLG) and NOAA GEODAS bathymetry points to generate a triangulated irregular network (TIN) model produced the bathymetry grid. The accuracy of the model was tested by comparing grid cell values to known point values collected via NOAA hydrographic surveys. The bathymetry grid covers an extent of the Santa Barbara Channel and its environs from Pismo Beach to Point Mugu and offshore to a distance of 100 miles.

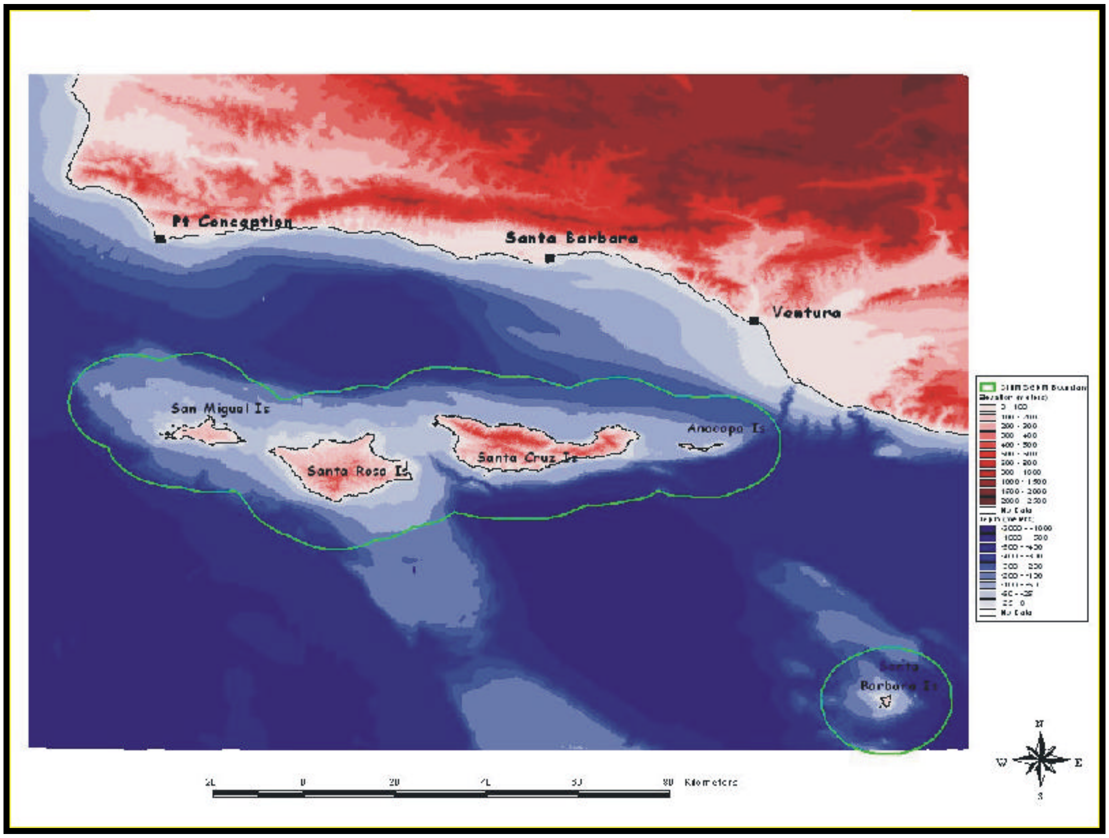


Figure 2. Bathymetry image (created by Ben Waltenberger)

Substrate Data

Substrate data, also provided by Ben Waltenberger, consisted of one ArcView shapefile and one text file of point data, describing the sediment type from grab samples of the sea floor in the Santa Barbara Channel. The shapefile is composed of 5192 substrate samples collected in 1967 by Continental Shelf Data Systems and digitized by the Conception Coast Project (Appendix B). The text file contains 800 substrate sample points consolidated by the USGS in 2000 (Appendix C). The exact protocol for substrate sampling for either dataset is unknown. However, it is believed that the samplers utilized Loran for the 1967 sampling, and a Global Positioning System (GPS) in the later sampling in order to determine geographic location. These samples have a relative accuracy of 50 meters (Ben Waltenberger, personal communication).

Substrate Type	Number Of Points	Percentage
Gravel	151	2.5%
Mud	1398	23.3%
Rock	921	15.4%
Sand	3139	52.4%
Shell	383	6.4%
Total	**5992**	

Table 4. Summary of substrate data

The substrate shapefile and the text file categorized substrate into 5 classes containing as many as 40 subclasses. For the purposes of this investigation, a detailed description of substrate was not necessary, so the sample points were reclassified into five general types: mud, rock, sand, shells, and gravel, and then imported into ArcView as a dBase file. These points were then converted into a shapefile.

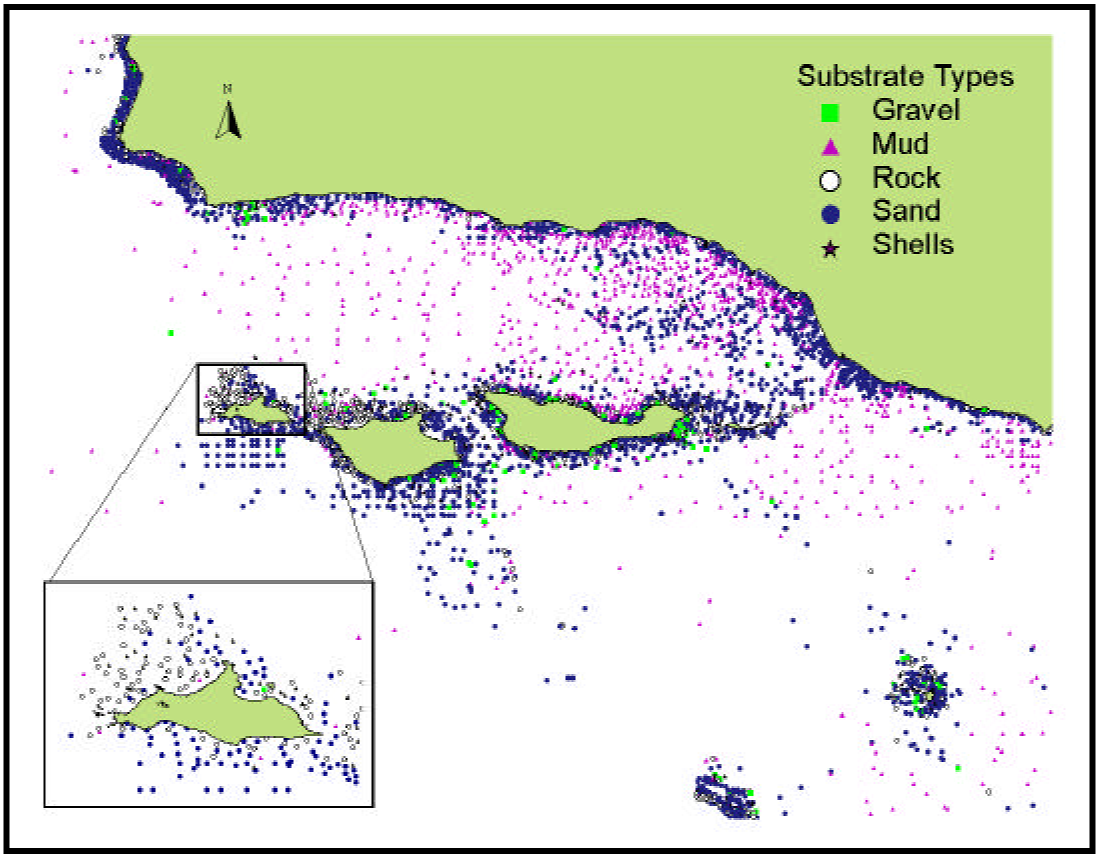


Figure 3. Substrate data image

Temperature Data

The group used sea surface temperature (SST) data from the Institute for Computational Earth System Science (ICESS) at UCSB. ICESS operates a SeaSpace TeraScan ground station that automatically receives High-Resolution Picture Transmission (HRPT) telemetry from the Advanced Very-High Resolution Radiometer (AVHRR) sensors on board the NOAA-12 and NOAA-14 satellites. The information is processed to produce SST and near-infrared albedo data (www.icess.ucsb.edu, 2001). A year 2000 composite was acquired from Mark Otero at ICESS as a text file. The SST will be used to delineate the Oregonian, Californian, and Transitional biogeographical regions created in the Santa Barbara Channel from the convergence of Alaskan cold waters and Mexican warm waters. Bathed by the California Current, San Miguel and northern Santa Rosa Island clearly lie in the Oregonian Province, supporting biotic assemblages characteristic of central and northern California, Oregon, and Washington (Murray et al. 1980, Seapy and Littler 1980). In contrast, Anacapa and the eastern tip of Santa Cruz Island are surrounded for most of the year by warm temperate waters characteristic of the Californian Province (Murray et al. 1980, Seapy and Littler 1980). Sea surface temperature maps suggest that Santa Barbara Islands and southern Santa Rosa and Santa Cruz Islands represent a transition between cooler and warmer temperate waters (ICESS 2001).

Fortunately, the Science Panel involved in the Marine Reserve planning for the CINMS had delineated the biogeographical regions. The science advisory panel used available information on sea surface temperature (ICESS 2001) for rough guidance and, in the areas of sharpest transition, drew biogeographical boundaries that followed the deepest bathymetric contour (under the assumption that these might provide a significant boundary to movement of some species, especially nearshore species that rarely enter pelagic waters) (Airame et al. 2000). Delineations of the boundaries of the three biogeographical regions were acquired from the CINMS in shapefile format.

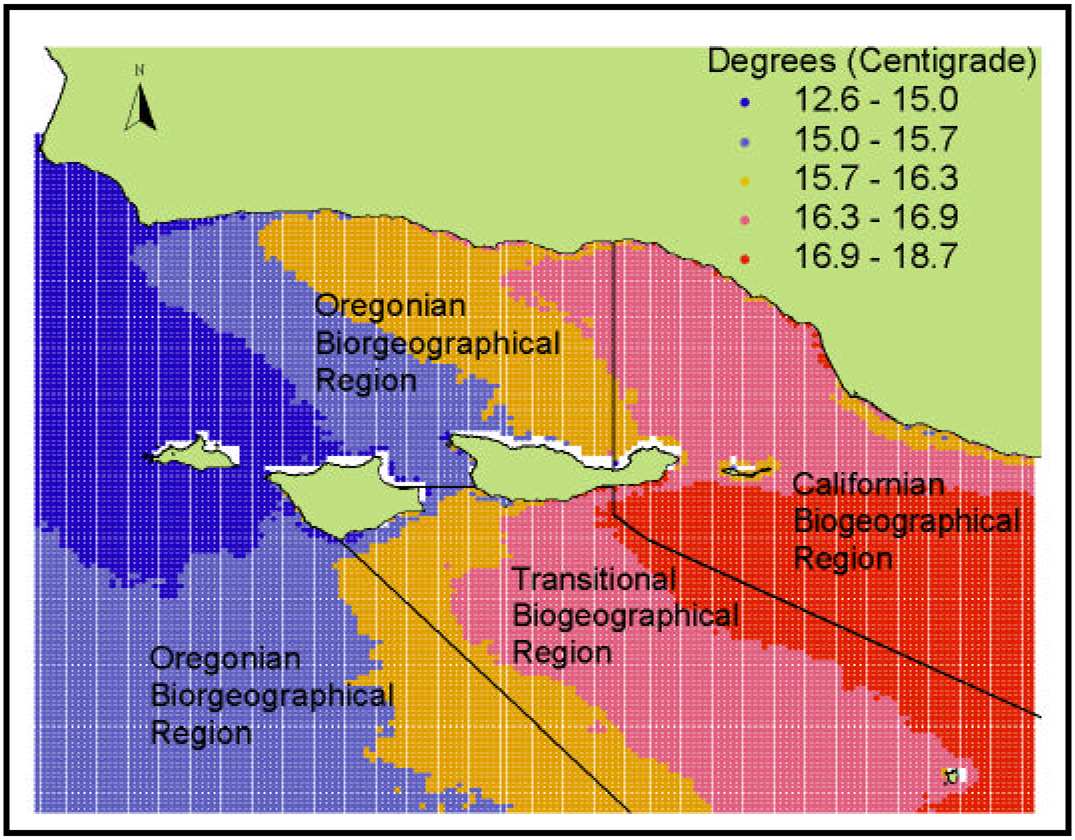


Figure 4. Sea Surface Temperature (SST) Composite for 2000

Wave Exposure Data

We determined areas of high wave exposure by calculating the prevailing direction of the strongest waves in the Santa Barbara Channel, and then estimating at what depth these waves will begin to affect the underlying substrate. We used "significant height" as a proxy for wave strength (see definitions below). The depth at which wave energy begins to affect the substrate and, therefore, organisms at depth is the depth at which the wave ceases to be a deep ocean water wave: when depth ≤ ½ the wavelength (Thurman and Burton, 2001).

The Coastal Data Information Program (CDIP) provided the wave data we used to calculate areas of high wave exposure. CDIP's website provides access to several U.S. Army Corps of Engineers buoys off the United States' west coast, each providing wave data. Harvest Buoy, located 9 miles west of Pt. Arguello, California is the pertinent data source for wave data in the Santa Barbara Channel. Measurements taken by the buoy include significant height (Hs), peak period (Tp), and wave direction (Dp). Hs is described as the "the average height of the one third highest waves in the record." Tp is defined as the "inverse of the frequency with the highest energy in the reported spectrum." Dp is defined as the "mean direction from which energy is coming at the peak period in degrees clockwise from true North. These measurements are defined, recorded, and formatted in ASCII text files accessible through the CDIP website (http://cdip.ucsd.edu, 2001). The table below shows a sample of the dataset provided by the Harvest Buoy.

File Name: pm07101200001 Analyzed(UTC): 2000 10/05 2238 hrs
Station Name: HARVEST BUOY
Location: 34 27.50 N 120 46.80 W Sensor Type: Spherical Drctnl Buoy
Water Depth(m): 548 MLLW Sensor Elev(m): 548.6 Shore Normal(deg): N/A

Year	Month	Day UTC	Hour	Minute	Hs m	Tp sec	Dp deg	Ta sec	Sea Temp C
2000	1	1	0	8	0.99	11.11	277	7.02	13.7
2000	1	1	0	38	1	11.11	280	7.31	13.7
2000	1	1	1	8	0.91	7.14	318	6.68	13.6
2000	1	1	1	38	1.02	10.53	288	6.85	13.6
2000	1	1	2	8	0.98	10.53	280	6.28	13.6
2000	1	1	2	38	0.93	10	280	5.7	13.6

Table 5. Sample Harvest Buoy dataset

Wave Strength/Direction Model:
The Harvest Buoy dataset was used to determine the strength and direction of the waves in the Santa Barbara Channel. We took data spanning one year, the year 2000, and determined monthly mean, mode, and median values for Hs, Tp, and Dp. Histograms showed the highest Hs monthly values to be approximately 2-3 meters corresponding to Tp values of approximately 13-15 seconds and Dp values between 287 and 308 degrees of true north (northwesterly origins).

The peak period values for each month were used to derive wave speeds through the equation:

$$\boxed{Sw = [9.8(m/s^2)*Tp(s)] / [2\pi]} \qquad \textbf{Eq. 1}$$

where Sw is wave speed and Tp is wave period (Thurman and Burton, 2001).

The resulting wave speed values were then used to derive wavelengths through the equation:

$$\boxed{Lw = Sw(m/s)*Tp(s)} \qquad \textbf{Eq. 2}$$

where Lw is wavelength, Sw is wave speed and Tp is wave period (Thurman and Burton, 2001).

The resulting wavelengths were divided by 2 in order to determine the depth at which the waves begin to affect the ocean floor. The average resulting depth is 160 meters. Qualitative analyses of the Santa Barbara bathymetry show that this depth occurs up to three kilometers from the Channel Islands' shores and, therefore waves are highly unlikely to break at these depths. Consequently, benthic organisms may not be adversely affected at these depths. However, the chance of wave breaking increases as depth decreases from 160 meters, approximately 1/2 the wavelength of the largest waves in the Santa Barbara Channel. According to Dr. Libe Washburn (Geography Dept., UCSB), a reasonable but rough estimate for depth at which high wave exposure would be significant is a depth of 1/8 the wavelength: 40 meters.

To define areas of high wave exposure, we used contoured bathymetric data of depths less than or equal to 40 meters around the Channel Islands. We defined the 40-meter depth as the furthest seaward extent of high wave exposure areas and 0-meter depth as the shoreward extent. We then manually digitized this area as a shapefile in ESRI's ArcView GIS software package. A cone of directions from 270 to 310 of true North (consistent with the Dp values corresponding to the peak periods) was used as a guiding tool during the manual digitization of the spatial extent of high wave exposure areas. During digitization, refraction processes that cause waves to change direction were not considered because of the inherently complex nature of the phenomena.

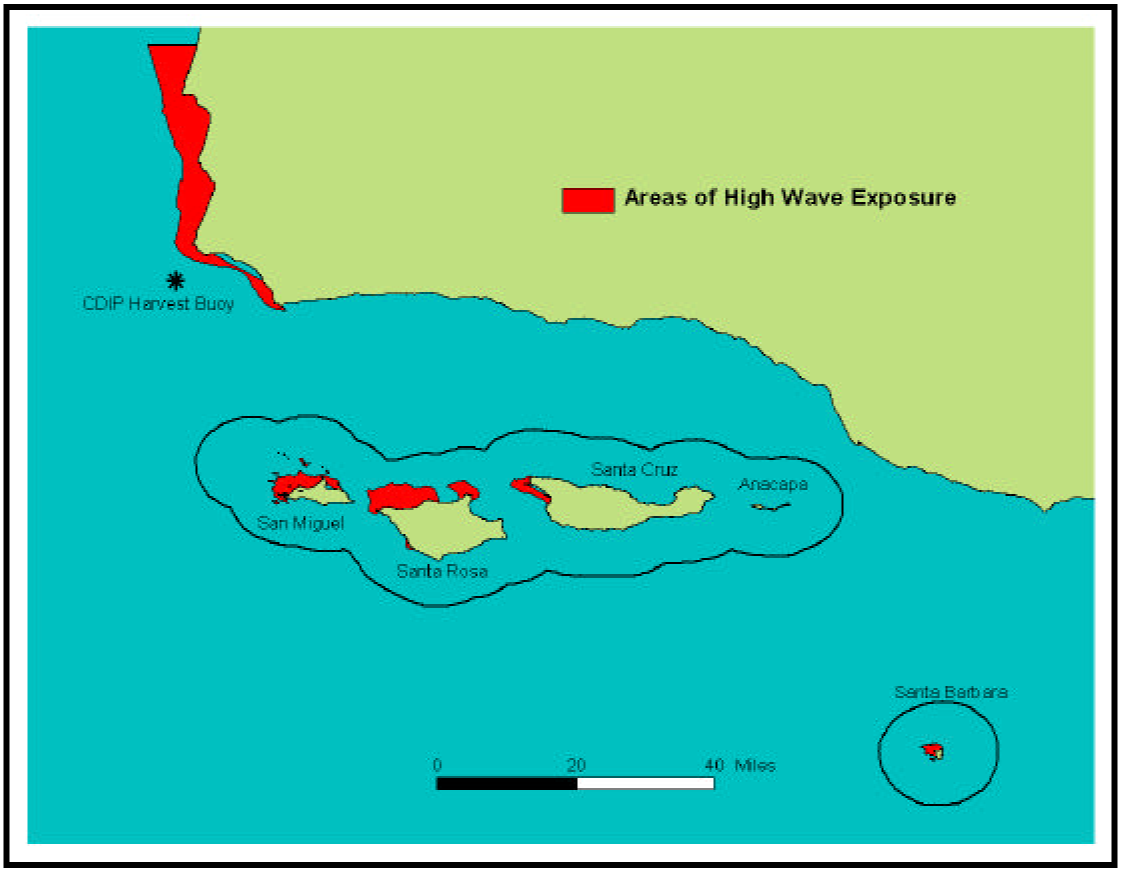


Figure 5. Areas of high wave exposure

Test Data

A nine-year kelp composite of kelp distribution in the Santa Barbara Channel was also collected from Ben Waltenberger. This information was digitized from aerial photos taken during 1980-1989 by the Conception Coast Project. This data was received in ArcView shapefile format and accompanied by partial metadata (Appendix D). The kelp composite data was used to test the relative accuracy of potential kelp habitat extents produced by the habitat model developed during this investigation.

The group also received test data from David Kushner of the Channel Islands National Park (CINP). The CINP maintains 16 survey transects in the park, at least 2 at each island, for long term population monitoring (Davis, et al., 1997). The data was received in MS Excel and MS Access format. The data consists of presence/absence information for Giant Kelp, Red and Purple Sea Urchins, California Spiny Lobster, White Abalone, and Sheephead.

Miscellaneous Data

Supplemental data collected consisted of ArcView shapefiles for the CINMS boundaries, delineations of California and the Channel Islands, and Digital Elevation Models (DEM) for California and the Channel Islands. These data sets were received from Ben Waltenberger with no accompanying metadata.

Phase III: GIS Habitat Model Construction

Once all the available data were collected and processed, the GIS model construction phase proceeded. The framework for the model is similar to the design of the EFH classification scheme. For this investigation, a species' potential habitat is defined by a combination of abiotic and biotic parameters. The abiotic parameters in the model include SST, depth, substrate, and wave exposure. For species where Giant Kelp is a suitable habitat, a merged dataset consisting of the potential distribution of Giant Kelp and the 9-year kelp data composite, was included as a biotic parameter. This maximized the potential habitat extent for species that require Giant Kelp as a habitat and included kelp areas not captured by the models.

For each species of interest, the specific abiotic and/or biotic parameter was queried in ArcView depending on the habitat requirements present in the literature. Once each data layer was queried, it was clipped. The first layer clipped was depth, followed by substrate, SST, and wave exposure. The result is a shapefile displaying the distribution of potential habitat in the Santa Barbara Channel for a species. If a species requires Giant Kelp as a habitat, then the shapefile of Giant Kelp potential habitat distribution was also clipped and aggregated. The specific instructions for producing a potential habitat distribution shapefile can be viewed in Appendix E.

Two modeling methods were used to produce the potential habitat distributions. Both methods included the biotic and abiotic parameters previously mentioned, but differed in the statistical interpolation technique applied to the substrate data. (The interpolation of substrate data is necessary to estimate the substrate type at points where substrate is unknown.) Two such techniques were applied: Thiessen polygons and Kriging.

Thiessen Technique

The substrate data collected is nominal, mud, gravel, etc. The Thiessen polygon technique provides a method of interpolation most applicable to nominal data. Conceptually, the operation works on the premise that the best information about an unknown point can be inferred from the data point nearest to it. Polygon boundaries are created around points that are equidistant to all of the neighboring points. Thiessen polygons divide up an area in a manner that is determined by the configuration of the data points. If the data points are irregularly spaced, then an irregular lattice of polygons will result (DeMers, 1997).

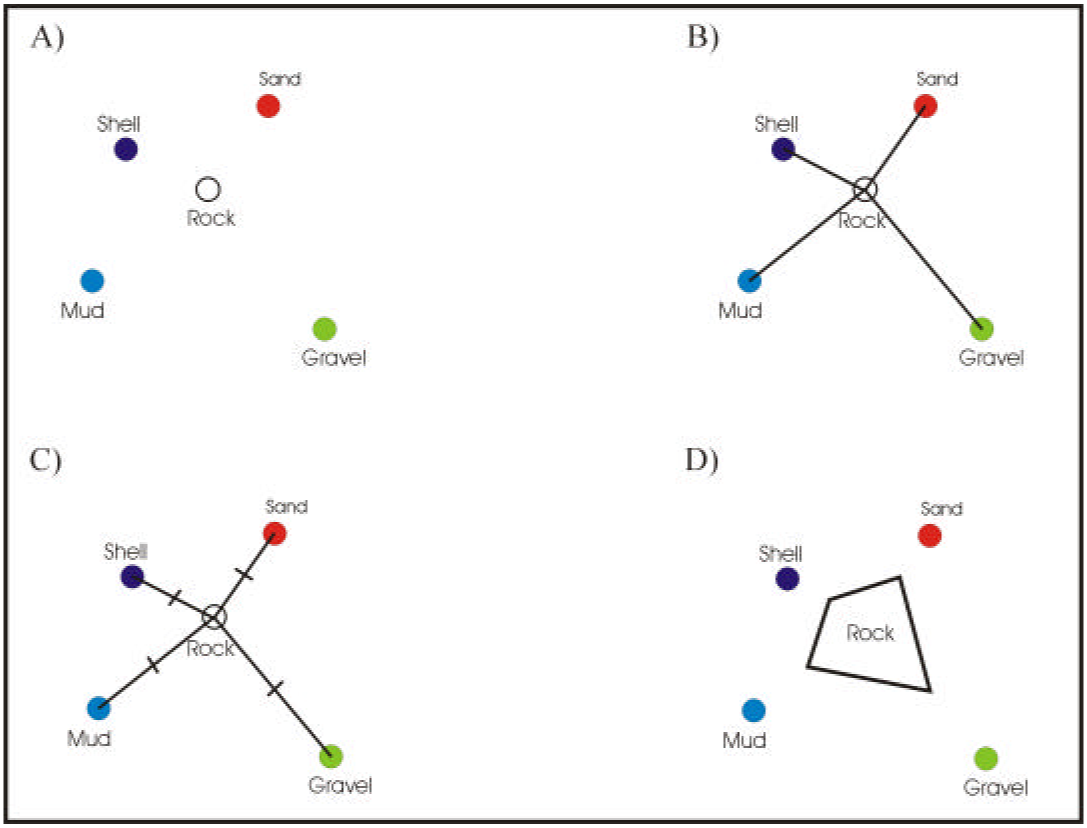


Figure 6 (previous page). Thiessen polygon operation: A) Substrate points. B) Draw lines that connect points to nearest neighbor. C) Find the bisectors of each line. D) Connect the bisectors of the lines and assign the resulting polygon the value of the center point.

In ArcView, the Thiessen polygon technique was applied to the substrate shapefile using the ASSIGN PROXIMTY operation. Utilizing the same geographic extent and cell size parameters as the bathymetry grid, a substrate grid theme was produced.

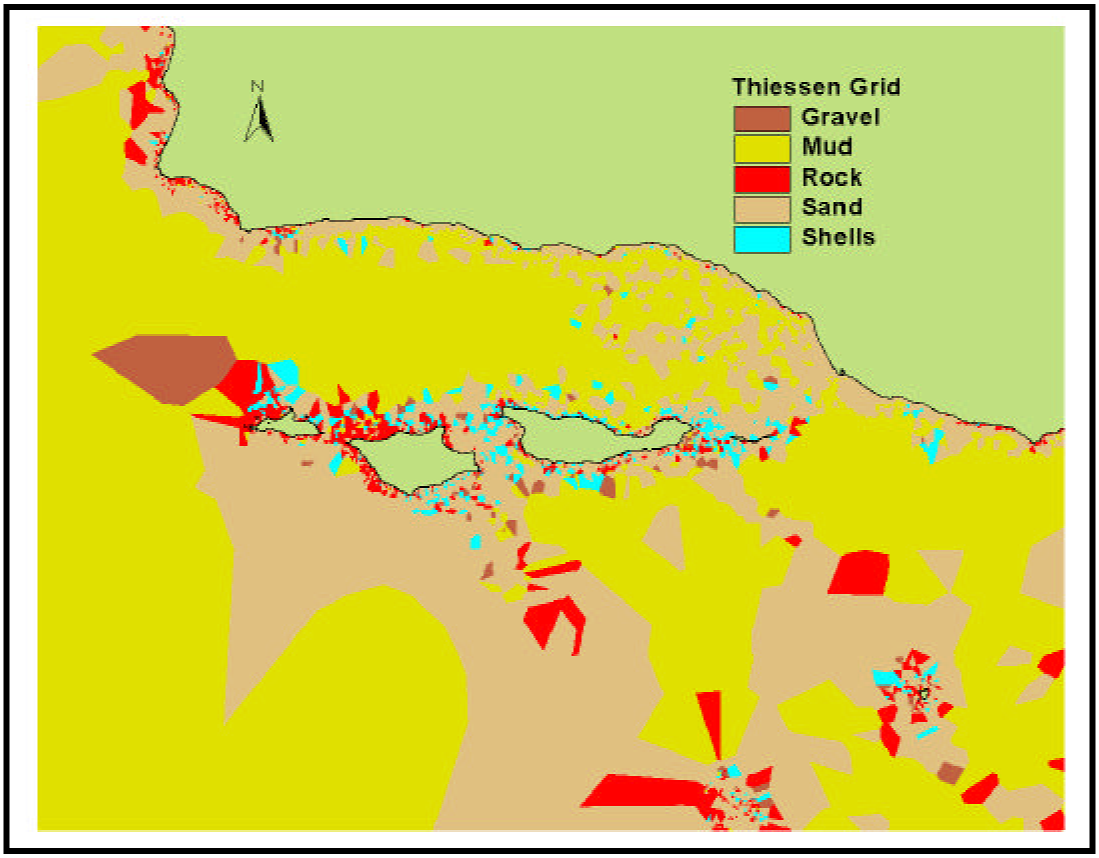


Figure 7. Substrate Thiessen grid: Irregularly spaced substrate points produce an erratic network of Thiessen polygons. Where few varieties of substrate sample points exist, large distorted polygons are produced.

Kriging Technique

Kriging is an advanced geostatistical procedure that generates an estimated surface from a set of points. Unlike other interpolation methods, kriging involves an interactive investigation of the spatial behavior of the phenomenon before selecting the best estimation method for generating the output surface. Kriging is a form of weighted average estimator, where weights are assigned by a model fitted to a function, which represents spatial variability in the property of interest. Indicator kriging, which was used for this analysis, is unique in that it can be applied to nominal data such as substrate types.

The principal tool of most kriging analyses is the semi-variogram, a function that relates half the average squared difference between paired data values to the distance (and direction, where anisotropy is considered) by which they are separated. A mathematical model may be fitted to the semi-variogram and the coefficients of the model may be used to assign optimal weights for interpolation using kriging.
The semi-variogram model was selected to best fit the sample semi-variogram which was computed from the substrate points. The semi-variogram is a theoretical function that is fitted to the sample semi-variogram. The value of the sample semi-variogram for a separation distance of h (referred to as the lag) is the average squared difference in z value between pairs of input sample points separated by h. The sample semi-variogram is calculated from the sample data with the equation:

$$\boxed{g(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (xi - yi)^2} \qquad \textbf{Eq. 3}$$

where *N(h)* is the number of pairs of sample points separated by distance *h*, and *xi* and *yi* correspond to the head and tail of each pair respectively (Deutsch and Journel, 1992).

The semi-variogram model describing the spatial relationship between neighboring locations is the critical element of any spatial estimation. The model is designed to match closely the spatial relationship observed in the sample data (e.g. the structure and dependence observed in the sample semi-variogram), paying particular attention to those distances, usually the shorter ones, that are used in the estimation.

There are several important features worth noting in the plot of the sample semi-variogram. At relatively short lag distances of h, the semi-variance is small, but increases with the distance between the pairs of sample points. At a distance referred to as the range, the semi-variance levels off to a relatively constant value referred to as the sill. This implies that beyond this range distance, variability is no longer spatially correlated. Within the range, the variation is smaller when the pairs of sample points are closer together.

Indicator semi-variograms were computed using the gamv program provided in GSLIB (Deutsch and Journel, 1998). Semi-variograms were created at 0°, 45°, 90°, 135°, and 180°. The models were then fitted to the two most varying directions, as identified by the plots. Each of the five substrate types was independently examined, and semi-variogram models were constructed for each. Figure 8 shows the semi-variogram in the 90° direction for mud. All other semi-variogram models can be found in Appendix E.

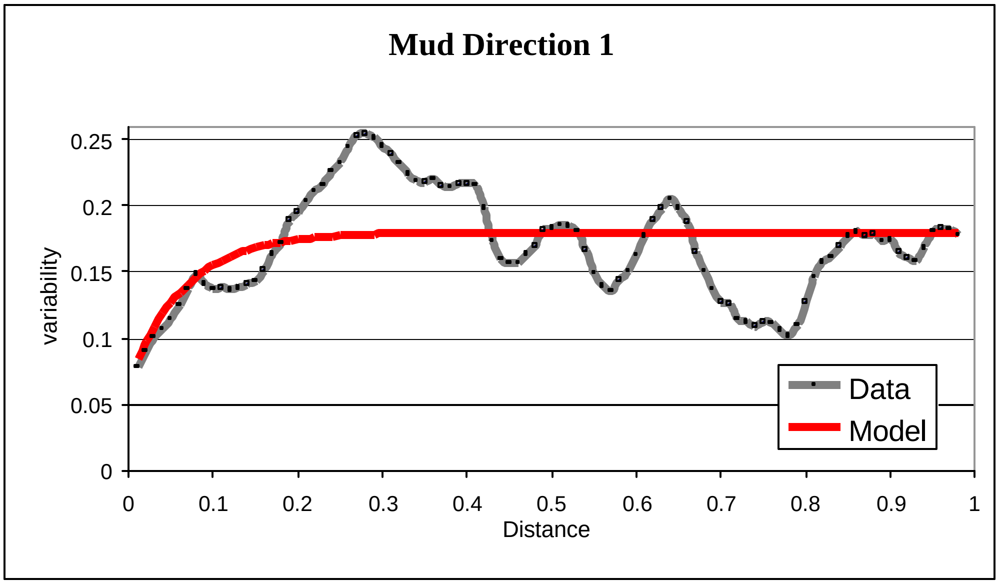


Figure 8. Modeled semi-variogram for mud in the 90° direction

The following parameters were developed based on examination of the sample semi-variograms:

Substrate	Nugget	Sill	Range	Anisotropy
Mud	.05	.13	200-300	0
Sand	.1	.15	50-150	0
Shells	.03	.035	200-300	135°
Gravel	.005	.02	150-300	135°
Rock	.06	.07	100-200	0

Table 6. Summary of Kriging parameters. All models use an exponential function.

The nugget effect corresponds to the amount of random variability associated with the data, and the sill corresponds to the maximum distance over which a correlation can be identified. The range is the horizontal range for which a correlation exists.

Indicator kriging was carried out using the ik3d code of GSLIB (Deutsch and Journel, 1998) with the input parameters identified above. Kriging was performed on each substrate type with a 500-cell search radius, and an output cell size of 60 meters. The output of the kriging operation is a probability surface, showing the probability of finding the specific substrate type in each pixel. The following map shows the probability of rock, based on the substrate sample data:

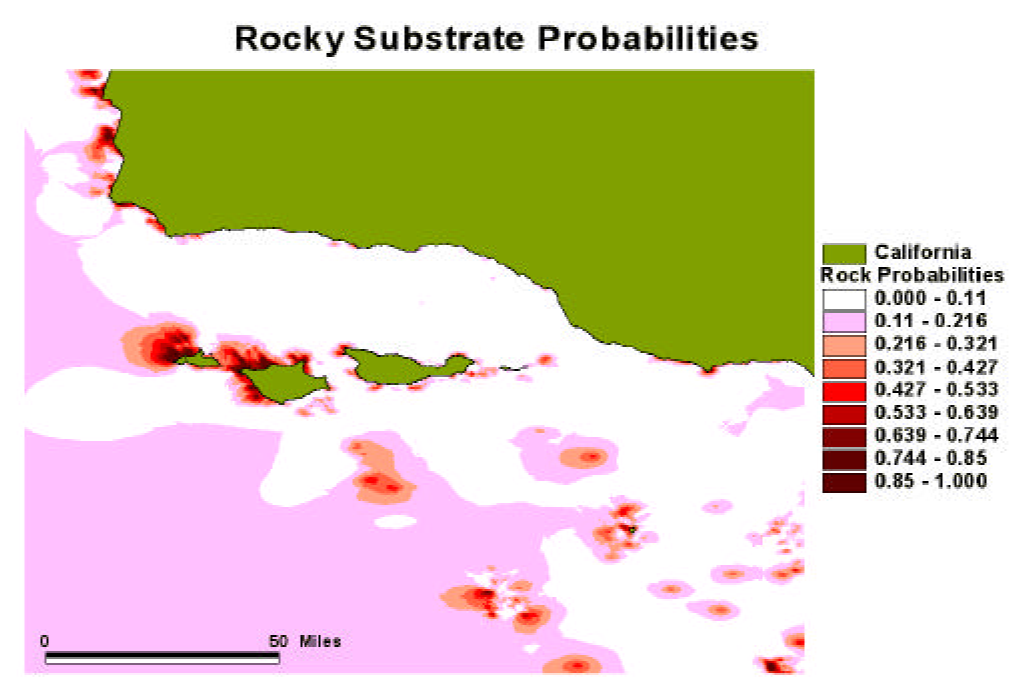


Figure 9. Rocky Substrate Probabilities

GIS Habitat Model Limitations

The intended purpose of the GIS habitat models was to delineate potential habitat distributions in the study area. How well this is accomplished depends on the data being employed by both models. A model's predictive ability is only as good as the input data. Any model output maybe erroneous if the quality of the input data is flawed to begin with.

Substrate type exhibits a high level of local variation, particularly in nearshore areas where accurate representation is most important. At the intensity of sampling present in the substrate data, much of this local variation cannot be modeled and effectively predicted by interpolation since the scale of the variability is smaller than the spacing of the data points. However, such local variability is an important characteristic of the distribution of a species. Thus, we did not want this local variability to become hidden behind a regional average of the resource, but to remain as apparent and accessible to the user as possible in the final estimated dataset.

The accuracy of the data created by any model is important information for users of those data. It is important to identify how well the output dataset portrays the characteristics of the phenomena it was designed to capture.

Local variability also adds uncertainty to any area estimate or summary. This is an additional factor in the interpolated datasets, because a point estimate is being assigned to represent an entire 60m by 60m cell. Spatial datasets, like non-spatial classifications, are themselves abstractions or generalizations of some spatial variation that is really there on the ground (Goodchild and Gopal, 1989). It is important to realize that in some cases it may not be possible to clearly delineate the substrate types since the boundaries are not sharp breaks but transition zones. The limits of the data, including sampling design and intensity, typically limit the level of resolution possible by interpolation. The inherent local variability of the phenomena has a large affect on the uncertainty of the predicted value at each location.

The model developed in this investigation has been built upon the best available data for the physical parameters that were selected. The model is highly dependent on the quality of the input data, specifically substrate. To make effective use of the substrate data, statistical interpolation techniques were implemented. The Thiessen polygon and the Kriging interpolation techniques applied to the substrate data were then tested for predictive reliability.

Thiessen

The Thiessen GIS habitat model applied the Thiessen polygon interpolation technique to the substrate data. The technique worked by drawing polygons around substrate points depending on the distance to neighboring points. The predictive power of the Thiessen polygon method was tested by removing a 5% random sample from the substrate dataset, running the Thiessen operation on the partial dataset, and comparing the resulting grid to a grid of the removed sample points. The idea is to observe whether the Thiessen operation of the partial dataset is capable of capturing the removed 5% sample. Out of 299 substrate points removed, 152 were captured by the Thiessen operation for a predictive power of 50.8%. The test was run for two more iterations for a predictive power of 53.5% and 52.8% respectively. The average for these tests was a predictive power of 52.4%. Although the Thiessen polygon interpolation method demonstrated a low predictive power, it did reveal that the Thiessen operation is highly dependent on the substrate points themselves to produce a reliable approximation of substrate variability.

To complement the Thiessen polygon interpolation, the group explored the creation of a confidence surface. A confidence surface is intended to show a decrease in probability of a substrate type as distance increases from the center of a Thiessen polygon. To accomplish this task, the nearest neighbor and the distance to the nearest neighbor were determined for each substrate point, using the Nearest Features ArcView extension written by Jeff Jenness (1999). Once the resulting file was imported in Excel, a column reflecting the similarity between the substrate point sampled and the nearest neighbor was created. If the sampled point and the nearest neighbor were of the same substrate type, the number one was assigned; if not, a zero was assigned. The similarity and the distance columns were used in a logistic regression to identify a correlation between distance and substrate predictability.

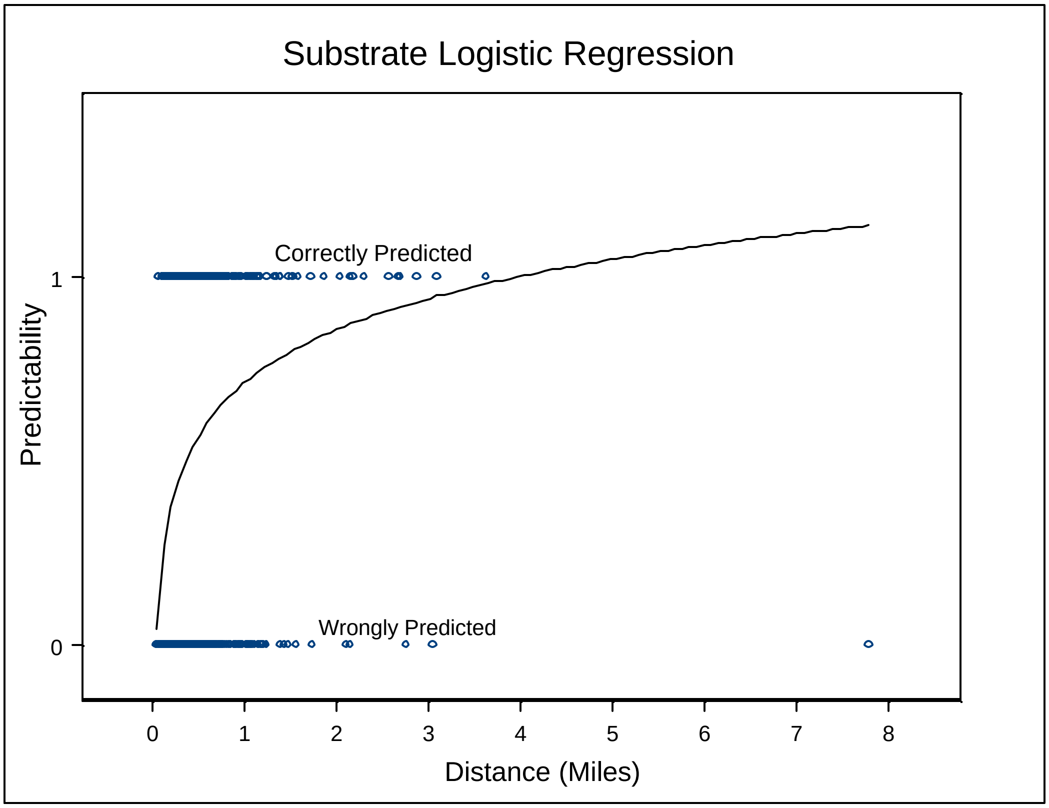


Figure 10. Logistic regression testing correlation between distance and predictive power of substrate data.

The logistic regression produced less than favorable results. Figure 10 shows that as distance increases from a substrate sample, one is better able to predict the substrate type of the nearest neighbor. This contradicts the base assumption of predictive power being the highest at short distance. Similar regressions were performed for individual substrate types and substrate types within the CINMS boundaries. The results for these regressions were also erroneous (Appendix F).

Although the Thiessen approach to substrate interpolation is a valid method given the categorical nature of the substrate data, further analysis of the Thiessen technique did reveal the heterogeneous nature of the substrate sampling. The random Thiessen testing approach and the confidence surface investigation led to the conclusion that the substrate variance was not equally distributed among all the substrate points sampled in the Santa Barbara Channel. Therefore, Thiessen interpolation can produce unreliable results. However, this result was expected given the high variability of substrate type in the Santa Barbara Channel.

Kriging

In terms of the Kriging model, a level of uncertainty is always associated with any estimate. Knowing how much uncertainty exists will help the user identify whether that uncertainty is acceptable for a specific task and how the data can be used. In addition, knowing how much uncertainty exists helps identify areas where additional sampling would improve the estimates. For estimates of species' presence/absence, indicator kriging provides a probability. Although not strictly an uncertainty value, a probability of occurrence value can be effectively used to select a cut-off that reflects the user's preferences for errors of omission versus commission in the identification of areas of species occurrence.

High local spatial variability contributes to the uncertainty that at any given point within that cell the estimate being reported would match what was measured on the ground. It affects the uncertainty of the estimate when substrate values vary over shorter distances than the sampling intensity resolves. This unexplained variation was reflected in the semi-variogram as a sometimes-substantial nugget and resulted in higher levels of uncertainty associated with the estimates in this study.

Kriging is based on the regionalized variable theory that assumes that the spatial variation in the phenomenon represented by the values is statistically homogeneous throughout the surface. This relies on the assumption that the same pattern of variation can be observed at all locations on the surface. This hypothesis of spatial homogeneity is fundamental to the regionalized variable theory. Thus, the data should not only represent the degree of variability in the landscape, but also the nature of that variation.

Summary of Modeling Process

We collected data from six sources: Conception Coast Project (CCP), U.S. Geological Survey (USGS), UCSB Geography Department, Coastal Data Information Program (CDIP), Harvest Buoy, and the Institute for Computational Earth Systems Science (ICESS). These datasets were processed into a useable format and are the basis of our model input parameters. By combining these parameters, our model predicted a species' potential habitat distribution in the following manner:

1. For all species, our model determined the presence or absence of an organism at a given depth (a probability (P) value of 1 indicates presence, and a probability of 0 indicates absence).
2. For all species, our model determined the presence or absence of an organism over a specific substrate type. When using the Thiessen interpolation technique, a probability value of 1 indicates presence at that substrate and 0 indicates absence. Because Kriging interpolation outputs a grid of probabilities for each cell being a particular substrate type, we classified a cell as a substrate type if it was ≥ 50% likely to be that substrate type. Our model then determined the presence or absence of an organism living over the classified substrate type by giving it a probability value of 1 or 0.
3. For those species affected by high wave exposure, our model determined the presence or absence of an organism in areas of high wave exposure using probability values of 1 or 0, respectively.
4. For species that live in specific bioregions, our model determined the presence or absence of an organism in those regions using probability values of 1 or 0, respectively.
5. For species that depend on Kelp for habitat, our model determined the presence or absence of organism in areas where Kelp is present using probability values of 1 or 0.
6. These probabilities are combined to determine the potential habitat distribution (where individuals of a species could be present).

Below is a summary of the model building process.

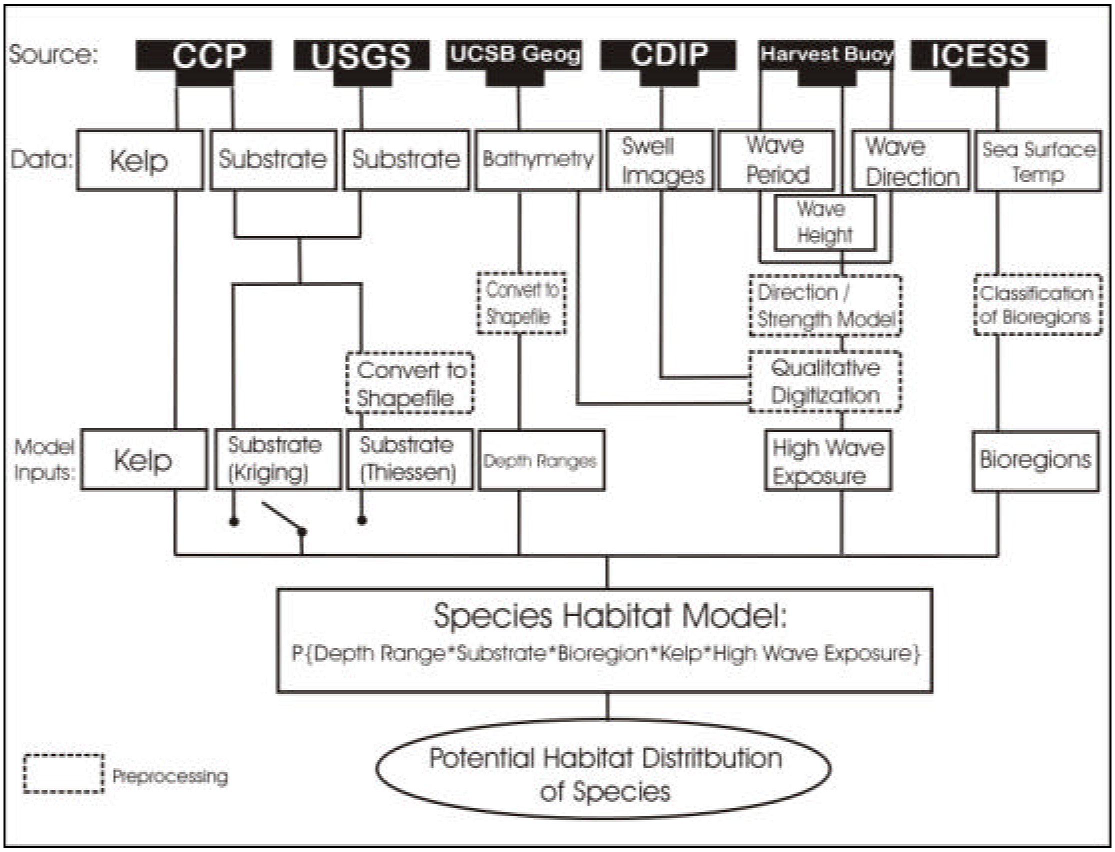


Figure 11. Summary of model building process

Model Output Testing

The potential habitat distributions created from the GIS habitat models were compared against test data to evaluate the models' predictive power. The test data available was limited, because the location of fish catch is generally considered a trade secret, and state and federal agencies feel publicizing the locations of species contradicts their conservation efforts. Furthermore, underwater surveys are very expensive and difficult to undertake for any concerned party. Nonetheless, the group did manage to acquire test data from the CINMS and the CINP. The test data consisted of a nine-year composite of Giant Kelp distribution in shapefile format and presence-absence data for White Abalone, Red Sea Urchin, Purple Sea Urchin, Sheephead, and the California Spiny Lobster. No test data was available for any other species of interest.

We tested all model outputs against point observations collected and provided by staff scientists at the Channel Islands National Park. The distribution of test sites can be seen in Figure 12.

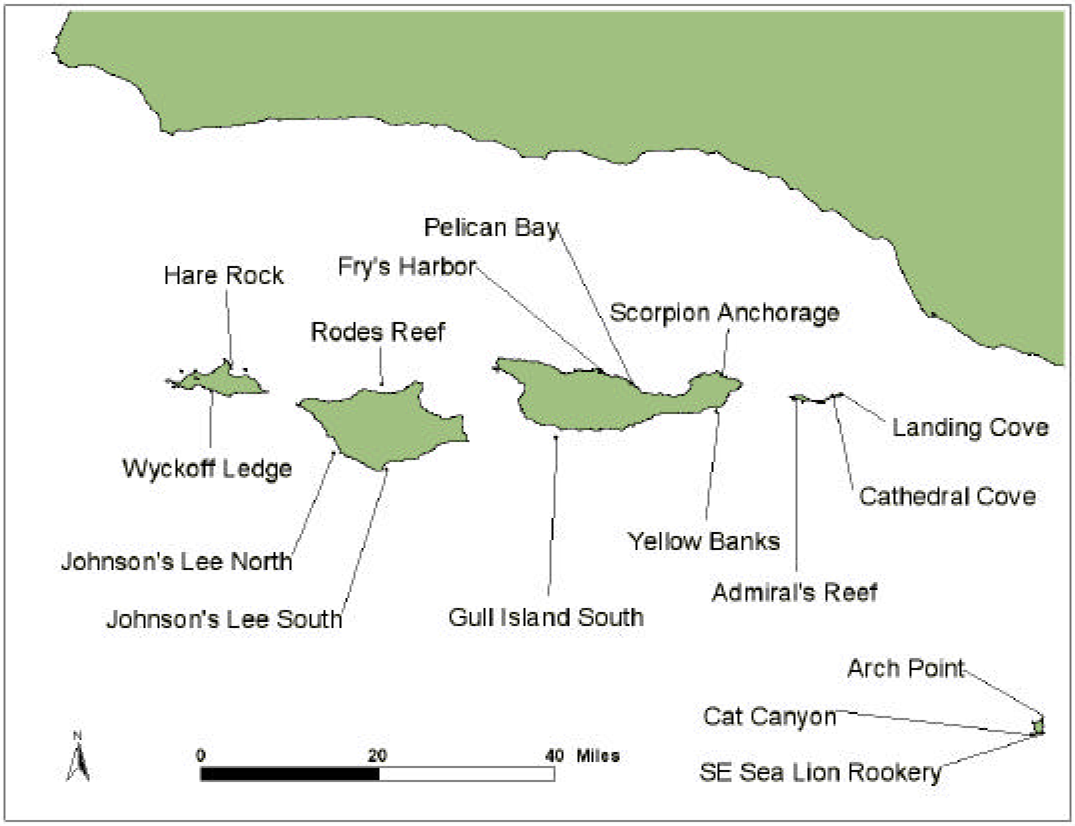


Figure 12. Location of test points

For the model outputs created using the Kriging method, the available test data was examined to identify the probability of finding suitable habitat at each site. The mean probability at all points provides an indication of the predictive ability of the model. Mean probabilities ranged from .28 to .76, with Spiny Lobster receiving the highest count. This is most likely a result of lobsters' affinity for multiple substrate types increasing its overall probability. Table 7 shows the distribution of habitat probability values across all of the test sites. Locations with no value indicate sites where the survey dives found the species not to be present. Since this is a predictive model of potential habitat, only locations where species were found to exist were tested.

Island	Location	**Giant Kelp**	**Purple Urchin**	**Red Urchin**	**Spiny Lobster**	**Sheep-head**	**White Abalone**
San Miguel	Wyckoff Ledge	.45	.45	.45	_	.44	_
San Miguel	Hare Rock	_	.1	.1	_	.1	_
Santa Rosa	Johnson's Lee North	_	.73	.73	.99	.70	_
Santa Rosa	Johnson's Lee South	_	.22	.21	_	.24	_
Santa Rosa	Rodes Reef	.34	.34	.34	_	.34	_
Santa Cruz	Gull Island South	.60	.61	.59	_	.59	_
Santa Cruz	Fry's Harbor	_	.1	_	.27	.09	_
Santa Cruz	Pelican Bay	_	.31	.31	.53	.26	_
Santa Cruz	Scorpion Anchorage	.61	.33	.34	.78	.31	_
Santa Cruz	Yellow Banks	.29	.15	.17	.90	.15	.36
Anacapa	Admirals Reef	.17	.13	.13	.6	.09	_
Anacapa	Cathedral Cove	.13	.17	.17	.86	.16	_
Anacapa	Landing Cove	_	.13	.13	.6	.13	_
Santa Barbara	Sea Lion Rookery	.18	.15	.18	.93	.14	_
Santa Barbara	Arch Point	.4	.4	.4	.93	.40	.55
Santa Barbara	Cat Canyon	.44	.45	_	.97	.49	_
_	**Mean Probability for All Test Points**	.36	.31	.31	.76	.28	.46

Table 7. Habitat probabilities for all test sites

Giant Kelp Testing
The potential habitat distribution for Giant Kelp in the Santa Barbara Channel was produced using the following abiotic parameters: a depth range of 0 to 40 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a rocky substrate type. Since Giant Kelp can tolerate the temperature regime that encompasses the channel and endure low to high wave exposure, depth and substrate type will be the determining abiotic factors in the distribution of Giant Kelp potential habitat.

Thiessen Technique:
The potential habitat distribution for Giant Kelp spans the extent of the Santa Barbara Channel. The coasts of Santa Barbara and Ventura counties contain numerous regions of potential kelp habitat. In particular, the coasts north of Point Conception experience significant offshore areas of potential kelp habitat distributions. Within the CINMS, potential kelp habitat regions surround the coasts of San Miguel, Santa Rosa, and Santa Barbara islands. The islands of Santa Cruz and Anacapa experience scattered areas of potential kelp habitat along their coasts.

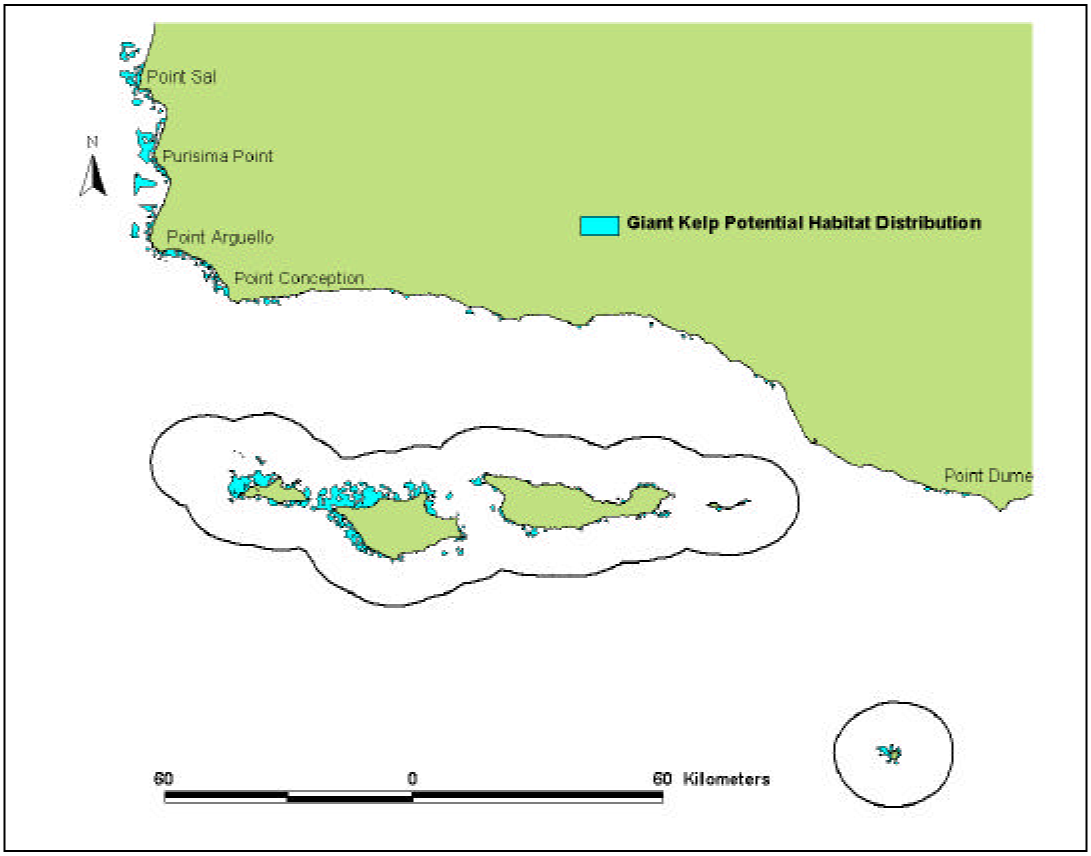


Figure 13. Giant Kelp model output (using Thiessen technique)

The potential habitat distribution of Giant Kelp was tested with the nine-year composite shapefile of Giant Kelp distribution in the Santa Barbara Channel acquired from the CINMS. The composite consisted of polygons where a growing kelp canopy was observed in the summer of 1989 and kelp distributions were observed from 1980 to 1988. Areal calculations were performed on both datasets. Composite areas within the potential kelp habitat distributions produced by the model were clipped. By comparing the areas of the composite captured by the predicted habitat distribution to the total area of the nine-year composite, a measure of predictive power can be attained.

The model correctly predicted 38.8% of the entire nine-year kelp composite dataset. Within the CINMS boundaries, the predictive power of the model improved to 57.4%. Along the Santa Barbara county coast, the model over-predicted north of Point Conception and severely under-predicted south of Point Conception to include the Ventura county coast. The predictive ability of the model along the coast was 14.5%. The predictive power of the potential kelp habitat distributions surrounding San Miguel (59.6%), Santa Rosa (66.2%), and Santa Barbara (46.2%) islands were the highest in the Santa Barbara Channel. In comparison, the model's predictive power around Santa Cruz (30.5%) and Anacapa (20.2%) islands were relatively low.

Kriging Technique:
Based on the model output, the highest probabilities for finding kelp habitat were identified northwest of San Miguel and Santa Rosa islands, as well as surrounding Santa Barbara Island, and from Point Sal to Point Conception.

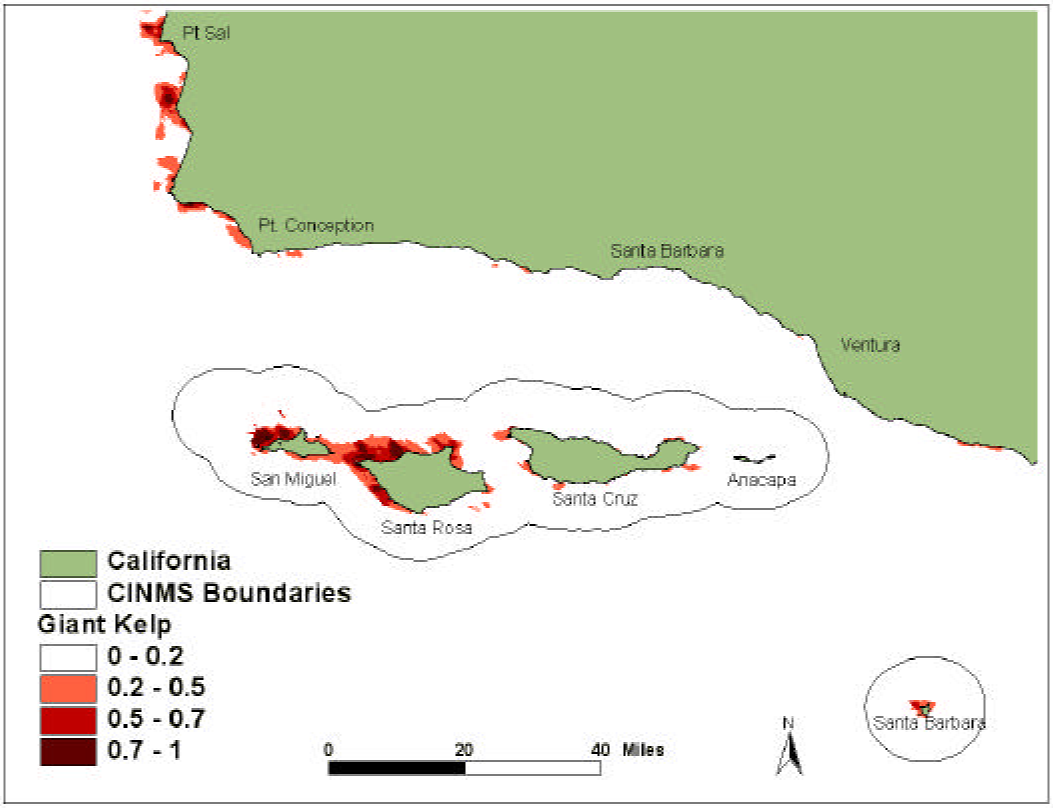


Figure 14. Giant Kelp model output (using Kriging technique).

Ten points of known kelp locations were available for testing. Of these ten points, all fell within the general habitat requirements, but with varying probabilities. Probabilities for kelp ranged from .13 at Cathedral Cove on Anacapa Island to .6 at Gull Island South on Santa Cruz Island. The mean probability for kelp at all the test points was .36.

White Abalone Testing

Two potential habitat distributions were produced for White Abalone in the Santa Barbara Channel. The maximum potential habitat distribution of White Abalone was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific abiotic requirements. The maximum potential distribution was produced with the following abiotic parameters: a depth range of 0 to 40 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a rocky substrate type. The prime distribution was produced with a depth range of 25 to 30 meters and the same wave exposure, temperature, and substrate parameters as the general distribution. The determining abiotic factors in creating the potential habitat distributions of White Abalone were substrate type and depth in this model.

Thiessen Technique:

Along the coast, the maximum potential habitat distribution for White Abalone is concentrated between Point Conception in the south and Point Sal in the north. In particular, there is a large potential habitat region identified between Point Arguello and Purisima Point. Within the CINMS, patches of potential habitat surround each island. Significant areas of potential habitat are apparent off the northeastern coasts of San Miguel and Santa Rosa islands.

The areas of prime White Abalone potential habitat were less observable since the depth parameter was restricted to 25 to 30 meters. Patchy areas of potential habitat are visible offshore along the coast from Point Conception to Point Sal. The CINMS contains numerous areas of potential habitat around each island. Significant potential habitat distributions are apparent off the northwestern coasts of San Miguel, Santa Rosa, and Santa Barbara islands.

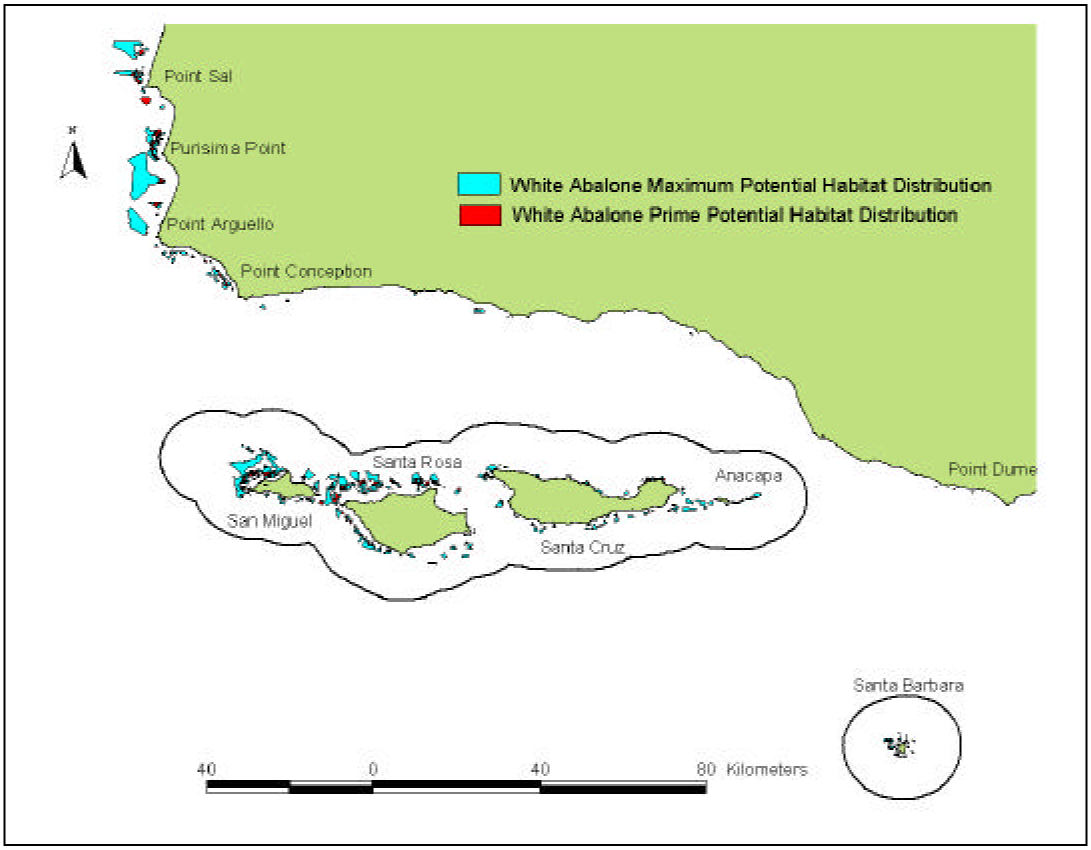


Figure 15. White Abalone model output (using Thiessen technique)

The potential habitat distributions of White Abalone was tested with the transect survey data acquired from the CINP. Of the 16 transects, only two reported the presence of White Abalone. Those two survey points were successfully captured by the maximum potential habitat distribution (depth range of 20 to 60 meters). The prime potential habitat distribution (depth range of 25 to 30 meters) for White Abalone only captured one of the survey points. The other transect observation was within 100 meters of the area identified as prime potential habitat.

Kriging Technique:
High probabilities for both the maximum and prime habitat for White Abalone are primarily around Santa Rosa and San Miguel islands. Additional potential habitat zones were also identified from Point Sal to Point Conception, and Surrounding Santa Barbara Island.

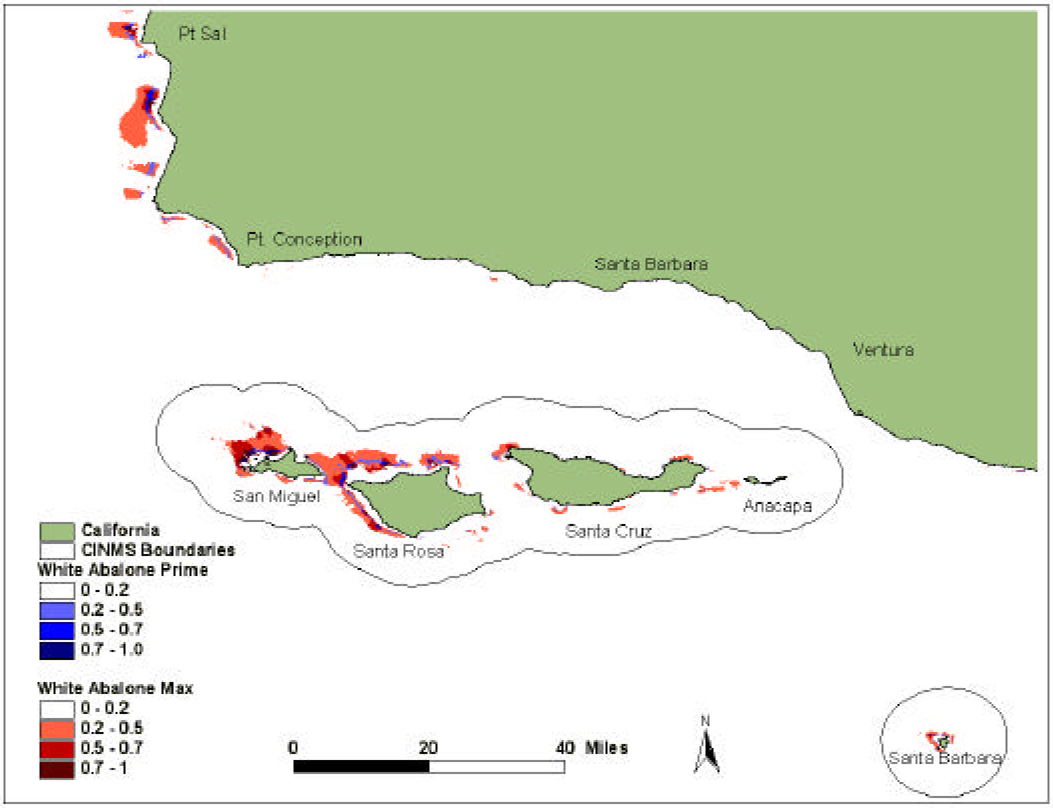


Figure 16. White Abalone model output (using Kriging technique)

Only 2 points of known white abalone locations were available for testing. Of these 2 points, both fell within the general habitat requirements, but with varying probabilities. Probabilities for white abalone ranged from .36 at Yellow Banks at Santa Cruz Island to .55 at Arch Point on Santa Barbara Island. The mean probability for white abalone at all the test points was .46.

Red Sea Urchin Testing

Two potential habitat distributions were produced for the Red Sea Urchin in the Santa Barbara Channel. The maximum potential habitat distribution of the Red Sea Urchin was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific biotic or abiotic requirements. The maximum potential distribution was produced with the following abiotic parameters: a depth range of 0 to 100 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate of rock and gravel. The prime distribution was produced with a depth range of 5 to 10 meters and the same wave exposure, temperature, and substrate parameters as the general distribution. The biotic parameter inputted into the model consisted only of Giant Kelp. Since the Red Sea Urchin can tolerate the temperature regime that encompasses the channel and has no wave exposure restrictions, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Red Sea Urchin potential habitat.

Thiessen Technique:

The distribution of maximum potential habitat distribution for the Red Sea Urchin is scattered throughout the Santa Barbara Channel. Along the coast, the narrow discontinuous zones of maximum potential habitat border the coastline from approximately Rincon Point to Point Sal. The most significant distributions along the coast can be found north of Point Arguello. Within the CINMS, patchy areas of potential habitat surround each island. Significant regions of potential habitat are apparent off the northwestern coasts of San Miguel and Santa Rosa islands and the entire shore of Santa Barbara island. Patchy clusters of maximum potential habitat can be observed surrounding Santa Cruz and Anacapa islands.

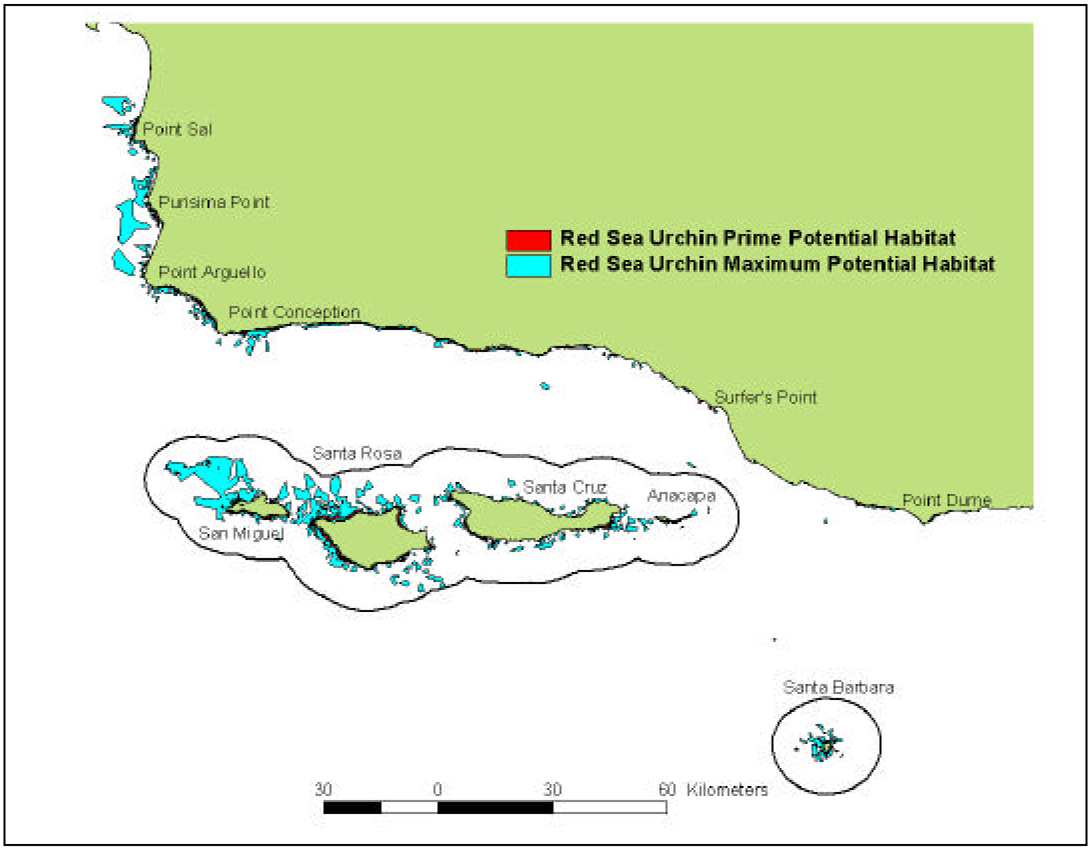


Figure 17. Red Sea Urchin model output (using Thiessen technique)

The areas of prime Red Sea Urchin potential habitat were less observable since the depth parameter was restricted to 5 to 10 meters. Small discontinuous zones of prime potential habitat can be found along the coast from Surfer's Point to Point Sal. The largest areas of prime potential Red Sea Urchin habitat, within the CINMS, can be observed off the coasts of San Miguel and Santa Cruz islands. Santa Cruz, Anacapa, and Santa Barbara islands have small discontinuous clusters of prime potential habitat off their coasts.

The potential habitat distributions of the Red Sea Urchin was tested with the transect survey data acquired from the CINP. Out of 16 transect survey observations, seven were captured by the maximum potential habitat distribution (depth range of 0 to 100 meters). Santa Rosa and Santa Barbara islands performed the best in the test by capturing two out of three transect samples at each island. San Miguel, Santa Cruz, and Anacapa islands only captured one out of two, two out of five, and zero out of three transect observations at each island respectively. The prime potential habitat distribution (depth range of 5 to 10 meters) for the Red Sea Urchin only captured one of the 16 survey points. This single observation was captured off the coast of Santa Barbara Island.

Kriging Technique:
Areas of highest Red Urchin habitat probability were identified primarily around Santa Rosa and San Miguel islands, with additional habitat between Point Sal and Point Conception. Scattered patches of habitat were also identified around each of the other islands.

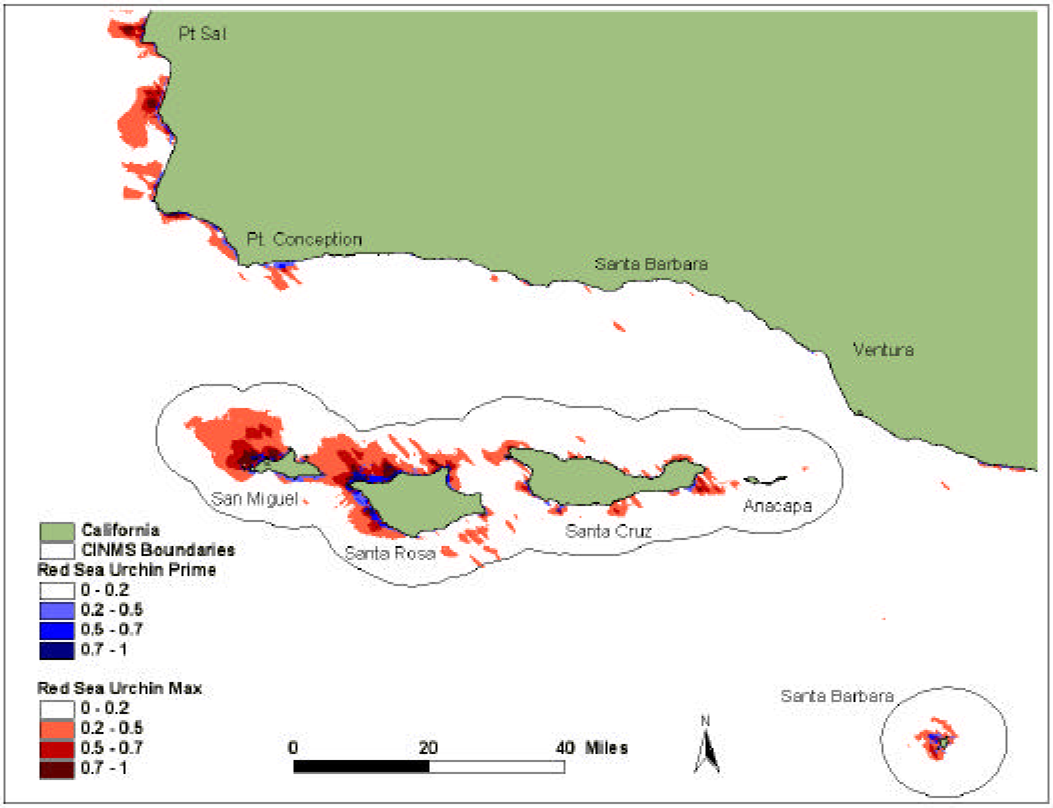


Figure 18. Red Sea Urchin model output (using Kriging technique)

14 points of known red urchin locations were available for testing. Of these 14 points, all fell within the general habitat requirements, but with varying probabilities. Probabilities for Red Urchin ranged from .1 at Hare Rock at San Miguel Island to .73 at Johnson's Lee North on Santa Rosa Island. The mean probability for Red Urchin at all the test points was .31.

Purple Sea Urchin Testing
The potential habitat distribution for Purple Sea Urchin in the Santa Barbara Channel was produced with the following abiotic parameters: a depth range of 0 to 38 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of rock and gravel. The biotic parameter inputted into the model consisted only of Giant Kelp. Since the Purple Sea Urchin can tolerate

the temperature regime that encompasses the channel and has no wave exposure restrictions, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Purple Sea Urchin potential habitat.

Thiessen Technique:

The potential habitat distribution of Purple Sea Urchin is scattered throughout the Santa Barbara Channel. Along the coast, the narrow discontinuous zones of potential habitat border the coastline from approximately Rincon Point to Point Sal. The most significant distributions along the coast can be found north of Point Conception. Within the CINMS, zones of potential habitat surround each island. Significant regions of potential habitat are apparent off the coasts of San Miguel, Santa Rosa, and Santa Barbara islands. Numerous discontinuous clusters of potential habitat can also be observed engulfing the coasts of Santa Cruz and Anacapa islands.

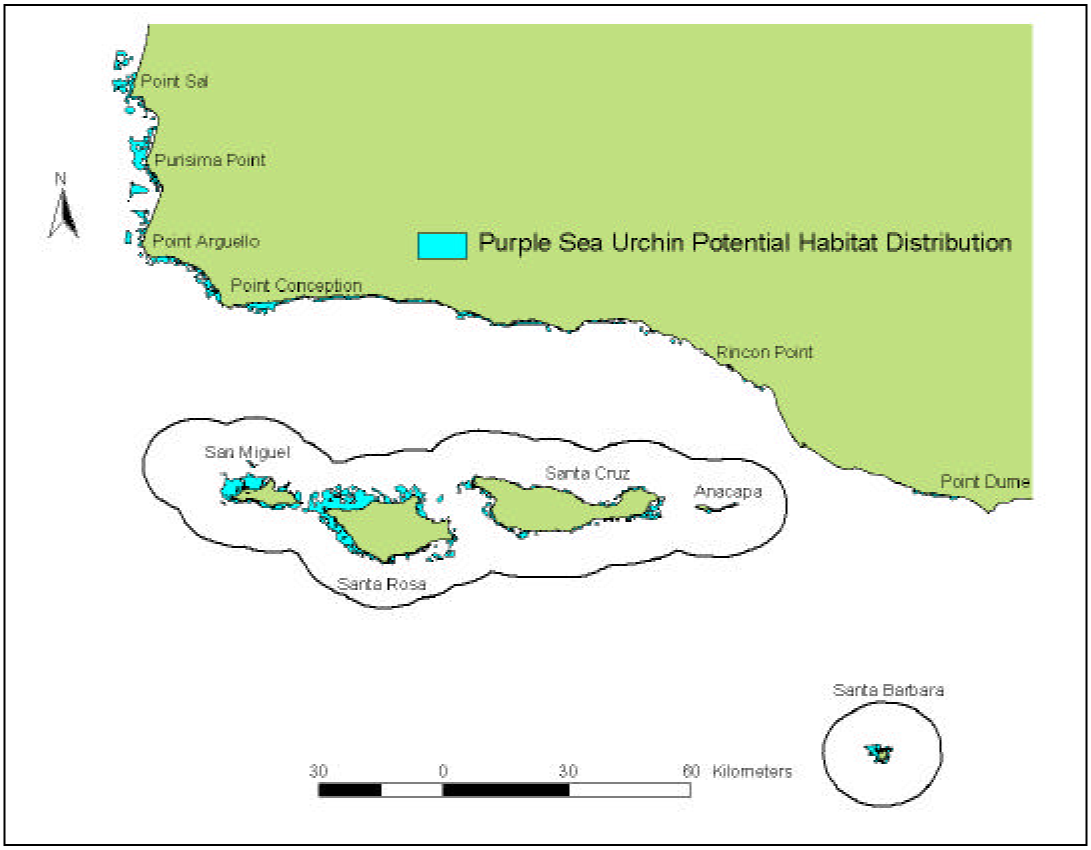


Figure 19. Purple Sea Urchin model output (using Thiessen technique)

The potential habitat distribution of the Purple Sea Urchin was tested with the transect survey data acquired from the CINP. Out of 16 transect survey observations, seven were captured by the maximum potential habitat distribution (depth range of 0 to 100 meters). Santa Rosa and Santa Barbara islands performed the best in the test by capturing two out of three transect samples at each island. San Miguel, Santa

Cruz, and Anacapa islands only captured one out of two, two out of five, and zero out of three transect observations at each island respectively.

Kriging Technique:
Areas of highest Purple Urchin habitat probability were identified primarily around Santa Rosa and San Miguel islands, with additional habitat between Point Sal and Point Conception. Scattered patches of habitat were also identified around each of the other islands.

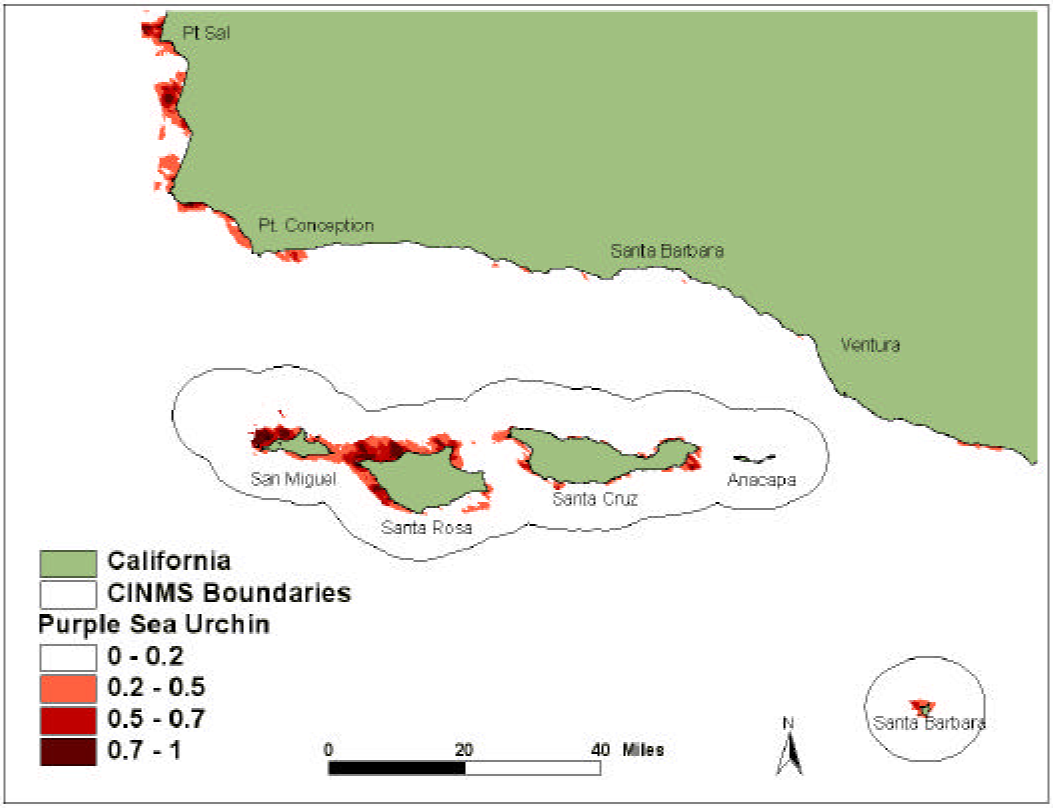


Figure 20. Purple Sea Urchin model output (using Kriging technique)

16 points of known purple urchin locations were available for testing. Of these 16 points, all fell within the general habitat requirements, but with varying probabilities. Probabilities for Purple Urchin ranged from .1 at Hare Rock at San Miguel Island to .73 at Johnson's Lee North on Santa Rosa Island. The mean probability for Purple Urchin at all the test points was .31.

California Spiny Lobster Testing

The potential habitat distribution for the California Spiny Lobster in the Santa Barbara Channel was produced with the following abiotic parameters: a depth range of 10 to 60 meters, a temperature range encompassing the three bio-regions, low-to-medium wave exposure, and a substrate type of rocky, gravel, and sand. The biotic parameter inputted into the model only consisted of Giant Kelp. Since California Spiny Lobster can tolerate the temperature regime that encompasses the channel, depth, the presence of Giant Kelp, depth, wave exposure, and substrate type will be the determining factors in the distribution of California Spiny Lobster potential habitat.

Thiessen Technique:

The potential habitat distribution of the California Spiny Lobster spans the extent of the Santa Barbara Channel. Along the coast, a semi-continuous zone of potential habitat can be observed approximately between Point Dume and Point Sal. Significant potential habitat regions within this zone are apparent along the shore between Port Hueneme and Rincon Point and north of Point Conception. Within the CINMS, clusters of potential California Spiny Lobster habitat areas border each island. In particular, significant regions of potential habitat surround the southern coasts of San Miguel, and Santa Rosa. In addition, the channel between Santa Rosa and Santa Cruz islands has been identified as significant potential California Spiny Lobster habitat since high wave exposure is limited in this area. A continuous zone of potential habitat also borders the eastern coast of Santa Barbara Island. Along the coasts of Santa Cruz and Anacapa islands, numerous small clusters of potential habitat can be observed.

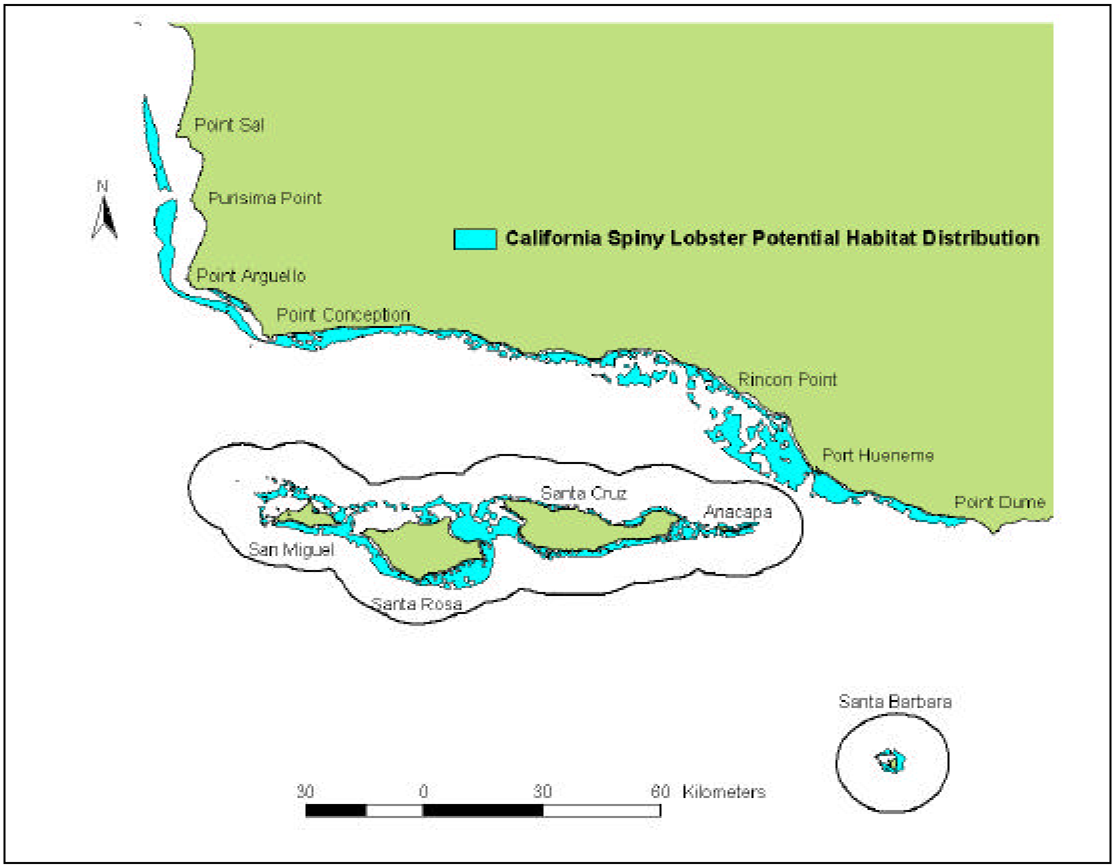


Figure 21. California Spiny Lobster model output (using Thiessen technique)

The potential habitat distribution of the Purple Sea Urchin was tested with the transect survey data acquired from the CINP. Out of 11 transect survey observations, four were captured by the California Spiny Lobster potential habitat distribution. Santa Rosa and Santa Barbara islands performed the best by capturing three out of four transect observations. Santa Cruz and Anacapa islands only managed to capture one out of seven observations. There were no California Spiny Lobster observations available for San Miguel Island.

Kriging Technique:

Due to the Spiny Lobsters' affinity for multiple substrate types, potential habitat surrounds every island, and can be found along the entire coast of the study area.

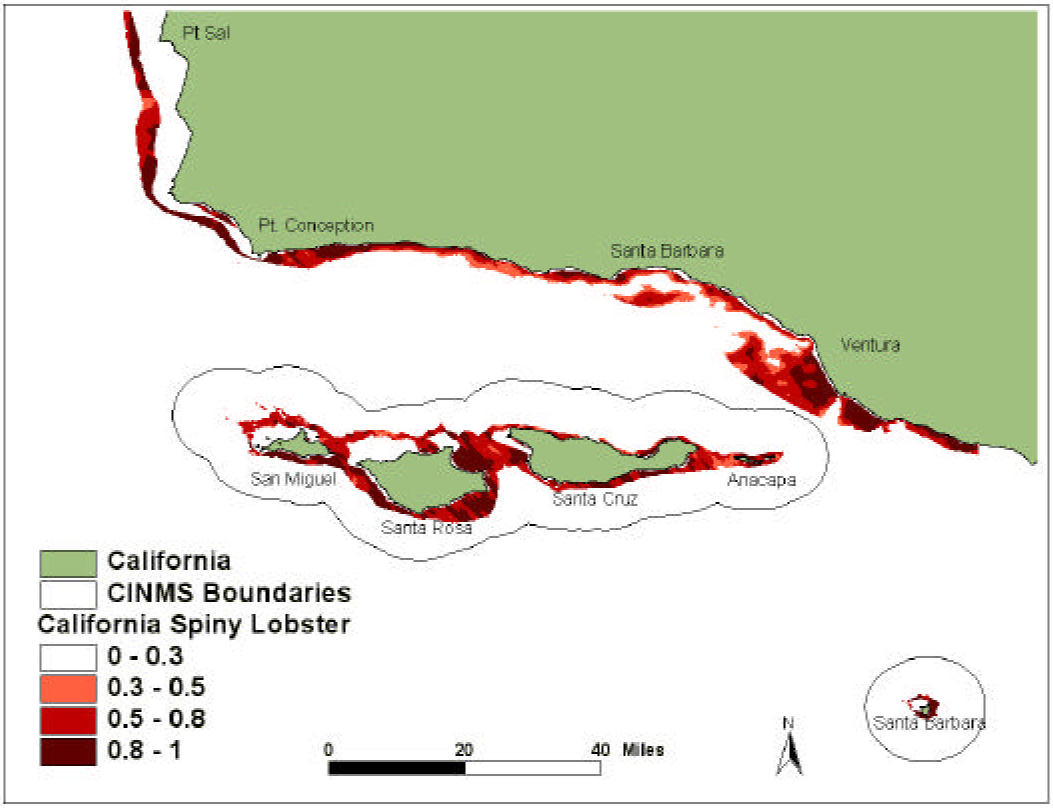


Figure 22. California Spiny Lobster model output (using Kriging technique)

11 points of known spiny lobster locations were available for testing. Of these 11 points, all fell within the general habitat requirements, but with varying probabilities. Probabilities for Spiny Lobster ranged from .27 at Fry's Harbor on Santa Cruz Island to .99 at Johnson's Lee North on Santa Rosa Island. The mean probability for Spiny Lobster at all the test points was .76.

Sheephead Testing

The potential habitat distribution for Sheephead in the Santa Barbara Channel was produced with the following abiotic parameters: a depth range of 0 to 85 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of rock and gravel. The biotic parameter inputted into the model consisted only of Giant Kelp. Since Sheephead can tolerate the temperature regime that encompasses the channel and has no wave exposure restrictions, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Sheephead potential habitat.

Thiessen Technique:

The potential habitat distribution of Sheephead spans the extent of the Santa Barbara Channel in discontinuous zones. Along the coast, the majority of the areas identified as potential habitat are concentrated approximately between Point Conception and Point Sal. The islands of CINMS are each encircled by areas of potential Sheephead habitat. In particular, significant regions identified as potential habitat surround the islands of San Miguel, Santa Rosa, and Santa Barbara. The islands of Santa Cruz and Anacapa experience scattered areas of potential Sheephead habitat along their coasts.

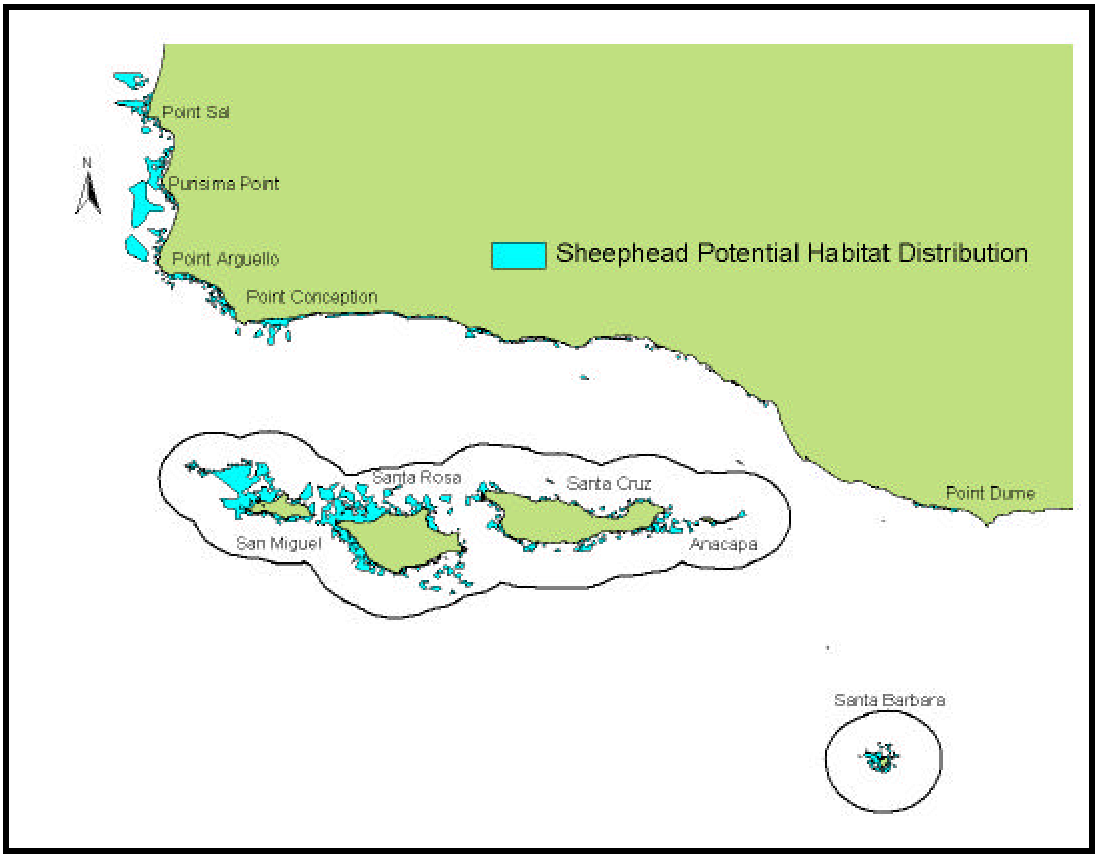


Figure 23. Sheephead model output using (using Thiessen technique)

The potential habitat distribution of Sheephead was tested using the transect survey data acquired from the CINP. All 16 transects reported the presence of Sheephead. Of the 16 survey points, seven were correctly captured by the potential Sheephead distribution. The best prediction of Sheephead habitat was off the coasts of San Miguel, Santa Rosa, and Santa Barbara islands, where five of eight survey observations were successfully predicted. The other three observations were within an average of 77 meters of potential habitat areas. Santa Cruz and Anacapa islands only predicted two of eight survey observations. The two survey points that were correctly captured by the potential habitat distribution were off the coast of Santa

Cruz Island. The average distance from potential habitat areas for the missed survey points was 282 meters for these islands.

Kriging Technique:
Areas of highest Sheephead habitat probability were identified primarily around Santa Rosa and San Miguel islands, with additional habitat between Point Sal and Point Conception. Scattered patches of habitat were also identified around each of the other islands.

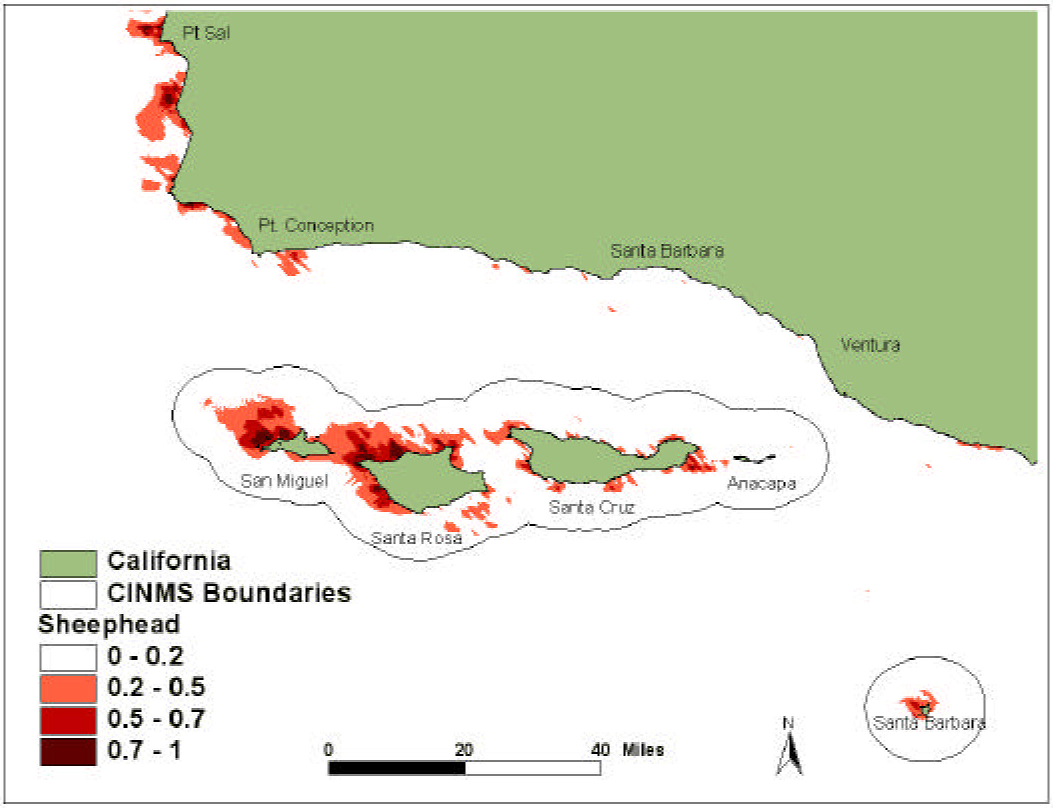


Figure 24. Sheephead model output (using Kriging technique)

16 points of known sheephead locations were available for testing. Of these 16 points, all fell within the general habitat requirements, but with varying probabilities. Probabilities for sheephead ranged from .1 at Hare Rock at San Miguel Island to .7 at Johnson's Lee North on Santa Rosa Island. The mean probability for sheephead at all the test points was .28.

Phase IV: Information Dissemination

To make the GIS habitat model and the model outputs useful to all stakeholders, we had to make them publicly accessible. In order to accomplish this task, we needed to create and design a website with mapping and GIS capabilities.

ESRI's ArcIMS software package integrates GIS and the Internet. The package has the basic GIS functionality of ESRI's ArcVIEW GIS software package but also offers client support for Internet streaming and local geoprocessing all through a web browser interface. This interface can display local desktop data, access Internet data, or integrate both.

Problems with ArcIMS

Because ESRI's ArcIMS software package is still in an early version, there are problems associated with it. Technical problems stem from glitches or "bugs" in the program which affect the map display. These problems are trivial and do not significantly prohibit the use of ArcIMS.

Functional problems with ArcIMS are significant. The first problem we encountered was the inability of the program to display and query grid maps. We worked around the display problem by manually programming ArcIMS into displaying grids; however, because the grids were displayed simply as background images, we were unable to query them. This severely limited the functionality of our website because some of the data we used, such as the bathymetric data from which depth was determined and the interpolated substrate data layers, are in grid format. Therefore, we were unable to include these datasets in our site for users to manipulate. Additionally, ArcIMS does not allow querying of more than one distinct data layer. In fact, the querying capabilities of the package are so limited, we were unable to provide users with the kinds of spatial querying that would be most useful when manipulating species habitat requirements.

Useable Features of ArcIMS

ArcIMS has two features that users will find useful. The first feature, "MapNotes," allow users to comment on our model's predicted potential habitat distributions by posting messages to the site directly on the map images. Other users can access these comments and then respond with a "map note" of their own. The second feature, "MapEdits," allow users to draw points, lines, and polygons on the map images and then submitting them to our site. We can then incorporate these features into our maps should we choose to do so. These web-based features are useful tools for exchanging information and ideas between stakeholders and resource managers. Specifically, they are effective methods for drawing attention to mistakes in our model outputs as well as providing us with additional data we can incorporate into our model.

Website Creation

We considered several basic functions when we created the project website:

1. Project Description
2. Data Availability
3. Model Availability

The structure of the website is centered on the ArcIMS output files of our GIS model. The entry page (http://www.bren.ucsb.edu/msg) consists of a brief introduction of our group and our project. The menu bar is displayed on the top of the web page and consists of the following options buttons:

1. Home
2. CINMS
3. MSG Project
4. Habitat Distribution
5. Miscellaneous
6. Group Members

Each menu button leads to a section of the site dealing with its own unique menu bar located on the left side of the web page. The "Home" section is simply the entry page. The "CINMS" section provides users with a brief history of the Channel Islands National Marine Sanctuary, oceanographic conditions in the Channel, biological characteristics of the Channel, a brief overview of the CINMS objectives, and an overview of the current Management Plan Review Process. The "MSG Project" section of the site summarizes our project. We include images of the datasets used, as well as tables detailing how we created our species list. By posting our abstract, executive summary, as well as brief overviews of the four project phases, users are informed of the manner in which our model was created and utilized. The "Habitat Distribution" section has a menu bar containing a button for each species on our Species of Interest List. When accessing these buttons, users are shown a page containing the habitat requirements of each species as well as links to images of the model outputs and the ArcIMS output files we created for each species. Detailed instructions on how to use the ArcIMS interface are included in this section. The "Miscellaneous" section of the site contains links to pertinent information on the Internet that help users better understand the project. Links to the marine resources websites (including the Sanctuary's site), GIS-related sites, and sites of agencies from which we collected data are included in this section. Additionally, the model input parameters that we used and a printable (PDF) version of our paper are available for download.

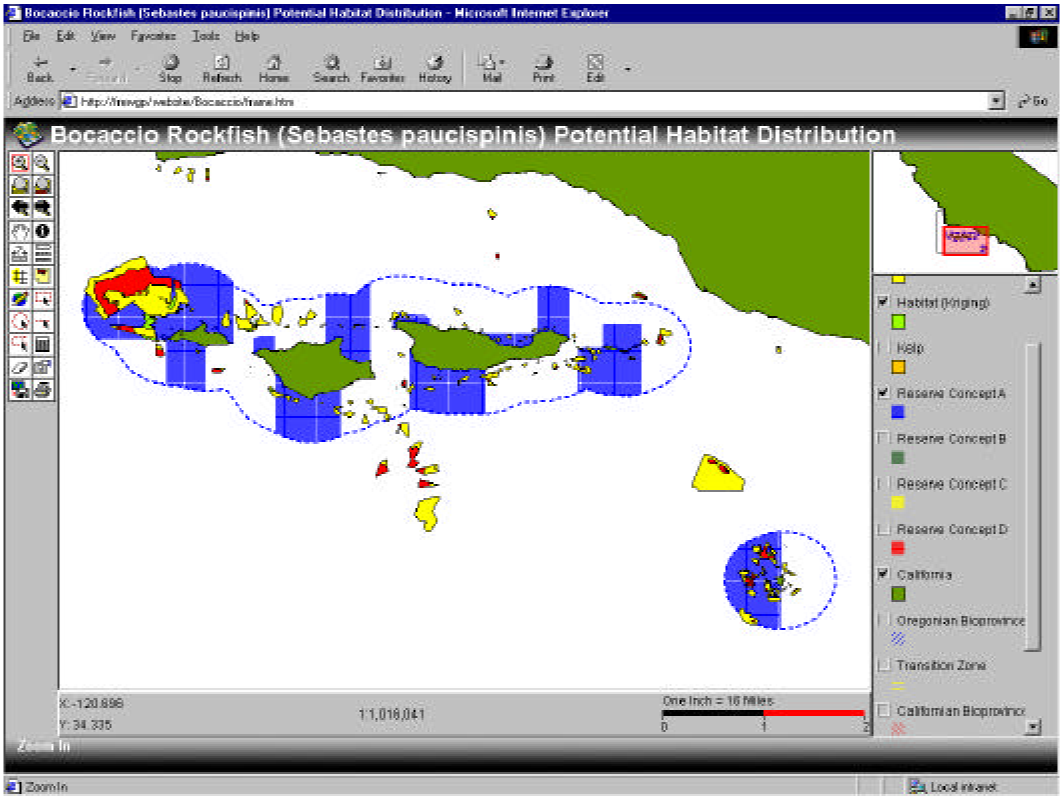


Figure 25. Website ArcIMS interface snapshot

User Testing

Website:
Three students from the Bren School of Environmental Science and Management were asked to participate in testing the website interface: Katie Siegler, Jeremy Gress, and Martin Schulz. They were asked to respond to the following questions:

1. What do you think of the site's functionality (i.e., is it easily navigable, menu bars intuitive, etc.)?
2. Are there sections and/or information you feel we should add to the site in order to increase understanding of the MSG Project and its relation to the CINMS and resource management?
3. In addition to your responses above, are there other ways we can improve the website?

Based on the testers' responses, we replaced the JavaScript main menu bar (on the top of the page) with a more intuitive HTML-based menu bar. All image navigation buttons were replaced with HTML text-based buttons and, with the exception of the "HOME" page, all other pages do not have decorative images that tend to slow page download. Finally, the original color scheme of red and blue was replaced with a more conservative and less obtrusive blue and white scheme. As for site content, the students did not suggest drastic changes to the website.

ArcIMS:

The same three students from the Bren School were asked to test the ArcIMS interface by responding to the following questions:

1. What do you think of the ArcIMS interface's functionality?
2. Are there additional data layers you would like to see to help you better understand the CINMS' natural resources?
3. What kinds of operations would you like to be able to do to the data layers?

The main concern of the three testers is the fact that the functions of several "MapNotes" and "MapEdits" submenu buttons are difficult to understand. In response, we provided more detailed instructions in the "Instructions" page. As for additional data layers, no new ones were requested. However, in a conversation with CINMS Environmental Consultant, Satie Airame, the addition of data layers representing suggested marine reserve areas was discussed as a way to enhance public participation in resource management. By overlaying these reserve area layers over potential habitat distributions, users might better understand which areas would be more effective as "no-take" zones. Two of the three students suggested the addition of multiple data layer querying; however, as mentioned previously, ArcIMS does not support that operation.

Habitat Requirements

Ignoring Biotic Factors:
This model is an attempt to use abiotic factors and kelp to predict potential habitats, thus, it explicitly does not take into account predator/prey relationships. The presence of suitable habitat for any given species may depend on a variety of complex ecological interactions. A species may be constrained by a lack of prey items, competition, or predation. Any of these factors can limit the suitability of a site beyond simple abiotic constraints; however, this model does not take these interactions into account. Thus, the habitat extents identified in this study may be considered the maximum potential range of the species. In reality, potential habitat includes a prime region where reproduction and survival potential are maximized, beyond which habitat quality declines monotonically to the habitat boundary, where survival and reproduction are barely possible. Identification of habitat suitability or quality would require more detailed investigation of the trophic interactions for a given site.

Species Ranges:
The model used in this study is a crude simplification of complex ecological processes. Although exact areas with clear boundaries represent input parameters, it is important to realize that in reality this is not necessarily the case. Habitat requirements for a specific species may vary to some degree from place to place, and should be considered to lie on a continuum. A species may be generally limited to the constraining bounds identified in this study, however the density within those bounds can vary considerably. Individuals of the same species may also exhibit varying habitat preferences to some degree, although this type of analysis cannot capture this level of detail. There has been no attempt to determine species density across the habitat range.

For many species the majority of the individuals can be found near specific depths, however the maximum range extends much farther. Since the maximum depth range was used in this model to determine suitable habitat, in some areas this habitat may represent the extreme limits that the species is willing to tolerate. In reality the depth range for a species can be viewed as a distribution function, with the peak at the prime depth, and tails diminishing in either direction. For some species, where information was available, the prime habitat zone where the species is most commonly observed was also identified.

An additional issue is that the habitat preference for some species varies with its life history. This study only addressed potential habitat for adult individuals, however both the depth and substrate preference can vary over the life of an individual.

Model Inputs

The habitat model we developed used as parameters depth, substrate, wave exposure, SST, and a nine-year composite of kelp distribution in the Santa Barbara Channel. After testing the potential habitat model, it was evident that the data parameters of depth and substrate were the primary determining factors in the distribution of potential habitat. The depth range of a species delineates the maximum extent of a species' potential habitat, while substrate data refines the potential habitat within a specified depth range. The input of these two datasets created the foundation of the potential habitat model.

Of the 15 selected species, only the California Spiny Lobster, the Squid, and the Southern Sea Otter required the input parameter of wave exposure. The Quillback was the only selected species restricted to the Oregonian Bio-region, thus requiring the input of the SST data. The kelp composite provided by the CINMS was used as a biotic input for the Red and Purple Sea Urchins, Copper, Cowcod, Quillback, and Bocaccio Rockfish, the Southern Sea Otter, the Giant Sea Bass and the Sheephead. The potential habitat distribution of the remaining selected species (Black Abalone, White Abalone, California Halibut, Giant Kelp) relied entirely on the substrate and depth datasets.

Input Data Limitations

Datasets may be restricted by the manner in which the data was created, collected, and/or converted into inputs for our model. Additionally, the number of data points in the set may affect the GIS model output. Below are more detailed descriptions of each dataset's limitations.

Substrate Data:
The main limitations of the substrate dataset are the number of points it contains and the spatial distribution of these points. Seafloor is highly variable in the Channel. In some regions, it is known to change every couple of meters (Luyendyk, personal communication). Because substrate types vary greatly in a given area, numerous data points are needed to make interpolation techniques as accurate as possible. Additionally, most of the data points were sampled close to shore. This near-shore bias makes the interpolation of substrate types less accurate with increasing distance from the shore. A qualitative analysis of Figure 3 (substrate snapshot) shows the

biased spatial distribution of data points, as well as highlighting under-sampling in far-shore regions.

Substrate is dynamic and changes with time as a result of erosion processes as well as deposition and transport mechanisms. The substrate dataset contains points taken from 1967 to 2000 (not continuously); therefore, some of these points may no longer be valid. Physical processes may have replaced one substrate type with another (i.e., from sandy to rocky substrate).

Sea Temperature Data:
The sea surface temperature dataset is a static and composite representation of sea surface temperatures in the Santa Barbara Channel. It cannot illustrate the shifting temperature boundaries as well as the changes in temperature over time. Additionally, temperature regimes with temporal resolutions of less than one year cannot be described by the dataset. This means that any seasonal variations in temperature that affect the Channel and, the distribution of temperature-dependent organisms cannot be incorporated into our GIS model. All of the data inputs are static maps, thus no temporal variability is included in this analysis

Wave Exposure Data:
The assumptions used to derive wave exposure are not entirely accurate. For instance, at a depth of ½ the wavelength of a wave, a wave only begins to affect the ocean floor. This does not necessarily mean it will have adverse effects on organisms that are sensitive to physical perturbations. A true measure of high wave exposure would be the point at which the wave actually breaks. Given the data available to us as well as the tools at our disposal, it was not possible to determine the exact point at which wave breaking occurs. Thus, only a coarse estimate of the depth (the chosen 40-meter depth) can be obtained from the given data. Additionally, since the average significant heights were used to derive the data, above average waves were not considered. Similarly, since average directions were used, waves originating from other directions were not considered. Another limitation is the possible errors created during the manual digitization of the data: the 40-meter depth line may not completely coincide with the outermost limit of high wave exposure areas.

Test Data Limitations

The testing of the habitat model's output was limited by the observation data available. The datasets acquired for testing consisted of a nine-year Giant Kelp composite (1980 – 1989) provided by the CINMS and transect data from the CINP. The only species tested were Giant Kelp, White Abalone, Red Sea Urchin, Black Sea Urchin, the California Spiny Lobster, and the Sheephead.

The distribution of Giant Kelp is highly temporal. Consumption or climatic events such as El Niño can adversely impact the distribution of Giant Kelp. The model's Giant Kelp potential habitat distribution performed poorly in capturing the areas of Giant Kelp habitat identified by the nine-year composite. This can be attributed to the inadequate sampling of rocky substrate in the Santa Barbara Channel. What the composite does show is areas of habitat that existed between 1980 and 1989 that may or may not exist today. These areas could be considered potential habitat that should have been captured by the model.

The presence/absence data provided by the CINP is limited to the transect locations around the Channel Islands. The sixteen transects are restricted to areas that CINP personnel can dive, usually no deeper than 30 meters. Also, the location of the transect observations were determined with a GPS to a relative accuracy of 100 meters (Waltenberger, personal communication). For a majority of the species tested, a 100-meter buffer around each observation would significantly increase the model's predictive power. Testing was further restricted to the CINMS since no presence/absence data was available for areas outside the sanctuary.

Model Limitations

Thiessen:

The substrate shapefiles produced from the Thiessen method are of poor relative accuracy since the distance between the substrate samples was not consistent throughout the dataset. The biggest disparity in distance can be viewed between the substrate samples in and out of the CINMS. Within the sanctuary, substrate sampling is more uniform. Outside the CINMS, no consistent pattern could be observed. In addition, the distance between the core of the substrate sampling in and out of the sanctuary is relatively high. This became apparent when the rocky substrate shapefile was produced utilizing the Thiessen method. A noticeably large rocky substrate area was identified off the northwestern coast of San Miguel. The reason for such a large rocky area can be attributed to the fact that the closest rock sample was 12,000 meters away. Similar results were produced for rocky substrate off the northwestern coast of Santa Rosa Island and the shores of Purisima Point. Thus, the potential habitat distributions produced using rocky substrate will be exaggerated. In contrast, limited rocky substrate was captured off the coasts of Santa Cruz and Anacapa islands. Therefore, the potential habitat distributions produced using rocky substrate will show no suitable habitat in those areas.

The size and shape of the resulting polygons depends on the sample point layout. Awkward shaped polygons will result from a skewed sampling protocol. This was very apparent in some of the potential habitat distributions produced. For species that required a substrate type of rock, peculiar shaped potential habitat distributions were produced off the northwestern coast of San Miguel island and off the shores of Purisima Point.

The Thiessen method applied for interpolating substrate types is highly dependent upon the substrate samples. The Thiessen method is very limited in representing gradual change in substrate. The 5992 substrate samples may be insufficient to capture the variability of substrate within the Santa Barbara Channel. To accurately delineate areas of rock, sand, mud, shells, or gravel substrate, the substrate sampling should be focused in regions where substrate variability is the highest. Applying the Thiessen method to a larger, more focused substrate sample dataset would produce better results.

Kriging:
The effectiveness of kriging interpolation also relies greatly on the spatial distribution of the data. A major assumption in kriging is that points close together will be more similar than points that are far apart. Kriging depends on this concept in order to generate a model of spatial variability over distance. Unfortunately, not all of the substrate types seemed to follow this pattern very well. For some types such as mud and sand, many samples were available, and a clear proximity correlation was visible. This smooth increase in variability can be seen in the mud and sand semi-variograms in Appendix H. Far from shore there seem to be vast areas of continuous mud and sand, so unknown points near these areas can be expected to also contain mud or sand. However, near shore there appears to be considerably more spatial variability in the substrate types. Rocky areas seem to exist in small reefs, often surrounded by other substrate types. Also, there were much fewer sample points for rocky substrates, making the patterns even harder to identify. The wide range of variability over distance for rocky areas is apparent in the semi-variogram plots found in Appendix H. It is clear from these plots that in some cases the model does not closely match the visible distribution of the data.

Error Propagation

The error in each dataset in the GIS habitat model gives rise to further errors when the datasets are combined, transformed, or analyzed. When maps that are stored in a GIS database are used as input to a GIS operation, the errors in the input will propagate to the output of the operation. Moreover, the error propagation continues when the output from one operation is used as input to an ensuing operation (Heuvelink, 1998). This propagation of error can lead to uncertainty in the validity of the conclusions that are drawn.

The input data sets with the most significant error are bathymetry and substrate. These datasets form the foundation of the GIS habitat model we used to create species potential habitat distributions. Thus, the errors inherent in these datasets propagate to the final potential habitat map. The bathymetry data has a 60-meter resolution and a vertical precision of 0.75 to 10 meters. The sampled substrate points were located using Loran, a radio navigation system used by a ship or aircraft to determine geographical location, with a positional accuracy of 50 meters, as well as GPS (Waltenberger, personal communication). When the two datasets are combined, the artifacts in uncertainty will alter the positional accuracy of the distribution of species' potential habitat.

By including the GIS database error into the habitat model, one can attempt to quantify the effect error propagation would have on potential habitat distributions produced. The ability to determine how much each individual input contributes to the output error is extremely valuable. It allows users to explore how much the quality of the output improves, given a reduction of error in a particular input (Heuvelink, 1998).

To analyze the propagation of errors in our GIS habitat model, a potential habitat map was produced by including the error inherent in each data set to the abiotic habitat requirements of a particular species. The species chosen for this test was the White Abalone because of its considerable dependence on depth and substrate type in determining its potential habitat.

Thiessen Method:

The maximum potential habitat distribution for the White Abalone was produced with a depth range of 20 to 60 meters and a rocky substrate type. By incorporating the error of the two datasets in these abiotic parameters, the maximum potential habitat distribution would be enlarged to a depth range of 10 to 70 meters, with a 50 meter buffer encircling areas identified as rocky substrate.

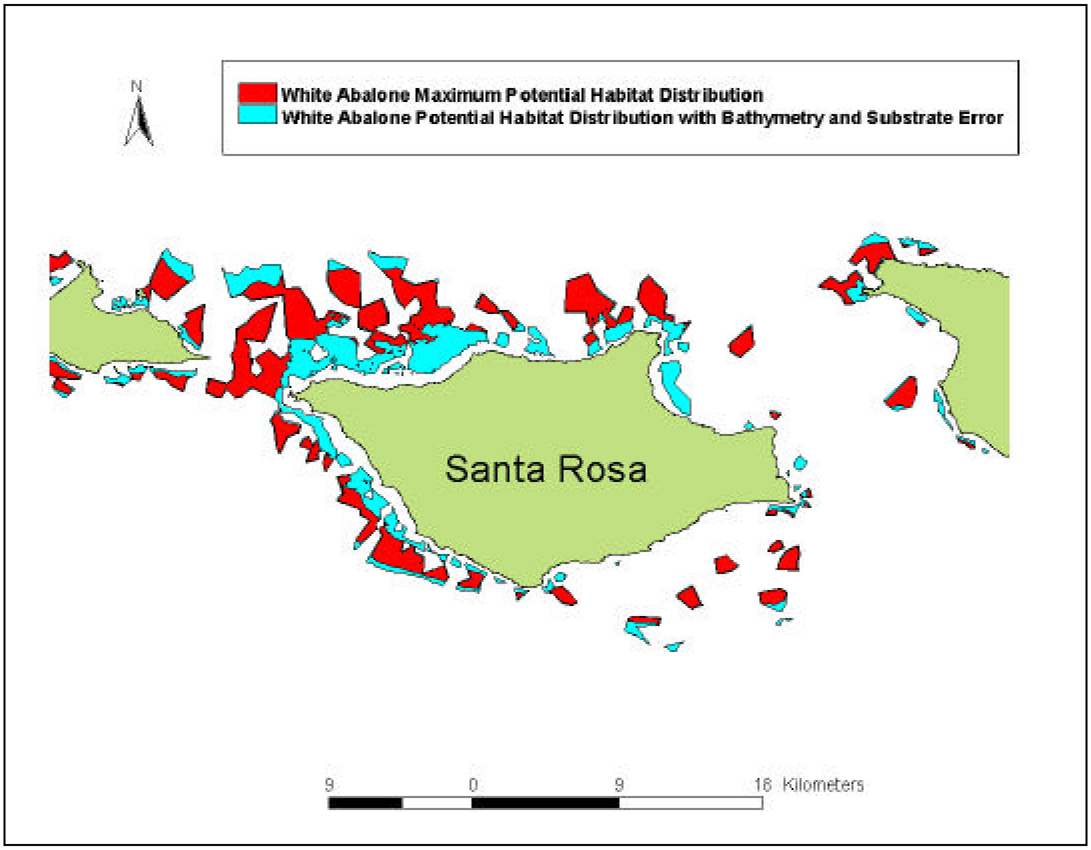


Figure 26. Illustration of model output with database error

Figure 26 shows the extent of the disparity between the White Abalone potential habitat distribution and the habitat distribution produced by including the GIS database error. Upon analysis, the 50-meter buffer created around areas identified as rocky substrate did not significantly increase the size of the distribution. However, the 20 meters added to the bounding depth range did notably augment the areas identified as maximum White Abalone potential habitat. This test shows that the intrinsic error in the bathymetry play a prominent role in the output error produced by the model. Knowing this, one can state that the areas of potential habitat are located within the extent produced by incorporating dataset error into the model, (with the caveat that the locational accuracy of potential habitat areas cannot be determined.)

Kriging Method:
The kriging methods employed in this study were used to provide a best estimate of the substrate at unknown points. However, there was a 50-meter horizontal margin of error in the samples that were used. Although not employed here, there are techniques that can account for this error. One method would be to randomly move each sample point from 0 to 50 meters in any direction, and re-run the kriging. This would then be repeated several times, each time counting the substrate type with the highest probability at each cell. The number of times that the same substrate is

predicted can be compared to a threshold value. Cells that predict the same substrate less than the threshold can be considered susceptible to sampling error. Likewise, cells that predict the same substrate in nearly every run are not susceptible to sampling error.

Conclusions

Species Information

Since this habitat model is based solely on abiotic habitat constraints, proper identification of these limits is essential to effective habitat prediction. Unfortunately, in some cases only limited information exists on these constraints:

1. For many species exact temperature limitations are unknown, and only vague regional distributions of the species are available. Temperature restrictions had to be inferred from these general distributions to determine if the species would be limited within the study area.
2. The impact of wave exposure was also difficult to identify. For many species the influence of high wave exposure on habitat potential has not been clearly identified, and also had to be inferred from available literature.
3. The model could also be improved to more accurately represent depth ranges if better information were available. For most species only the maximum and minimum depth range is known. However, if data existed on how species density varies with depth, this information could be incorporated into the model. This function, which would decrease from the prime habitat zone to the maximum and minimum depths, could be used to generate a more accurate probability model.

Habitat Classification

In the face of ever increasing pressure on natural resources, both adjacent to and inside sanctuary waters, scientists and managers need tools that help predict the likely consequences on valuable marine resources. It would be ideal to have two different systems of habitat characterization for the CINMS: a scheme/classification based on generalized habitat information, and a modeling system capable of constructing and spatially identifying habitat types. The habitat classification will be a hierarchical scheme that has generalized habitat into "types." The habitat model will be able to accept continuous environmental data and redefine habitat boundaries accordingly. Both systems are intrinsically linked. The habitat modeling system will redefine the habitat classification scheme over time and as environmental conditions change. The habitat classification system generalizes the habitat model for use in management and conservation purposes, where concerned parties do not require the same level of detailed information.

For the purposes of the CINMS, a habitat classification scheme coupled with a habitat model will serve their management and educational needs. By using the EFH classification scheme, the general public will have no problem identifying critical marine habitats. The scheme is simple to understand since it is based on a few abiotic parameters (substrate, depth, SST, and wave exposure). It is relatively straightforward, and does not require a key or an extensive ecology background to understand the classification nomenclature, unlike that of other cumbersome classification schemes (e.g. Marine-Offshore-Pelagic-Mesopelagic-Aphotic).

GIS Model

An overall assessment of the performance of the GIS habitat model was based on how well the potential habitat distributions produced from the Thiessen or Kriging substrate interpolation methods captured the test data. The testing phase of the project revealed that the model's performance varied spatially.

Thiessen Method:
When using the Thiessen method, the model performed well where the substrate sampling captured the variable nature of marine sediment in the Santa Barbara Channel. Specifically, where rocky substrate was sampled since this is the substrate preference for the majority of the species of interest. The coasts of San Miguel, Santa Rosa, and Santa Barbara islands performed well in all of the species tests. However, since the distance between the core of the substrate sampling in and out of the CINMS was quite large, the habitat model tended to over-predict the potential habitat distributions in those areas. The islands of Santa Cruz and Anacapa Islands performed much worse. The Thiessen method failed to capture the substrate variability due to the inadequate substrate sampling in those areas. Hence, the potential habitat distributions around Santa Cruz and Anacapa islands were severely under-predicted. Along the mainland coast, the model's performance varied. North of Point Conception where rocky substrate was sampled well, the model tended to over-predict the distribution of potential habitat, while south of Point Conception, potential habitat distributions were severely under-predicted.

The performance of the habitat model utilizing the Thiessen method of substrate interpolation would greatly improve with a sophisticated substrate sampling protocol capable of capturing the variability of marine sediment in the Santa Barbara Channel.

Kriging Method:
The kriging interpolation also suffered from similar problems in the testing phase. For any given substrate type, the probability depends on both the homogeneity of the substrate, as well as the proximity to known points. Unfortunately, the substrate coverage had problems in both of these areas. At some locations there was a large distance between sample points, which reduced the confidence, and thus probability for unknown points. Also, in some areas the sample points were highly variable in substrate type, which also acted to reduce the probability of finding any one substrate at an unknown point. These substrate issues resulted in relatively low probabilities

overall. Thus, although all of the test points fell within the general model bounds based on depth, temperature, and wave exposure, many of them received low probabilities due to the substrate interpolation. The best results occurred in areas where the model was able to effectively capture rocky reefs, such as the coasts of San Miguel, Santa Rosa, Santa Barbara islands, as well as north of Point Conception.

Input Data

Sampling and mapping in the Earth sciences are complicated by complex spatial and temporal variations. The patterns of phenomena being sampled often cannot be determined or predicted reliably with deterministic models because of data limitations and uncertainties in both the input data and the phenomena under investigation. Given the limitations of our datasets, it is evident that higher quality data is needed to predict species habitat distribution more accurately. The under-sampling of substrate types in the Santa Barbara Channel is the most influential limiting parameter in our model. A more complete and finer spatial resolution dataset, perhaps incorporating temporal dependencies, will greatly improve the accuracy of the model outputs. Similarly, sea temperature data with finer temporal resolution would enable the model to address shifting temperature-dependent biological provinces.

Additional input parameters would make the model more robust. Biotic inputs such as the location of a species' food sources or the presence of predators would have an effect on the distribution of habitats. A more robust model would incorporate both biotic and abiotic factors to predict habitat distribution.

Information Dissemination

The efficacy of the Internet-based model as a tool for information dissemination had not been fully explored. We were unable to establish a method for quantifying the stakeholders as well as the number of stakeholders who would use the website primarily because of the short duration of the project. Additionally, we did not make the model available to the general public at the time we finished writing this report. Given additional time, we may have been able to create a system for tracking the number of visits to the web model and a login survey that could give us more information on the types and number of people visiting the site, as well as other data concerning how helpful they thought the site was as a source of information. Fortunately, the CINMS will be appropriating the results of this project and implementing it in their website. With their resources, they will be able to further analyze the efficacy of this project.

A First Step

Although the model is limited, it is limited primarily by the quality of the input data rather than the way the datasets are incorporated. More sampling of substrate in the Santa Barbara Channel, particularly nearshore where it is under-sampled, can drastically improve accuracy of the model outputs. Recent work being developed by the U.S. Geological Survey in the use of side-scan sonar for substrate analysis may be applicable to this project and should be considered when refining this model. Besides better sampling, the addition of a temporal component to any of our input parameters would improve the model's efficacy. We are limited by the static datasets available to us given the time constraints and the scope of our project; however, the addition of a temporal component to our model is a logical next step that the CINMS should consider once they appropriate this project.

As a method for illustrating biological dependencies on abiotic factors, the GIS model's strength lies in its ability to incorporate better datasets or more input parameters in order to make the predictions more robust. As technology evolves, more information will be available and easily adapted to suit this model—for instance, abiotic parameters that further delineate species habitats. As the model's predictions become more accurate, its usefulness to resource managers, stakeholders, and the public as a tool for identifying areas for conservation, preservation, and use will grow.

Appendix

Appendix A: Santa Barbara Channel Bathymetry and Topology Metadata

Metadata Data Set Name:
Santa Barbara Channel Bathymetry and Topography
1 Identification Information
1.1 Citation:
8 Citation Information:
8.2 Publication Date:
19981008
8.4 Title:
Bathymetry & Topography of the Santa Barbara Channel Area
8.5 Edition:
Version 1
8.6 Geospatial Data Presentation Form:
Model
8.8.1 Publication Place:
Santa Barbara, CA
8.8.2 Publisher:
University of Calif. Santa Barbara Dept. of Geography
8.9 Other Citation Details:
Mertes, L.A.K., et al. 1996,1998. Waltenberger, B. et al. 1996. Waltenberger, B. 1998.
1.2 Description
1.2.1 Abstract:
An integrated coverage of bathymetry and topography was created from 1994 USGS Digital Line Graphs (DLGs) and NOAA GEODAS bathymetry points. Bathymetry points were pulled from the GEODAS data and run through an AWK program to attach NOAA survey number information and thus a link to the GEODAS metadata. Topography and bathymetry covers were merged into a single dataset by building a TIN model hardsurfaced to the USGS mean high tide line.
1.2.2 Purpose:
To create a single bathymetry and topography coverage of the area from the California Channel Islands to the mainland for the enhancment of coastal process analyses.
1.2.3 Supplemental Information:
Used as a base coverage for a range of analyses

ranging from sediment influx into the marine environment to correlating migration patterns of marine mammals.

1.3 Time Period Of Content
  9.3 Range of Dates/Times
    9.3.1 Beginning Date:
      19340423
    9.3.3 Ending Date:
      19970827
  1.3.1 Currentness Reference:
      Ground Condition
1.4 Status
  1.4.1 Progress:
      In Work
  1.4.2 Maintenance and Update Frequency:
      As Needed
1.5 Spacial Domain
  1.5.1 Bounding Coordinates
    1.5.1.1 West Bounding Coordinate:
      -120.94
    1.5.1.2 East Bounding Coordinate:
      -118.84
    1.5.1.3 North Bounding Coordinate:
      35.506
    1.5.1.4 South Bounding Coordinate:
      33.369
1.6 Keywords
  1.6.1 Theme
    1.6.1.1 Theme Keyword Thesaurus:
      Physical Parameters
  1.6.2 Place
    1.6.2.1 Place Keyword Thesaurus:
      Channel Islands
      1.6.2.2 Place Keyword:
        California
      1.6.2.2 Place Keyword:
        Channel
      1.6.2.2 Place Keyword:
        Bight
      1.6.2.2 Place Keyword:
        Islands
1.8 Use Constraints:
      Not for Navigation
1.9 Point of Contact

10.1 Contact Person Primary
  10.1.1 Contact Person:
    Leal Mertes
  10.1.2 Contact Organization:
    University of Calif. Santa Barbara, Dept. of Geography
10.4 Contact Address
  10.4.1 Address Type:
    Mailing and Physical Address
  10.4.2 Address:
    Dept. of Geography
  10.4.2 Address:
    Ellison Hall
  10.4.3 City:
    Santa Barbara
  10.4.4 State or Province:
    California
  10.4.5 Postal Code:
    93106
  10.4.6 Country:
    USA
10.5 Contact Voice Telephone:
    (805) 893-7017
10.7 Contact Facsimile Telephone:
    (805) 893-3146
10.8 Contact Electronic Mail Address:
    leal@geog.ucsb.edu
1.11 Data Set Credit:
    UCSB Department of Geography
1.13 Native Data Set Environment:
    UNIX-ARC/INFO
2 Data Quality Information
  2.1 Attribute Accuracy
    2.1.1 Attribute Accuracy Report:
      The attribute accuracy of this model is tested by comparing the grid cell values to known point values collected via NOAA hydrographic surveys.
  2.2 Logical Consistency Report:
      All surface interpolations were based on hardsurfacing the bathymetry and topography to USGS Mean High Tide polygons with a zero Z value.
  2.4 Positional Accuracy
    2.4.1 Horizontal Positional Accuracy
      2.4.1.1 Horizontal Positional Accuracy Report:

THe horizontal positional accuracy is tested by comparison with existing data sets that cover the same area.

2.5.1 Source Information

2.5.1.1 Source Citation:

8.1 Originator:

UCSB Dept. of Geography

8.1 Originator:

NOAA National Ocean Service

8.2 Publication Date:

19960000

8.4 Title:

Geophysical Data System for Hydrographic Survey Data

8.5 Edition:

3.3

8.6 Geospatial Data Presentation Form:

Database

8.8.1 Publication Place:

National Geophysical Data Center

8.8.2 Publisher:

NOAA

2.5.3.3 Type Of Source Media:

CD-ROM

2.5.1.4 Source Time Period Of Content:

9.3 Range of Dates/Times

9.3.1 Beginning Date:

19340423

9.3.3 Ending Date:

19970827

2.5.1.4.1 Source Currentness Reference:

Ground Condition

2.5.1.6 Source Contribution:

Points were downloaded, processed, and integrated into the model.

2.5.2 Process Step

2.5.2.1 Process Description:

Bathymetric data within the study extent were downloaded from the GEODAS CD, and processed in AWK to attach GEODAS survey IDs to each point. These data were then merged with USGS DLG data and converted into a single TIN coverage with all points hardsurfaced to a Z=0 line based on the USGS Mean High Tide data.

2.5.2.3 Process Date:
    Not Complete
2.5.2.6 Process Contact
  10 Contact Information
    10.1 Contact Person Primary
      10.1.1 Contact Person:
        Ben Waltenberger
      10.1.2 Contact Organization:
        NOAA, Channel Islands National Marine Sanctuary
    10.2 Contact Organization Primary
      10.1.2 Contact Organization:
        NOAA, Channel Islands National Marine Sanctuary
    10.3 Contact Position:
        Physical Scientist
    10.4 Contact Address
      10.4.1 Address Type:
        Mailing and Physical Address
      10.4.2 Address:
        113 Harbor Way, #150
      10.4.3 City:
        Santa Barbara
      10.4.4 State or Province:
        California
      10.4.5 Postal Code:
        93109
      10.4.6 Country:
        USA
    10.5 Contact Voice Telephone:
        (805) 966-7107
    10.6 Contact TDD/TTY Telephone:
        Unavailable
    10.7 Contact Facsimile Telephone:
        (805) 568-1582
    10.8 Contact Electronic Mail Address:
        ben.waltenberger@noaa.gov

3 Spatial Data Organization Information
  3.1 Indirect Spatial Reference:
        Raster, 60 meter grid cells.
  3.2 Direct Spatial Reference Method:
        Point
  3.4 Raster Object Information
    3.4.1 Raster Object Type:
        Grid Cell
    3.4.2 Row Count:

3940
3.4.3 Column Count:
3171
4 Spatial Reference Information
4.1 Horizontal Coordinate System Definition
4.1.2 Planar
4.1.2.1 Map Projection
4.1.2.1.1 Map Projection Name:
Albers Conical Equal Area
4.1.2.1.2.1 Standard Parallel:
34
4.1.2.1.2.1 Standard Parallel:
40.5
4.1.2.1.2.2 Longitude Of Central Meridian:
-120
4.1.2.1.2.3 Latitude Of Projection Origin:
0
4.1.2.1.2.5 False Northing:
-4000000
4.1 Horizontal Coordinate System Definition
4.1.3 Local
4.1.3.1 Local Description:
Albers Equal Area California
4.1.4 Geodetic Model
4.1.4.1 Horizontal Datum Name:
North American Datum of 1983
4.1.4.2 Ellipsoid Name:
Geodedic Reference System 80
4.2.2.1 Depth Datum Name:
Mean High Water
4.2.2.3 Depth Distance Units:
Meters
4.2.2.4 Depth Encoding Method:
Explicit Depth Coordinate Included With Horizontal Coordinates
5 Entity and Attribute Information
6 Distribution Information
6.1 Distributor
10.1 Contact Person Primary
10.1.1 Contact Person:
Ben Waltenberger
10.1.2 Contact Organization:
NOAA / Channel Islands NMS
10.4 Contact Address

10.4.1 Address Type:
Mailing and Physical Address
10.4.2 Address:
113 Harbor Way #150
10.4.2 Address:
Ellison Hall
10.4.3 City:
Santa Barbara
10.4.4 State or Province:
California
10.4.5 Postal Code:
93109
10.4.6 Country:
USA
10.5 Contact Voice Telephone:
(805) 966-7107
10.7 Contact Facsimile Telephone:
(805) 568-1582
10.8 Contact Electronic Mail Address:
ben.waltenberger@noaa.gov
6.3 Distribution Liability:

Although these data have been processed successfully on a computer system at the U.C. Santa Barbara Dept. of Geography, no warranty expressed or implied is made regarding the accuracy or utility of the data on any other system or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. This disclaimer applies both to individual use of the data and aggregate use with other data. These data are NOT for navigational use. It is strongly recommended that these data are directly acquired from U.C. Santa Barbara Dept of Geography or NOAA, Channel Islands National Marine Sanctuary; and not indirectly through other sources which may have changed the data in some way. It is also strongly recommended that careful attention be paid to the contents of the metadata file associated with these data. Neither University of California nor NOAA shall be held liable for improper or incorrect use of the data described and/or contained herein.

7 Metadata Reference Information
7.1 Metadata Date:

19981007
7.2 Metadata Review Date:
19990102
7.4 Metadata Contact:
10.1 Contact Person Primary
10.1.1 Contact Person:
Ben Waltenberger
10.1.2 Contact Organization:
NOAA, Channel Islands National Marine Sanctuary
10.2 Contact Organization Primary
10.1.2 Contact Organization:
NOAA, Channel Islands National Marine Sanctuary
10.3 Contact Position:
Physical Scientist
10.4 Contact Address
10.4.1 Address Type:
Mailing and Physical Address
10.4.2 Address:
113 Harbor Way, #150
10.4.3 City:
Santa Barbara
10.4.4 State or Province:
California
10.4.5 Postal Code:
93109
10.4.6 Country:
USA
10.5 Contact Voice Telephone:
(805) 966-7107
10.6 Contact TDD/TTY Telephone:
Unavailable
10.7 Contact Facsimile Telephone:
(805) 568-1582
10.8 Contact Electronic Mail Address:
ben.waltenberger@noaa.gov
7.5 Metadata Standard Name:
FGDC Content Standards For Digital Geospatial Metadata
7.6 Metadata Standard Version:
June 8, 1994
7.7 Metadata Time Convention:
Universal Time

Appendix B: Substrate Shapefile Metadata

Channel Islands National Marine Sanctuary
Metadata Descriptions

Sediments

1. sediments_ccp_dd

Coverage: Point data that describe the sediment type from grab samples of the sea floor around the Channel Islands region.

Type if Data: Point

Date: 1967

Source:
Continental Shelf Data Systems
Division of Doeringsfeld
Almuedo and Ivey, Engineers
Denver, Colorado

Contact:
Cory Gallipeau
805-687-2073
Conception Coast Project
32 W Anapamu Street 331
Santa Barbara, CA 93101
805-687-2073

Digitized by the Conception Coast Project.
Projection: Decimal Degrees

Appendix C: Substrate Text File Metadata

Channel Islands National Marine Sanctuary
Metadata Descriptions

2. More Substrate

Coverage:
Soft Sediments (mud, sand, gravel) from grab samples around the Channel Islands. Sources of grab samples vary. The data was comsolidated by the USGS.

Type of Data: Point

Date: 2000

Source:
United States Geological Survey
Coastal Marine Geology Team
345 Middlefield Road, MS 999
Menlo Park, CA 94025

Contact:
Halimeda Kilbourne
Kkilbourne@usgs.gov
United States Geological Survey
Coastal Marine Geology Team
345 Middlefield Road, MS 999
Menlo Park, CA 94025
650-329-5482

Appendix D: Giant Kelp Composite Metadata

Channel Islands National Marine Sanctuary
Metadata Descriptions

1. kelp_ccp_dd

Coverage:
Kelp forest canopy around the Northern Channel Islands and Santa Barbara Island. Total coverage represents the composite or maximum distribution for kelp between 1980-1989. One layer represents the kelp canopy in 1989.

Type of Data: Polygon

Date: 1980-1989

Source:
Ecoscan Resource Data
PO Box 1046
Freedom, CA 95019
408-728-3285

Contact:
Dale Gantz
dgantz@ispcorp.com
2145 Belt Street
San Diego, CA 92113
619-595-5194

Digitized by the Conception Coast Project.
Projection: Decimal Degrees.

Appendix E: Methodology for Creating Potential Habitat Shapefiles in ArcView

Methodology for Creating Potential Habitat Shapefiles in ArcView

Preparing the Bathymetry Layer

1. Have the Bathymerty grid loaded displayed in ArcView.
2. Query the Bathymetry grid for the depth range a specie inhabits using the MAP QUERY tool (i.e. Baththymetry > -40).
3. Convert the grid produced from the query into a shapefile using the CONVERT TO SHAPEFILE operation.
4. Query the converted shapefile using the QUERY BUILDER Tool (i.e. shapefile.gridvalue = 1).
5. Convert the highlighted features into a shapefile using the CONVERT TO SHAPEFILE operation.

Preparing the Substrate Layer

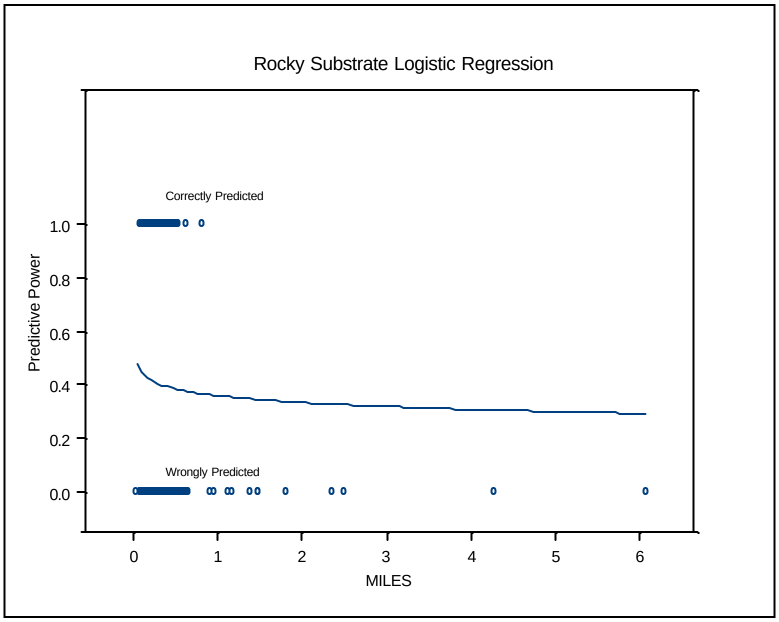
1. Have the Substrate Thiessen grid displayed in ArcView.
2. Query the Substrate Thiessen grid for the specific substrate(s) a specie inhabits using the QUERY BUILDER Tool (i.e. substrate = rock).
3. Convert the highlighted featured into a shapefile using the CONVERT TO SHAPEFILE operation.

Clipping the Bathymetry and Substrate Layers

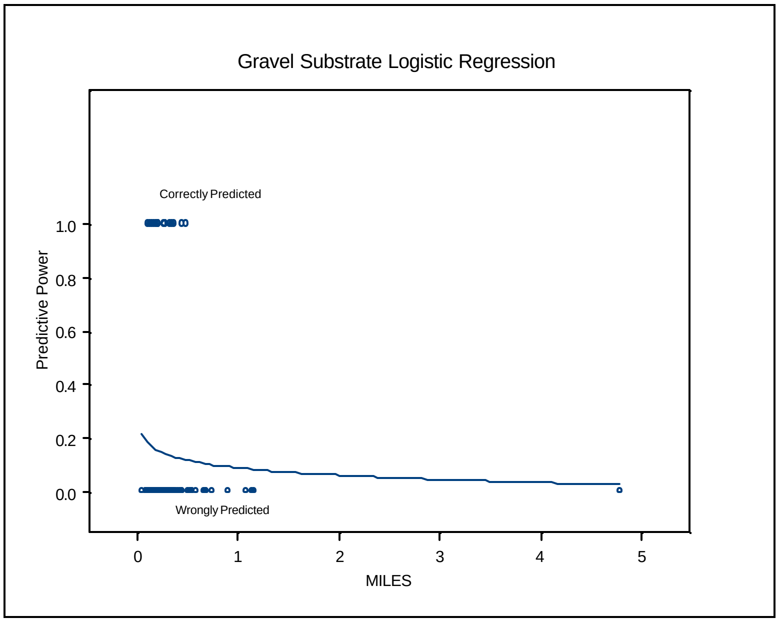
1. Highlight the Bathymetry and the substrate shapefiles.
2. Use the Clipping Theme ArcView Extension (Girard, 1998), select the CLIP THEME INSIDE tool.
3. Select the Substrate shapefile as the dataset to be clipped.
4. The substrate type within the specific depth range is now visible as a shapefile.

Appendix F: Logistical Regressions for Confidence Surface

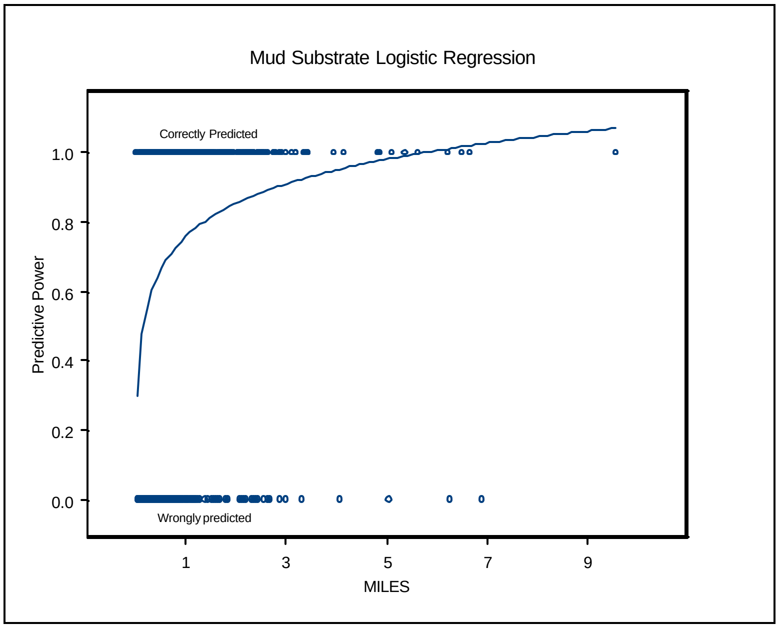
Logistic regressions: testing correlation between distance and predictive power of substrate data.



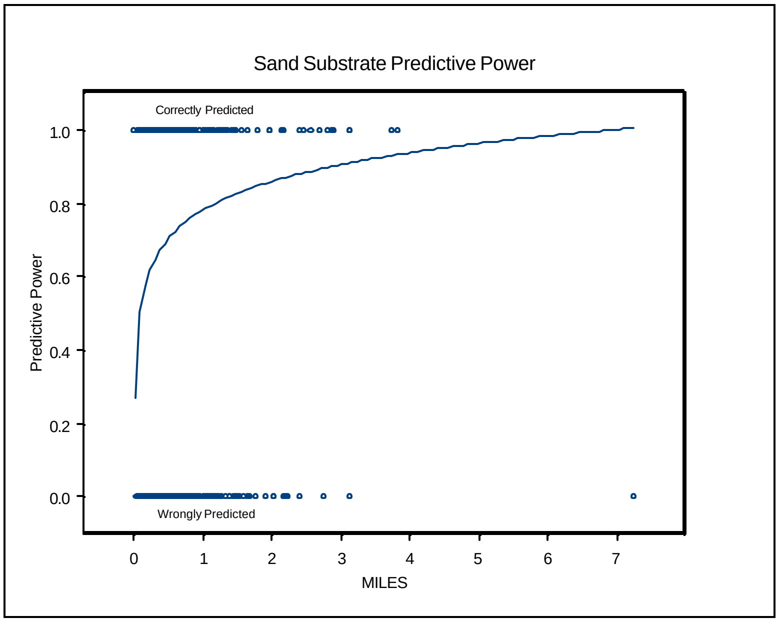
This graph shows low predictive power at a short distance for rocky substrate



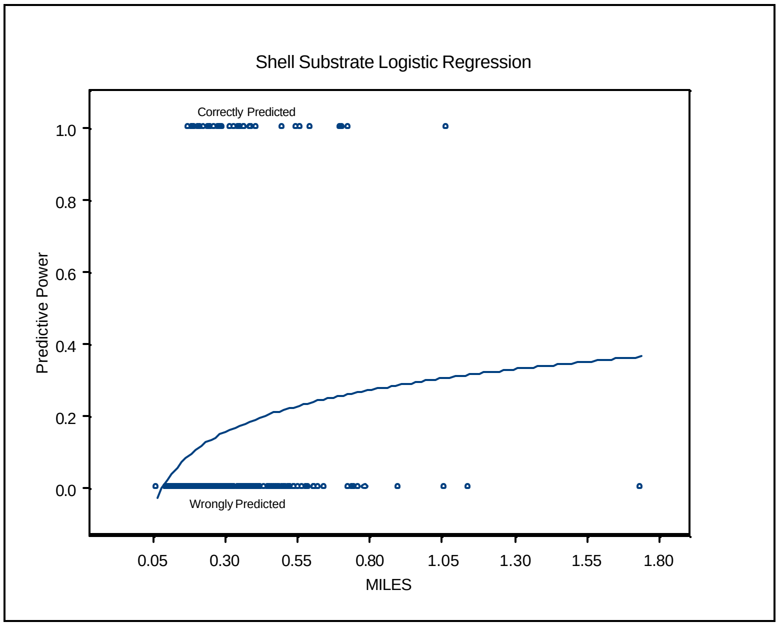
This graph shows low predictive power at a short distance for gravel substrate



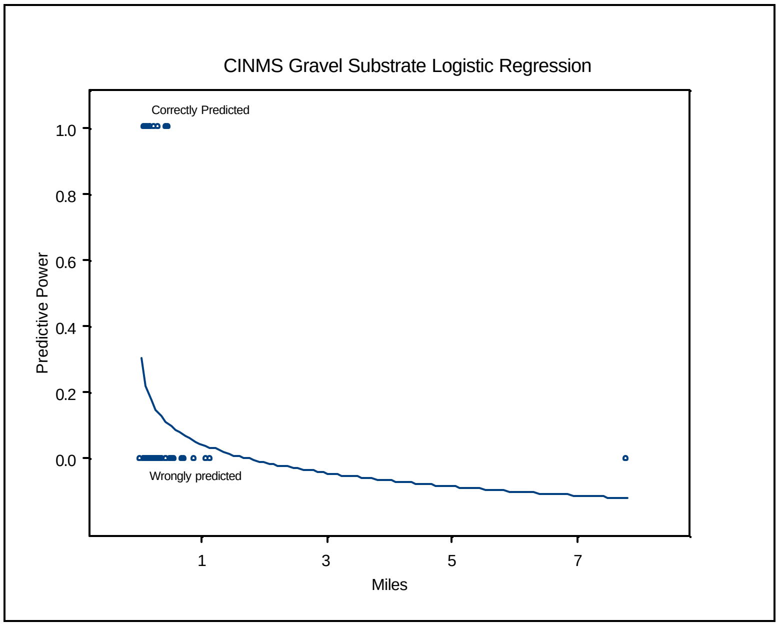
This graph shows high predictive power at a far distance for mud substrate



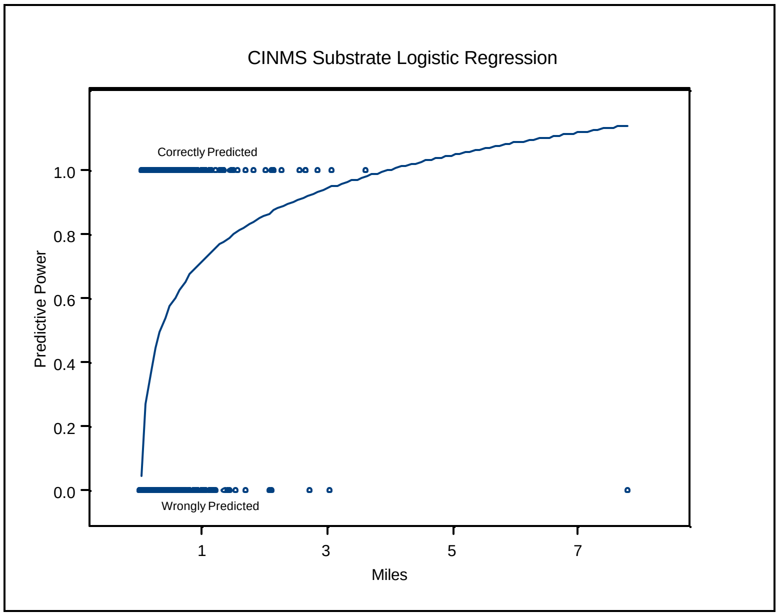
This graph shows high predictive power at a far distance for sand substrate



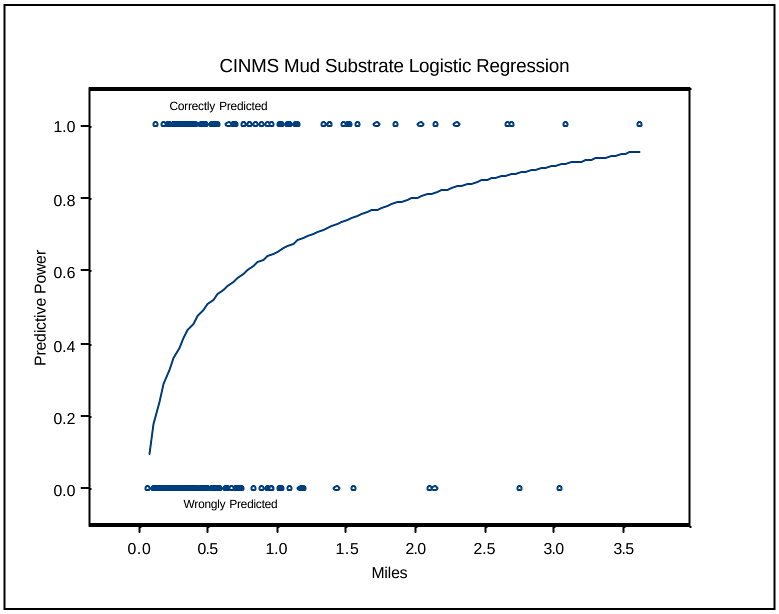
This graph shows low predictive power at a short distance for shell substrate



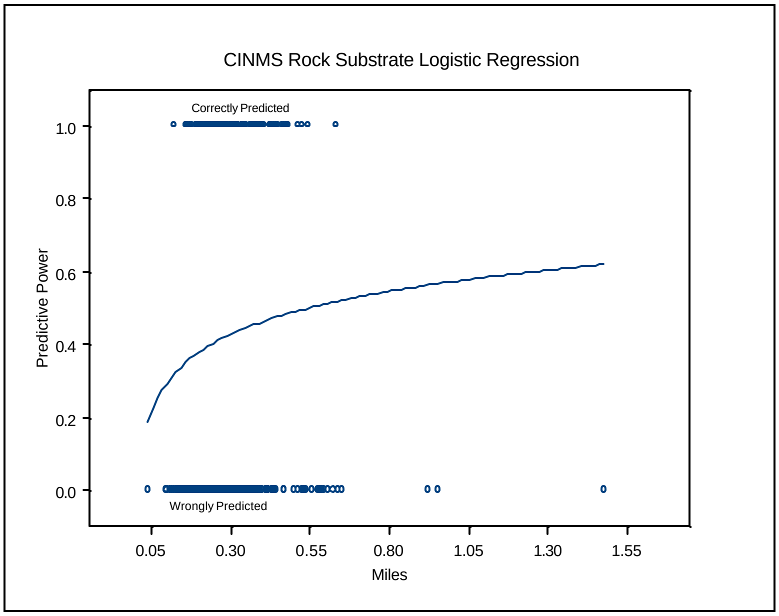
This graph shows low predictive power at a short distance for gravel substrate within CINMS



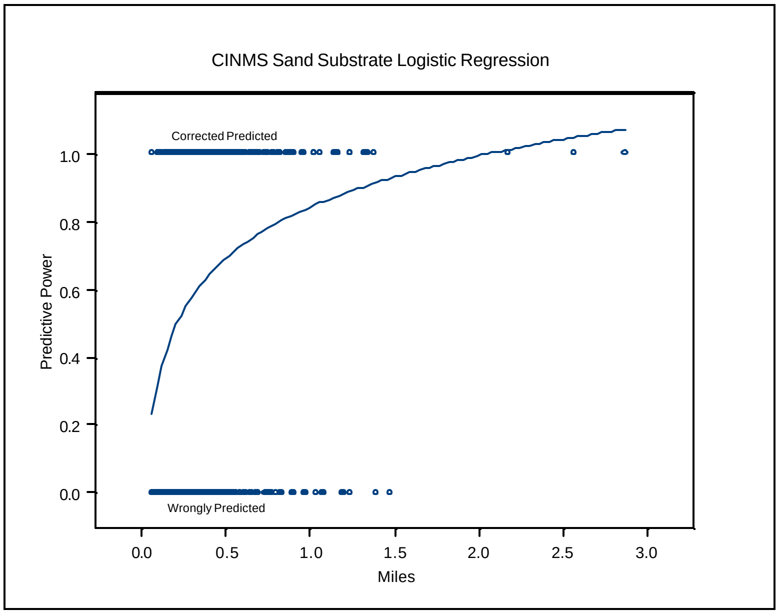
This graph shows high predictive power at a short distance for all substrate within CINMS



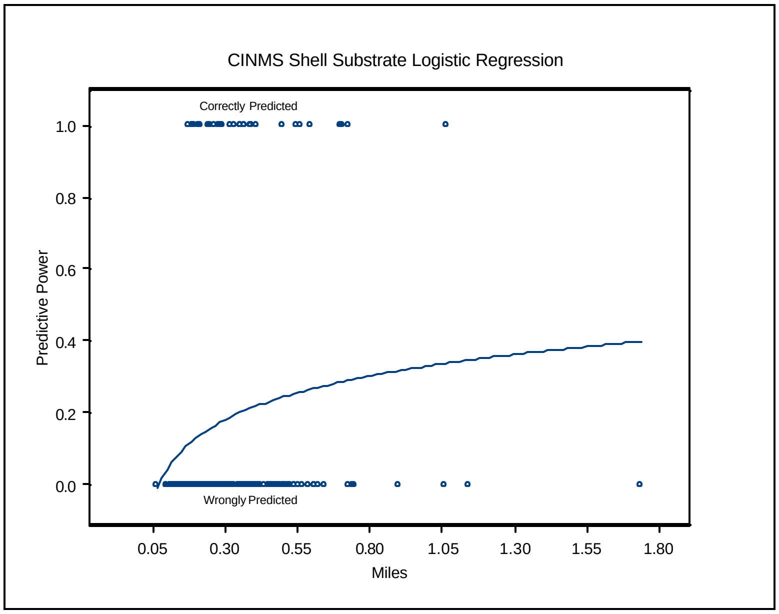
This graph shows high predictive power at a short distance for mud substrate within CINMS



This graph shows low predictive power at a short distance for rock substrate within CINMS



This graph shows high predictive power at a short distance for sand substrate within CINMS



This graph shows low predictive power at a short distance for shell substrate within CINMS

Appendix G: Model Outputs

Black Abalone Output

Two potential habitat distributions were produced for Black Abalone in the Santa Barbara Channel. The maximum potential habitat distribution of Black Abalone was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific abiotic requirements. The maximum potential distribution was produced with the following abiotic parameters: a depth range of 0 to 10 meters, a temperature range encompassing the three bio-regions, capable of withstanding low-medium-high wave exposure, and a rocky substrate type. The prime distribution was produced with a depth range of 2 to 3 meters and the same wave exposure, temperature, and substrate parameters as the general distribution. The determining abiotic factors in creating the potential habitat distributions of Black Abalone were substrate type and depth in this model.

Thiessen:

The distribution of maximum potential habitat for Black Abalone along the coast is largely concentrated north of Point Conception. This distribution is discontinuous and would be considered patchy at best. Within the CINMS, areas identified as maximum potential habitat are also patchy in nature. The majority of the maximum potential habitat distribution for the Black Abalone is located along the southwestern and northern coasts of Santa Rosa Island. San Miguel Island also exhibits areas of maximum potential habitat along its entire coast. The other islands are only sporadically lined with areas of maximum potential habitat along their shores.

The prime potential habitat distribution for the Black Abalone is less apparent in the Santa Barbara Channel. Along the coast, the few areas identified as prime potential habitat are mostly located around the shores of Purisima Point. The areas identified as prime potential habitat distribution for the Black Abalone within the CINMS are largely located around the northwestern coast of Santa Rosa Island. San Miguel, Santa Cruz, and Anacapa islands contain few prime potential habitat distributions along their coasts. No prime potential habitat areas were identified along the shores of Santa Barbara Island.

No test data for Black Abalone was available.

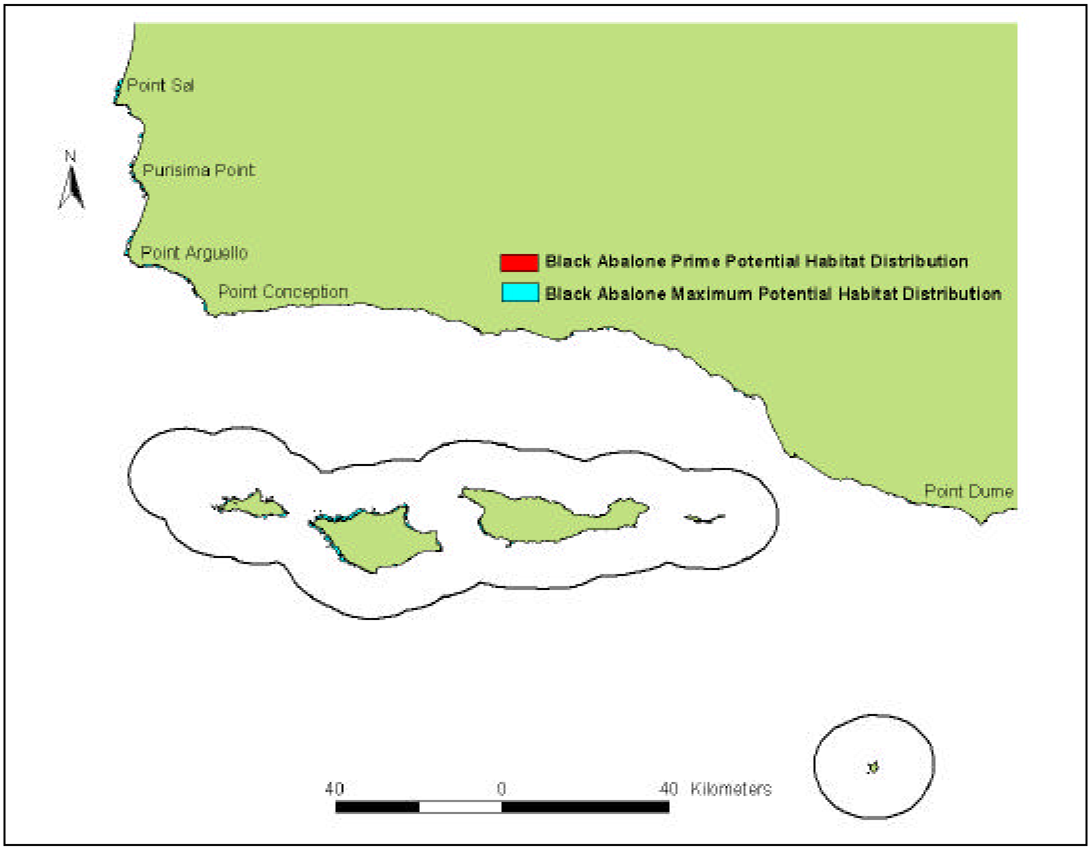


Figure depicting Black Abalone model output (Thiessen technique)

Kriging:
The highest probabilities for Black Abalone habitat were found around San Miguel, Santa Rosa, and Santa Barbara Islands. Several locations with probabilities above .7 were identified on the west side of Santa Rosa Island. Areas of prime habitat were more limited due to the small depth range for prime habitat. Small areas were found on the west side of Santa Rosa Island.

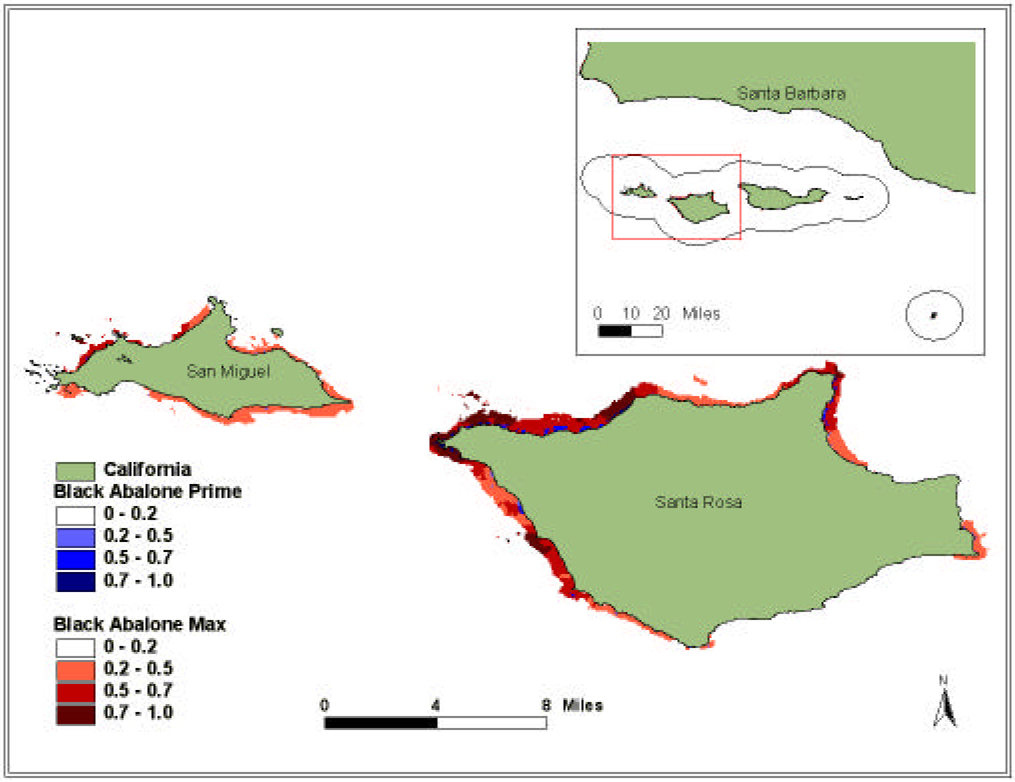


Figure depicting Black Abalone model output probabilities (Kriging technique)

Bocaccio Rockfish Output

Two potential habitat distributions were produced for Bocaccio in the Santa Barbara Channel. The maximum potential habitat distribution of Bocaccio was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific biotic and abiotic requirements. The maximum potential habitat distribution was produced with the following abiotic parameters: a depth range of 50 to 300 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of rock and gravel. The prime distribution was produced with a depth range of 100 to 150 meters and the same wave exposure, temperature, and substrate parameters as the general distribution. The biotic parameter inputted into the model consisted only of Giant Kelp. Since Bocaccio can tolerate the temperature regime that encompasses the channel and has no wave exposure restrictions, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Bocaccio potential habitat.

Thiessen:
Along the coast, the few areas identified as maximum potential habitat for Bocaccio are mainly scattered around the coasts of Point Conception and Point Arguello. Within the CINMS, patchy areas of potential habitat surround each island. Significant regions of potential habitat are apparent off the northeastern coasts of San Miguel and Santa Rosa islands, the entire coast of Santa Barbara island, and eastern Anacapa Island. Other noteworthy maximum potential habitat areas can be observed in bands approximately 30 kilometers south of Santa Cruz island and a large region about 20 kilometers north of Santa Barbara island.

The areas of prime Bocaccio potential habitat were less observable since the depth parameter was restricted to 100 to 150 meters. Patchy areas of prime potential habitat are more apparent within the CINMS boundaries. Discontinuous zones of potential habitat surround Santa Barbara Island. The largest region of prime potential habitat can be observed off the northeastern coast of San Miguel Island. Outside the CINMS, areas of discontinuous zones of prime potential Bocaccio habitat can be observed approximately 30 kilometers south of Santa Cruz Island and 20 kilometers north of Santa Barbara Island.

No test data for Bocaccio was available.

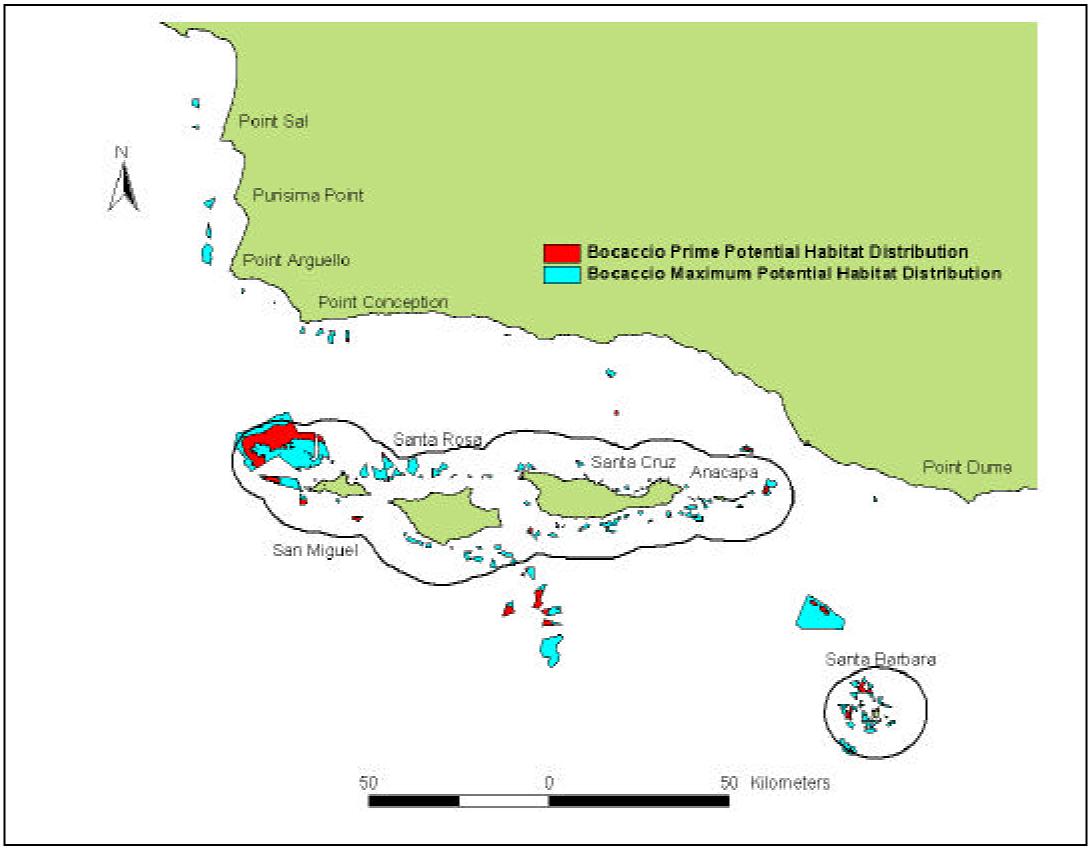


Figure depicting Bocaccio model output (Thiessen technique)

Kriging:
High probability zones for Bocaccio habitat were throughout the CINMS and beyond. The highest probabilities were identified northwest of San Miguel Island, and around Santa Barbara Island. Two additional large zones of potential habitat were found south of Santa Cruz Island and between Anacapa and Santa Barbara Islands.

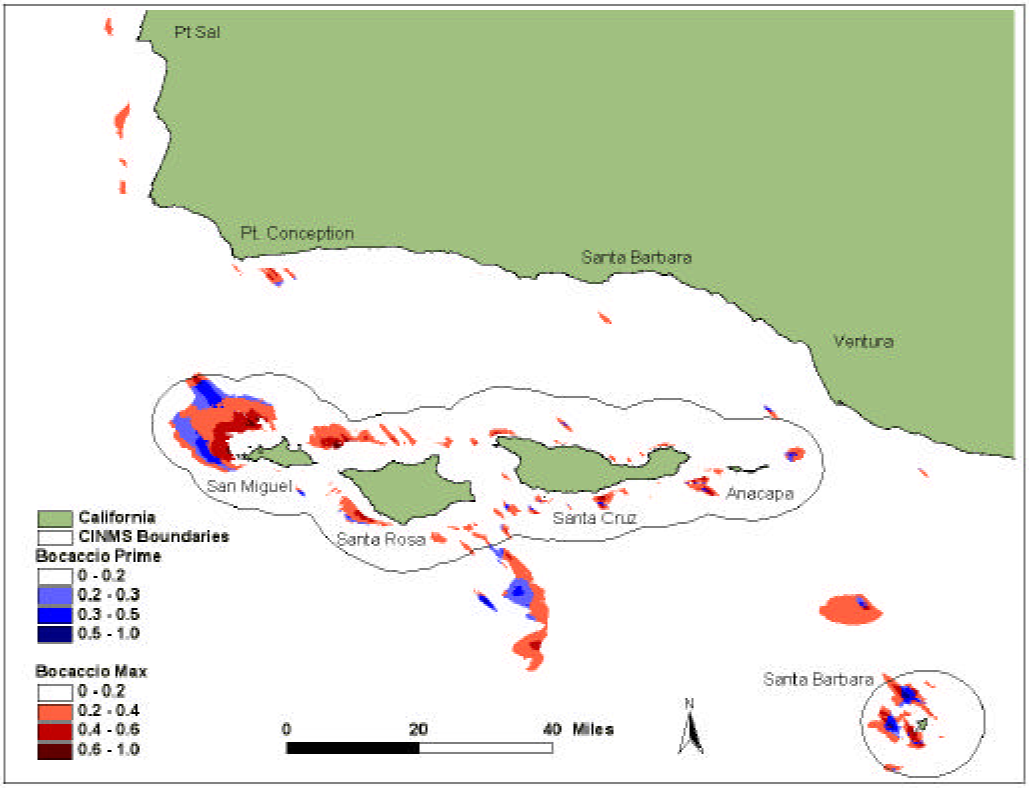


Figure depicting Bocaccio model output probabilities (Kriging technique)

Copper Rockfish Output

The potential habitat distribution for Copper Rockfish in the Santa Barbara Channel was produced with the following abiotic parameters: a depth range of 0 to 183 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of rocky and gravel. The only biotic parameter inputted in the model was the presence of Giant Kelp. Since Copper Rockfish can tolerate the temperature regime that encompasses the channel and endure low to high wave exposure, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Copper Rockfish potential habitat.

Thiessen:
The potential habitat distribution of Copper Rockfish spans the extent of the Santa Barbara Channel in discontinuous zones. Along the coast, the majority of the areas identified as potential habitat are concentrated approximately between Point Conception and Point Sal. The islands of CINMS are each encircled by areas of potential Copper Rockfish habitat. In particular, significant regions identified as potential habitat engulf the islands of San Miguel, Santa Rosa, and Santa Barbara. The islands of Santa Cruz and Anacapa experience scattered areas of potential Copper Rockfish habitat along their coasts.

No test data for the Copper Rockfish was available.

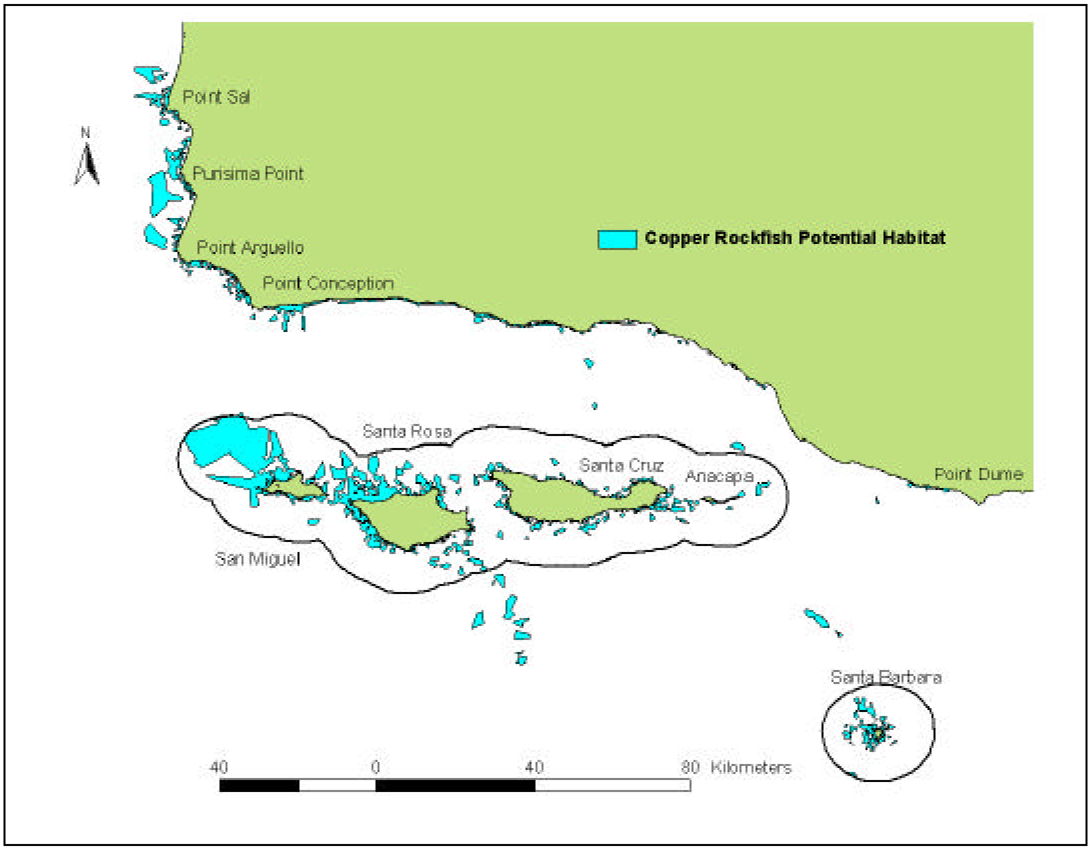


Figure depicting Copper Rockfish model output (Thiessen technique)

Kriging:
Regions of potential habitat for Copper Rockfish were found around each island. Highest probabilities were found northwest of San Miguel, Santa Rosa , and Santa Barbara Islands. Additional patches of habitat were fond around Pt. Conception.

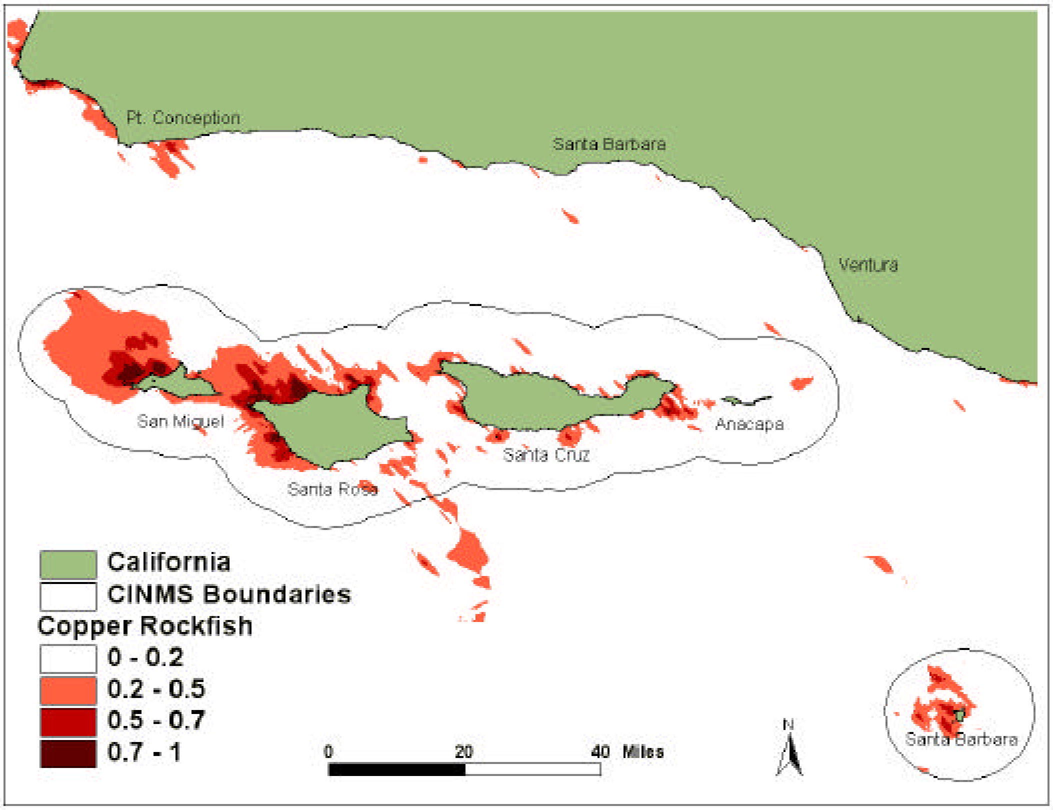


Figure depicting Copper Rockfish model output probabilities (Kriging technique)

California Halibut Output

The potential habitat distribution for California Halibut in the Santa Barbara Channel was produced with the following abiotic parameters: a depth range of 0 to 183 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of mud and sand. Since the California Halibut can tolerate the temperature regime that encompasses the channel and has no wave exposure restrictions, depth and substrate type will be the determining abiotic factors in the distribution of California Halibut potential habitat.

Thiessen:

The potential habitat distribution of the California Halibut spans the extent of the Santa Barbara Channel. Along the coast, a continuous zone of potential habitat can be observed approximately between Point Dume and Point Sal. This is the most significant potential habitat region in the channel. Within the CINMS, areas of potential California Halibut habitat encircle each island. In particular, Santa Rosa has a significant zone of potential habitat stretching approximately 30 kilometers southeast of its coast. Another significant area of potential California Halibut habitat can be observed approximately 50 kilometers southeast of Santa Rosa. In addition, 10 kilometers north of Santa Barbara Island lies a large band of potential habitat.

No test data for the California Halibut was available.

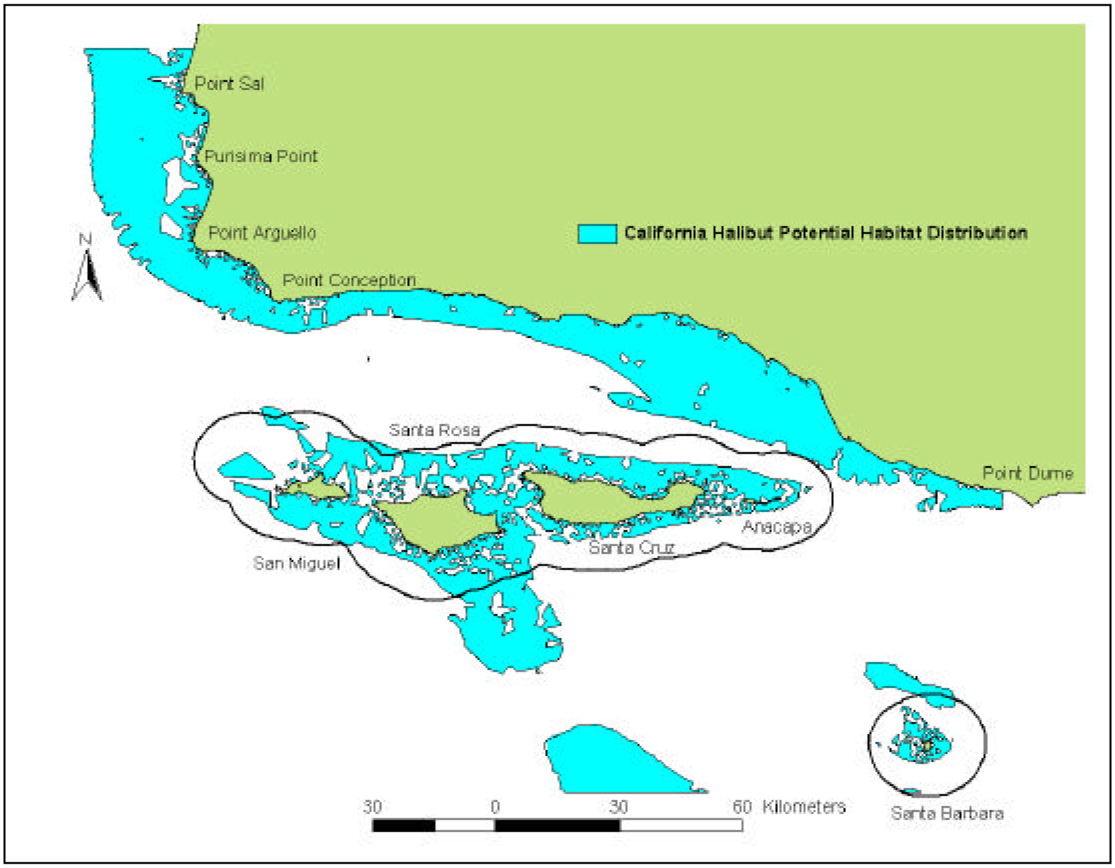


Figure depicting California Halibut model output (Thiessen technique)

Kriging:
Due to the wide range of suitable depth and substrate types, California Halibut habitat can be found throughout the study area. High probabilities were found from Pt. Sal to Pt. Dume, and within most of the CINMS. A large area of high probability was also found south of the sanctuary boundaries.

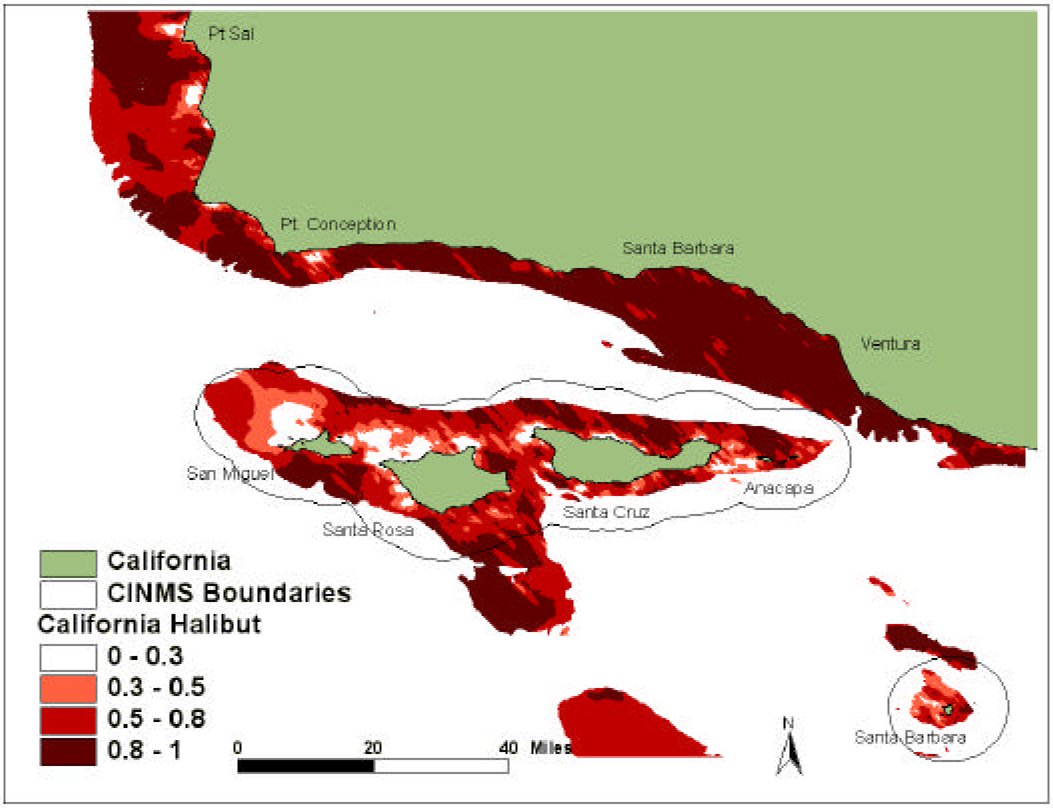


Figure depicting California Halibut model output probabilities (Kriging technique)

Cowcod Rockfish Output

Two potential habitat distributions were produced for Cowcod in the Santa Barbara Channel. The maximum potential habitat distribution of Cowcod was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific biotic and abiotic requirements. The maximum potential distribution was produced with the following abiotic parameters: a depth range of 21 to 366 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of rock and gravel. The prime distribution was produced with a depth range of 180 to 235 meters and the same wave exposure, temperature, and substrate parameters as the general distribution. The biotic parameter inputted into the model consisted only of Giant Kelp. Since the Cowcod can tolerate the temperature regime that encompasses the channel and has no wave exposure restrictions, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Cowcod potential habitat.

Thiessen:
Along the coast, the maximum potential habitat distribution for the Cowcod is concentrated between Point Conception in the south and Point Sal in the north. In particular, there is a large potential habitat region identified between Point Arguello and Purisima Point. Within the CINMS, patchy areas of potential habitat surround each island. Significant regions of potential habitat are apparent off the northwestern coasts of San Miguel and Santa Rosa islands and the entire coast of Santa Barbara island. Other noteworthy maximum potential habitat areas can be observed approximately 30 kilometers south of Santa Cruz Island and 20 kilometers north of Santa Barbara Island.

The areas of prime Cowcod potential habitat were less observable since the depth parameter was restricted to 180 to 235 meters. Patchy areas of prime potential habitat are only visible within the CINMS boundaries. Discontinuous zones of potential habitat surround Santa Barbara Island. Another band of prime potential habitat can be observed off the northeastern coast of San Miguel Island. The largest areas of prime potential Cowcod habitat can be observed approximately 30 kilometers south of Santa Cruz Island and 20 kilometers north of Santa Barbara Island.

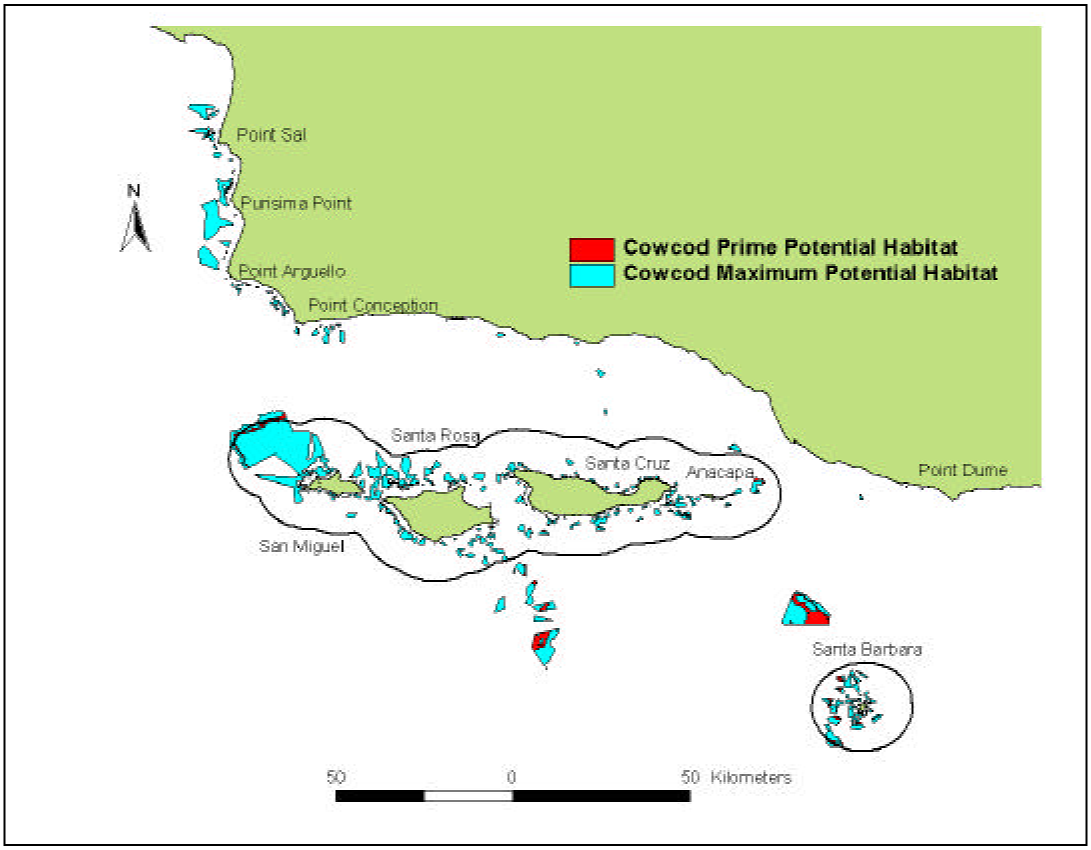


Figure depicting Cowcod model output (Thiessen technique)

Kriging:
Regions of potential habitat for Cowcod were found around each island. Highest probabilities were found northwest of San Miguel, Santa Rosa , and Santa Barbara Islands. Additional patches of Cowcod habitat were fond around Pt. Conception, and north to Pt. Sal.

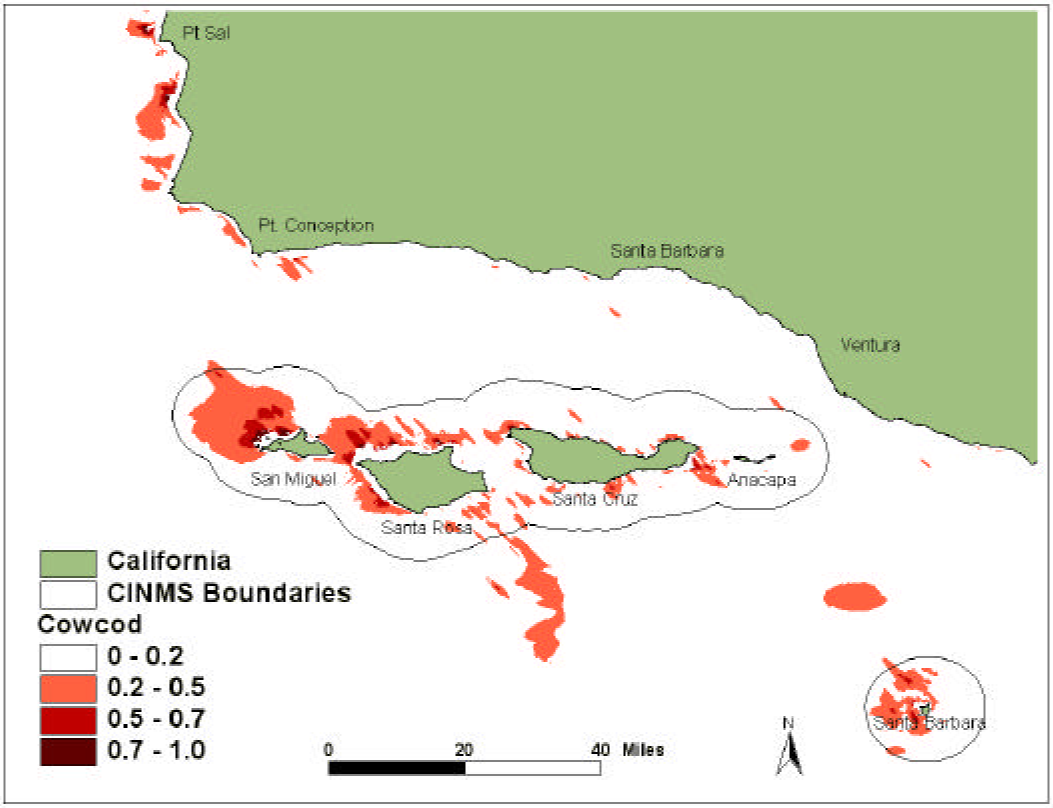


Figure depicting Cowcod model output probabilities (Kriging technique)

No test data for Cowcod was available.

Giant Sea Bass Output

The potential habitat distribution for Giant Sea Bass in the Santa Barbara Channel was produced with the following abiotic parameters: a depth range of 5 to 46 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate type of rock, gravel, and sand. The biotic parameter inputted into the model consisted only of Giant Kelp. Since the Giant Sea Bass can tolerate the temperature regime that encompasses the channel and has no wave exposure restrictions, depth, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Giant Sea Bass potential habitat.

Thiessen:
The potential habitat distribution of the Giant Sea Bass spans the extent of the Santa Barbara Channel. Along the coast, a semi-continuous zone of potential habitat can be observed approximately between Point Dume and Point Sal. Significant potential habitat regions within this zone are apparent between Port Hueneme and Rincon Point and north of Point Arguello. The islands of CINMS are each encircled by areas of potential Giant Sea Bass habitat. In particular, significant regions identified as potential Giant Sea Bass habitat surround the islands of San Miguel, Santa Rosa, and Santa Barbara.

No test data for the Giant Sea Bass was available.

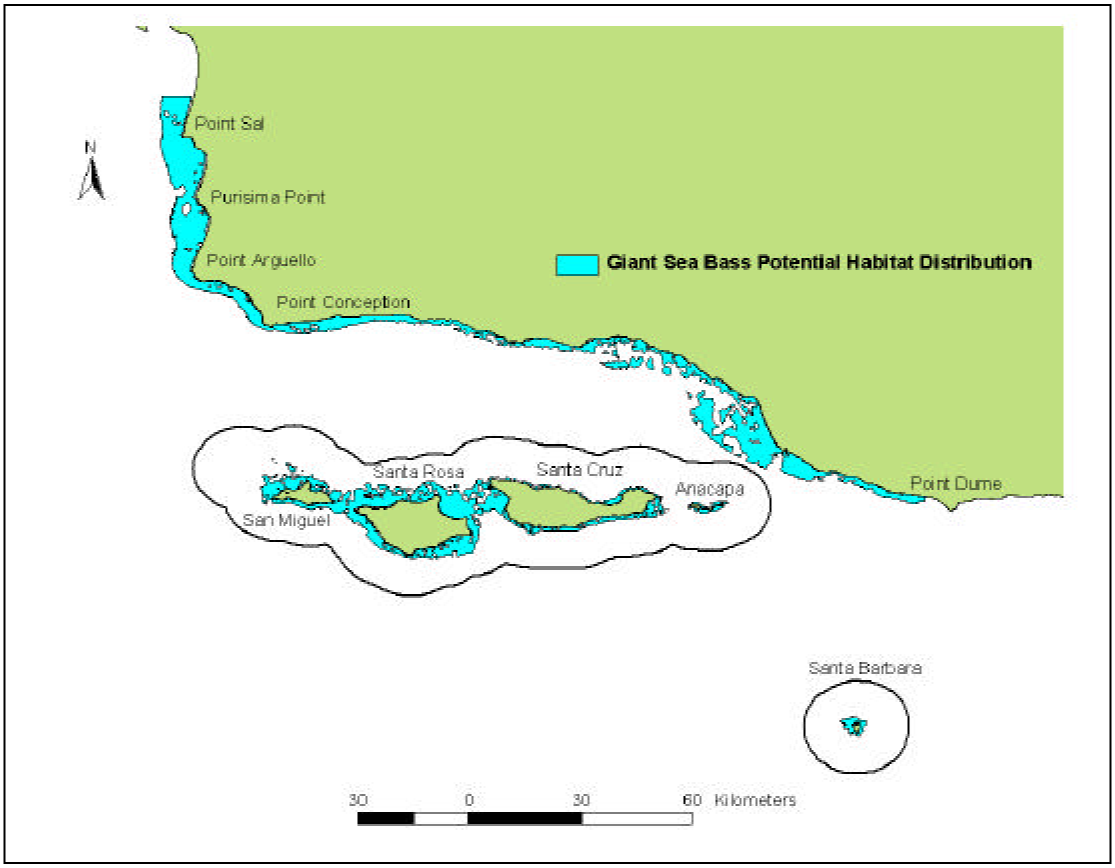


Figure depicting Giant Sea Bass model output (Thiessen technique)

Kriging:
High probabilities for Giant Seabass habitat were identified all along the coast of the study area, and around all of the islands. The largest areas of high probability were found between Pt. Sal and Pt. Conception, as well as around San Miguel, and Santa Rosa Islands. An additional large area of habitat was found off the coast of Ventura.

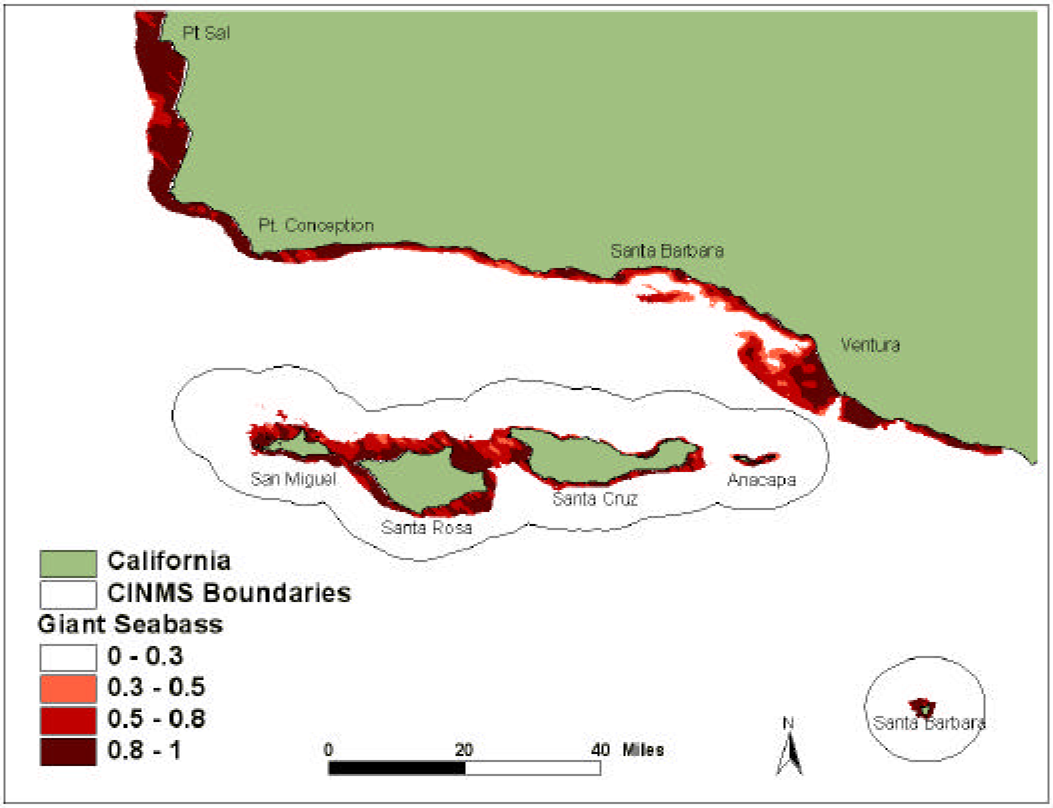


Figure depicting Giant Sea Bass model output probabilities (Kriging technique)

Quillback Rockfish Output

Two potential habitat distributions were produced for the Quillback in the Santa Barbara Channel. The maximum potential habitat distribution of the Quillback was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific biotic and abiotic requirements. The maximum potential distribution was produced with the following abiotic parameters: a depth range of 0 to 275 meters, a temperature range restricted to the Oregonian bio-region, no wave exposure restrictions, and a substrate type of rock and gravel. The prime distribution was produced with a depth range of 41 to 60 meters and the same wave exposure, temperature, and substrate parameters as the general distribution. The biotic parameter inputted into the model consisted only of Giant Kelp. Since the Quillback has no wave exposure restrictions, depth, temperature, the presence of Giant Kelp, and substrate type will be the determining factors in the distribution of Quillback potential habitat.

Thiessen:
Along the coast, the maximum potential habitat distribution for the Quillback is concentrated between Point Conception in the south and Point Sal in the north. In particular, there is a large potential habitat region identified between Point Arguello and Purisima Point. Within the CINMS, significant regions of potential habitat are apparent off the northeastern coasts of San Miguel and Santa Rosa islands. Other noteworthy maximum potential habitat areas can be observed approximately 30 kilometers south of Santa Cruz island.

The areas of prime Quillback potential habitat were less observable since the depth parameter was restricted to 41 to 60 meters. Patchy areas of prime potential habitat are visible within the CINMS boundaries. A discontinuous zone of prime potential habitat can be observed extending off the eastern coast of San Miguel to the northeastern shores of Santa Cruz Island. The southwestern coast of Santa Rosa Island was also identified as prime Quillback potential habitat. Along the mainland coast, large prime potential habitat regions were identified between Point Arguello and Purisima Point and north of Point Sal.

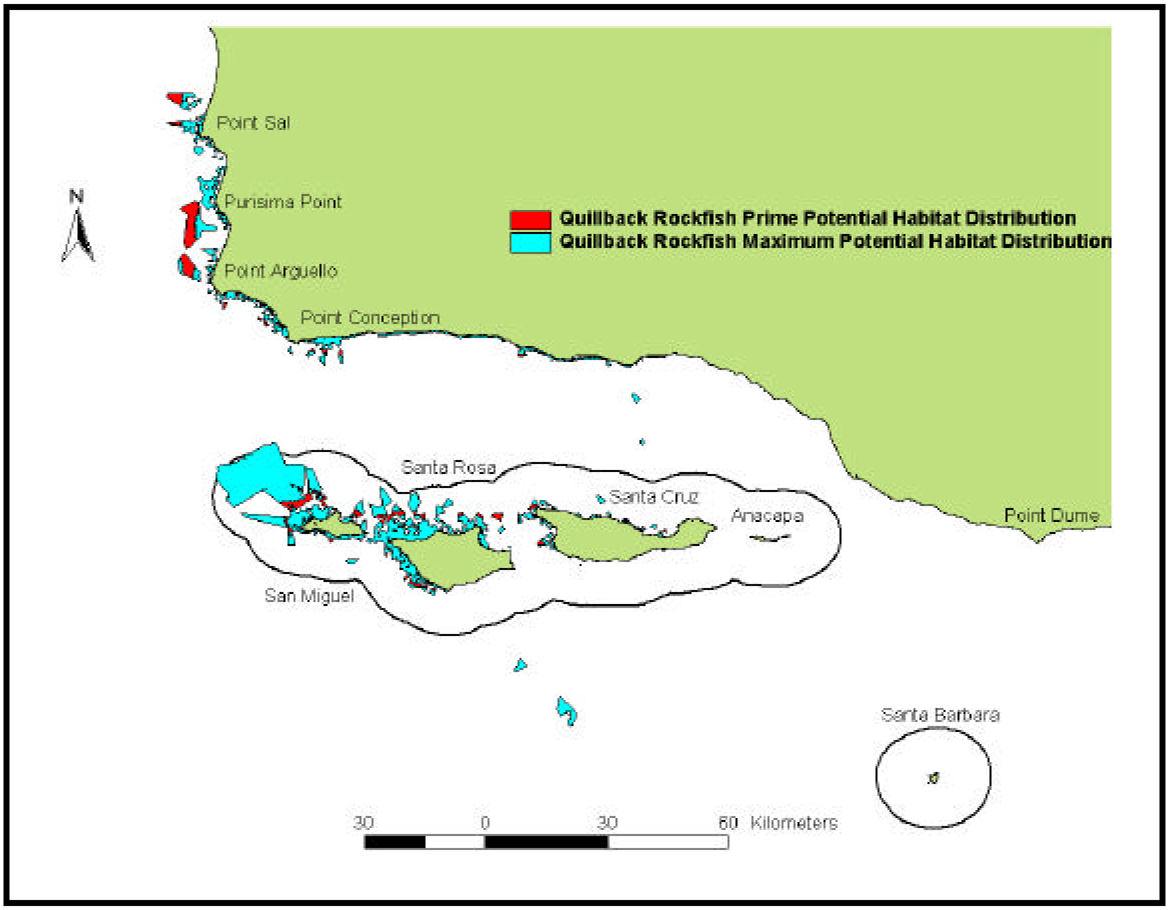


Figure depicting Quillback Rockfish model output (Thiessen technique)

Kriging:
Potential Quillback habitat was found along the coast from Pt. Sal to Pt. Conception, and around all of the Islands. The areas with the highest probability of finding prime Quillback habitat were northwest of San Miguel and Santa Rosa Islands.

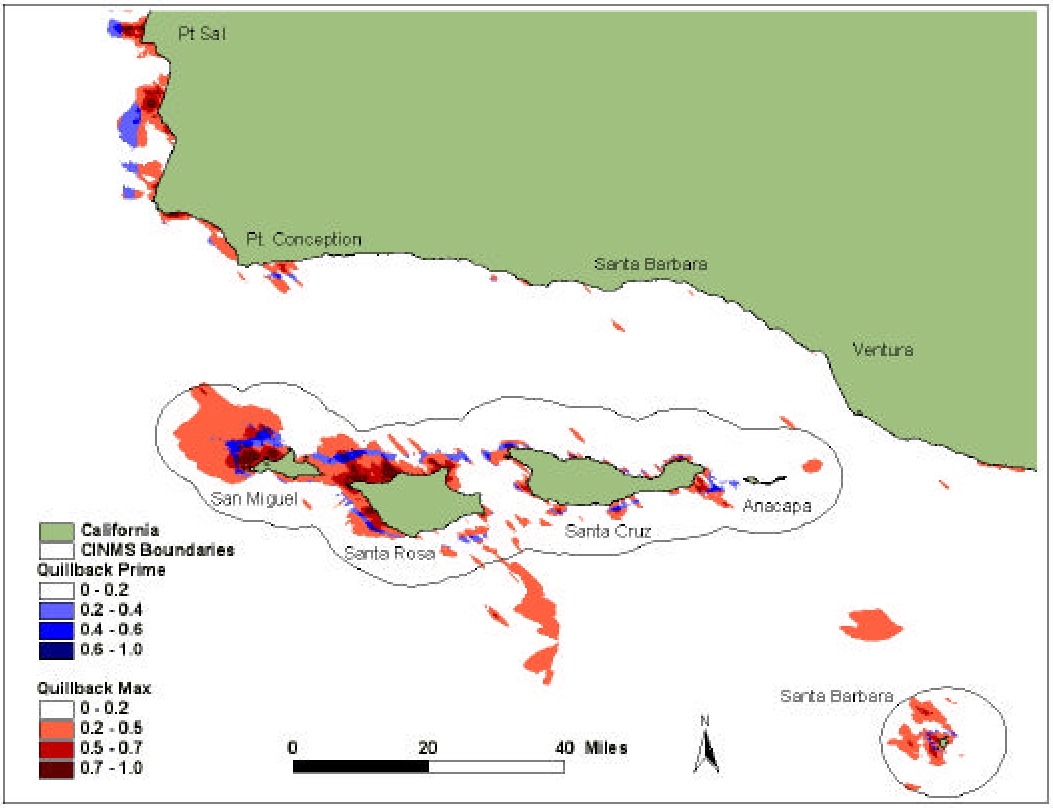


Figure depicting Quillback Rockfish model output probabilities (Kriging technique)

No test data for the Quillback was available.

Southern Sea Otter Output

Two potential habitat distributions were produced for Southern Sea Otter in the Santa Barbara Channel. The maximum potential habitat distribution of Southern Sea Otter was produced with the largest range of physical parameters. The preferred or prime potential habitat was a more refined distribution based on specific biotic or abiotic requirements. The maximum potential distribution was produced with the following abiotic parameters: a depth range of 0 to 37 meters, a temperature range encompassing the three bio-regions, no wave exposure restrictions, and a substrate of rock, sand, shells, mud, and gravel. The prime potential habitat distribution was produced with a depth range of 0 to 18 meters, a low to medium wave exposure, a temperature range encompassing the three bioregions, and a rocky substrate. In addition, the prime distribution also included the biotic parameter input of Giant Kelp.

Thiessen:
The maximum distribution of the Southern Sea Otter spans the coast of the Santa Barbara Channel from Morro Bay to Point Dume. The significant regions of potential habitat along the coast are located between Port Hueneme and Santa Barbara and north of Point Arguello. Within the CINMS, continuous areas of potential habitat surround each island. More noticeably, significant regions of maximum potential Southern Sea Otter habitat surround San Miguel, Santa Rosa, and Santa Barbara islands.

Areas identified as prime Southern Sea Otter potential habitat border the coastline from Point Arguello to Surfer's Point. These prime potential habitat regions are organized in small discontinuous clusters. Within the CINMS, the largest concentration of prime Sea Otter potential habitat is located along the southern coasts of San Miguel and Santa Rosa islands. Santa Cruz, Anacapa, and Santa Barbara islands are encircled by small numerous clusters of prime potential habitat.

The areas of prime Southern Sea Otter potential habitat were less observable since the depth parameter was restricted to 100 to 150 meters. Patchy areas of prime potential habitat are more apparent within the CINMS boundaries. Discontinuous zones of potential habitat surround Santa Barbara Island. The largest region of prime potential habitat can be observed off the northeastern coast of San Miguel Island. Outside the CINMS, areas of discontinuous zones of prime potential Southern Sea Otter habitat can be observed approximately 30 kilometers south of Santa Cruz Island and 20 kilometers north of Santa Barbara Island.

No test data for Southern Sea Otter was available.

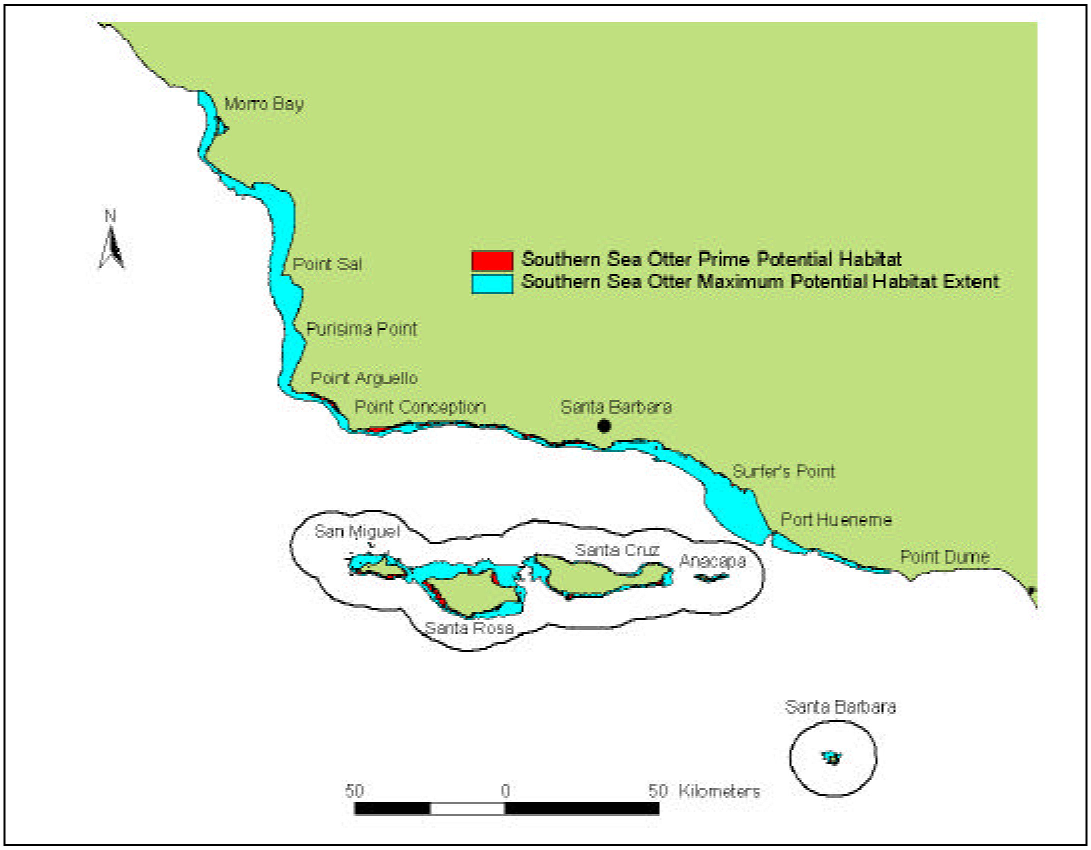


Figure depicting Southern Sea Otter model output (Thiessen technique)

Kriging:
Although Sea Otters can tolerate a wide range of habitats, the prime areas are confined to limited areas. A thin band of potential prime habitat can be found from Pt. Conception to Ventura. Additional areas of habitat were identified around Santa Rosa Island, with additional small patches around all of the other islands.

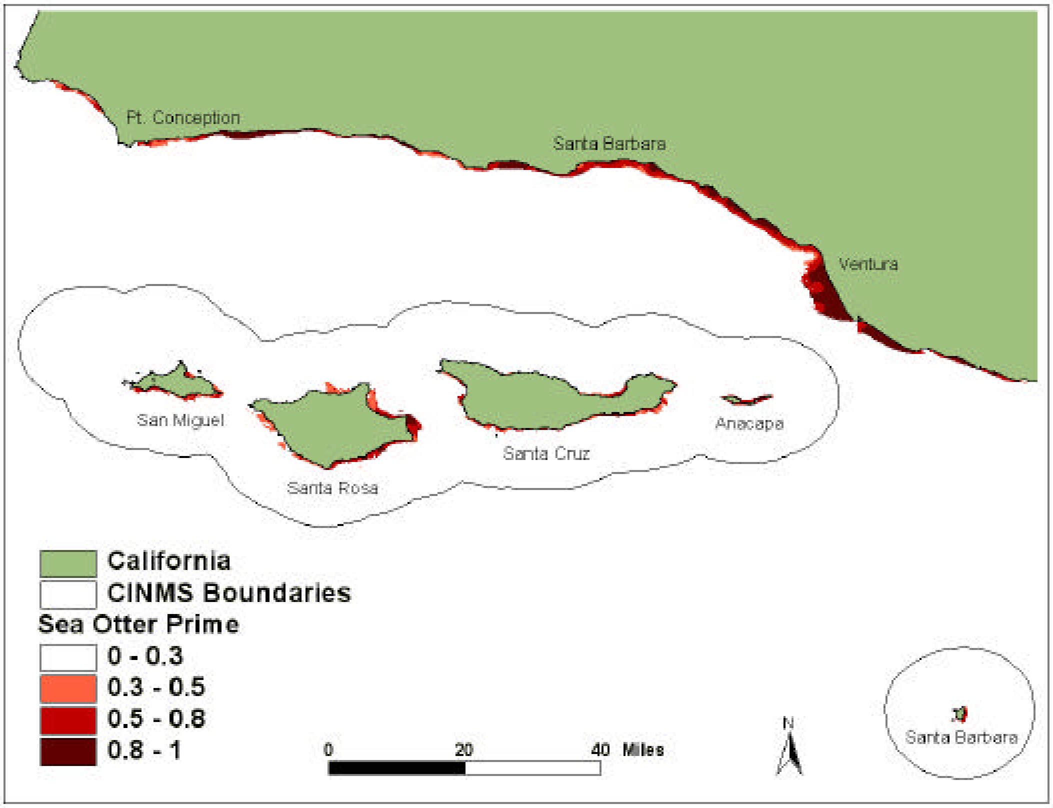


Figure depicting Sea Otter model output probabilities (Kriging technique)

Squid Output

Two potential habitat distributions were produced for Squid in the Santa Barbara Channel. The maximum potential habitat distribution of Squid was produced with the largest range of physical parameters. The potential distribution of spawning grounds was a more refined distribution based on specific abiotic requirements. The maximum potential habitat distribution was produced with the following abiotic parameters: a depth range of 0 to 800 meters, a temperature range encompassing the three bio-regions, low-to-medium wave exposure, and no substrate requirements. The potential distribution of Squid spawning grounds was produced with a depth range of 20 to 35 meters, low to medium wave exposure, and the substrate parameters of mud and sand.

Thiessen:

The maximum potential Squid habitat distribution covers the entire extent of the Santa Barbara Channel from approximately Point Dume to Point Sal. The only areas not covered by the potential habitat distribution are those regions deeper than 800 meters and those areas identified as high wave exposure. The majority of the CINMS lies within the maximum potential Squid habitat distribution.

The potential distribution of Squid spawning grounds lines the coast of the Santa Barbara Channel. Significant potential spawning areas can be observed on the coast between Port Hueneme and the city of Santa Barbara. Within the CINMS, numerous patchy areas of potential Squid spawning grounds are visible. In particular, the northeastern and southeastern coasts of Santa Rosa Island contain significant regions of Squid spawning grounds. In addition, the western coast of Santa Cruz Island was also identified as potential Squid spawning grounds.

No test data for Squid was available.

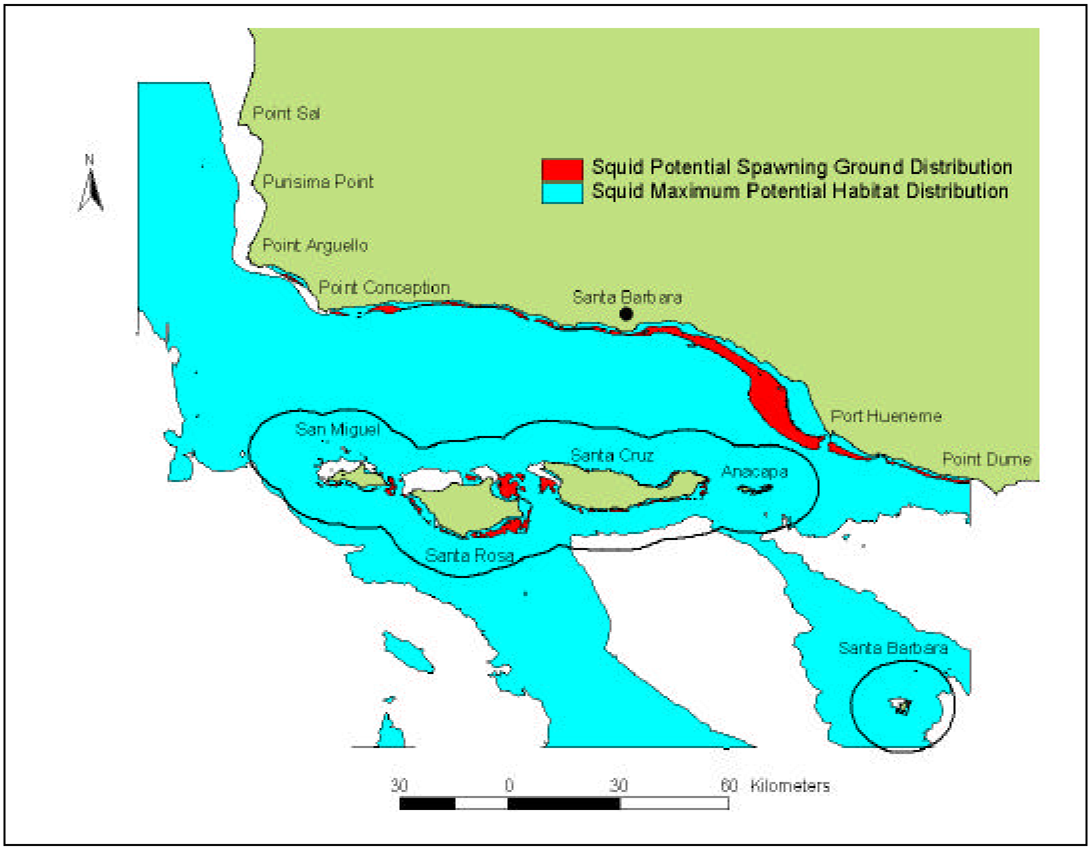


Figure depicting Market Squid model output (Thiessen technique)

Kriging:
Due to the wide range of suitable depth and substrate types, Squid habitat can be found throughout the study area. The highest probabilities for Squid habitat lie within the Santa Barbara Channel, with additional areas south of the Islands, and north of Santa Barbara Island. Spawning areas are confined primarily to the coast of Santa Rosa Island, and between Santa Barbara and Ventura.

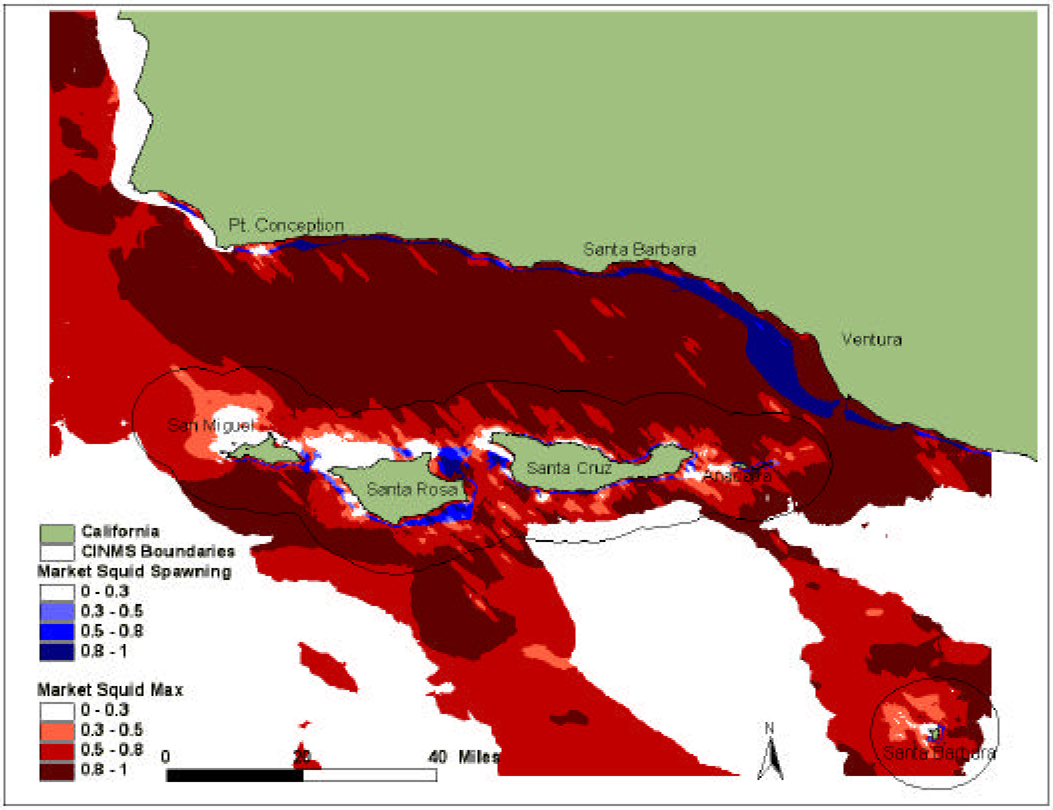
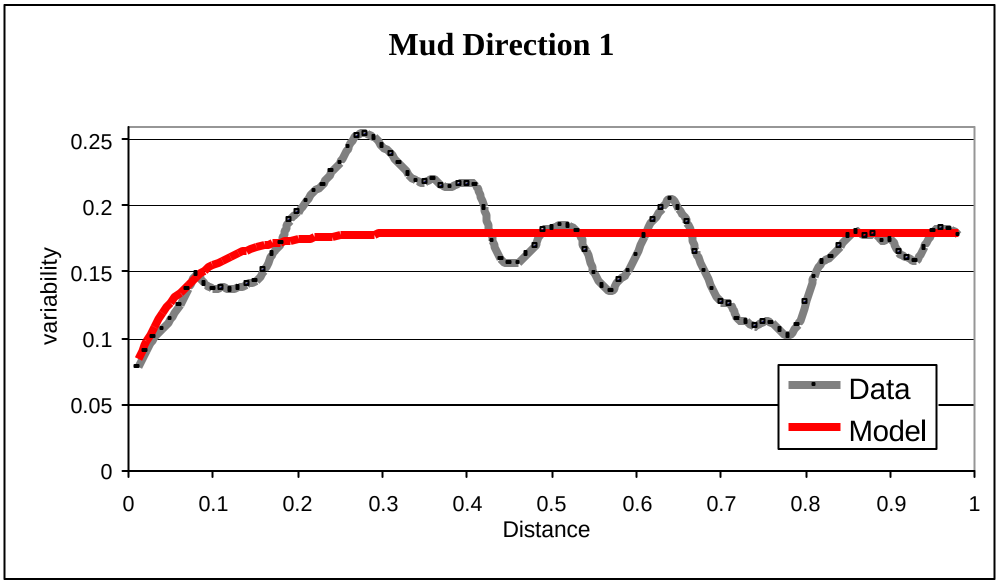


Figure depicting Market Squid model output probabilities (Kriging technique)

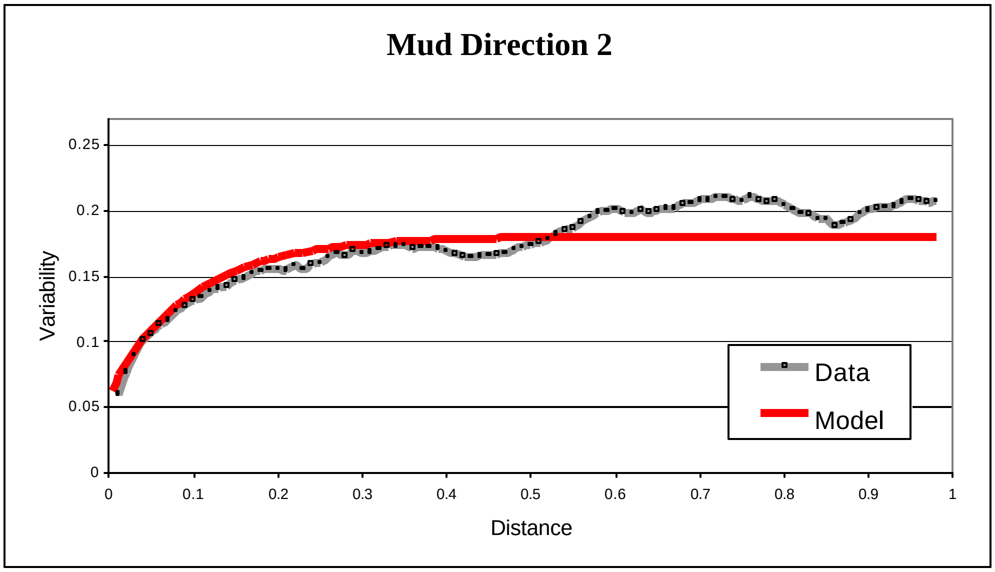
Appendix H: Kriging Variograms

The semi-variogram model describing the spatial relationship between neighboring locations is a critical element of any spatial estimation. The model is designed to match closely the spatial relationship observed in the sample data. This relationship is in turn used to estimate the values of unknown points

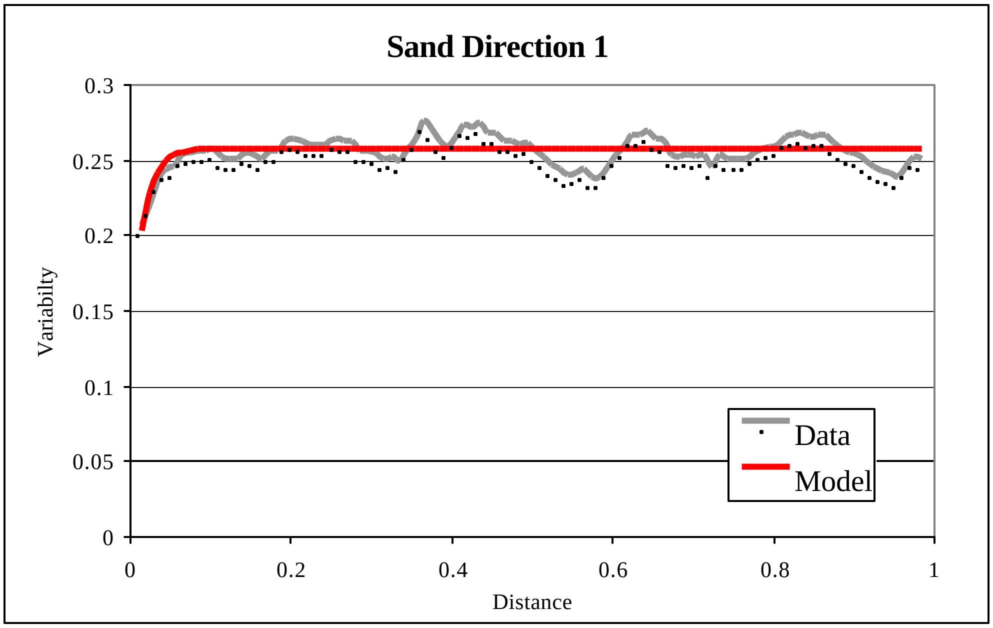
Semi-variograms were modeled from the available substrate samples in order to provide input for the kriging algorithm. Semi-variograms for each of the five substrate types were generated in four directions. Each Semi-variogram was in turn examined, and the two most variable plots for each substrate type were modeled for use in the kriging algorithm. The plots below represent the semi-variogram models for the two most variable plots of each substrate type. The gray lines represent the actual data values, while the red line illustrates the model function used in kriging.



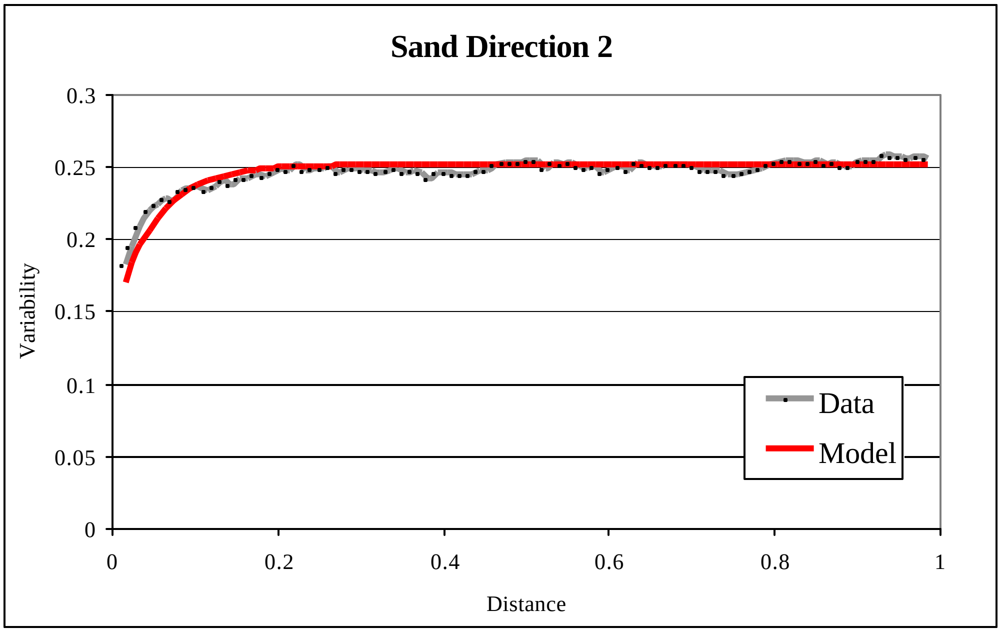
Mud semi-variogram model for 90°



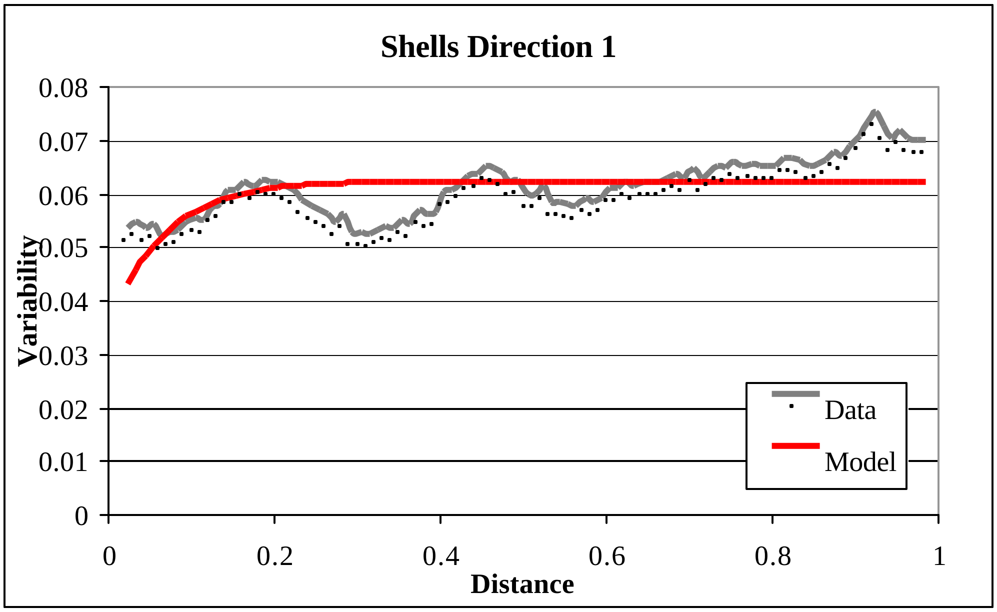
Mud semi-variogram model for 45°



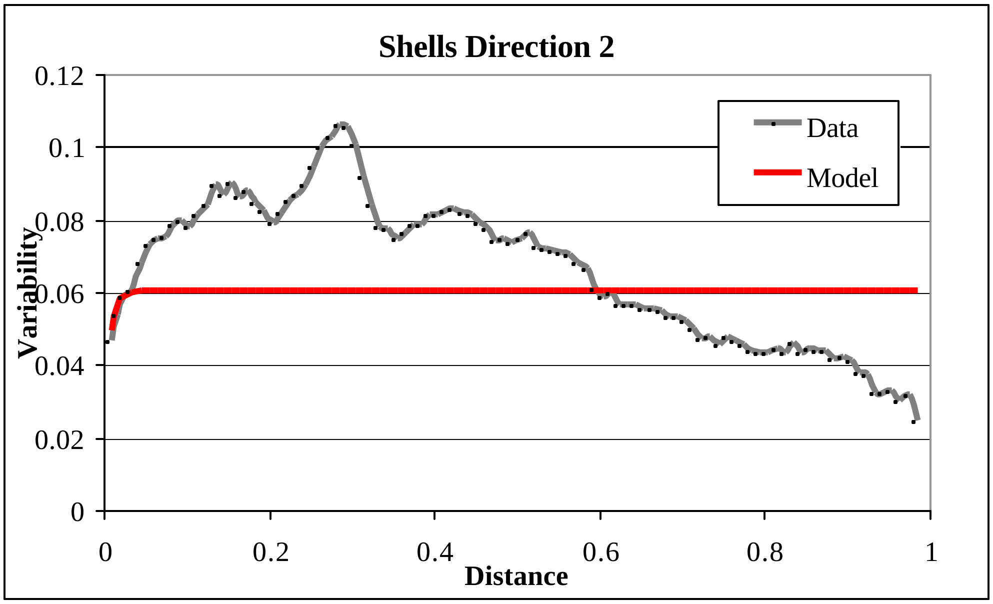
Sand semi-variogram model for 90°



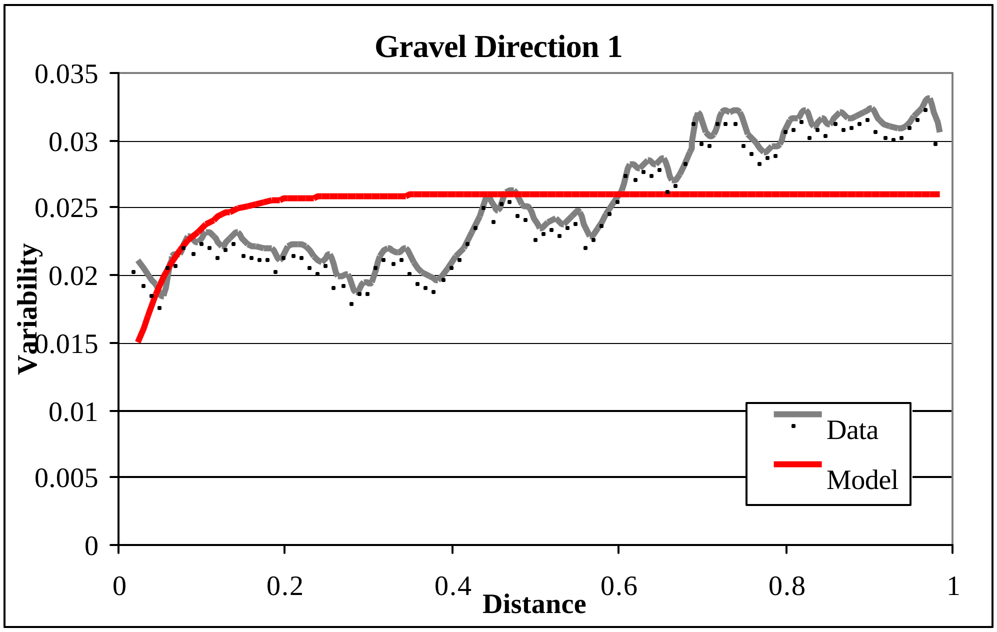
Sand semi-variogram model for 45°



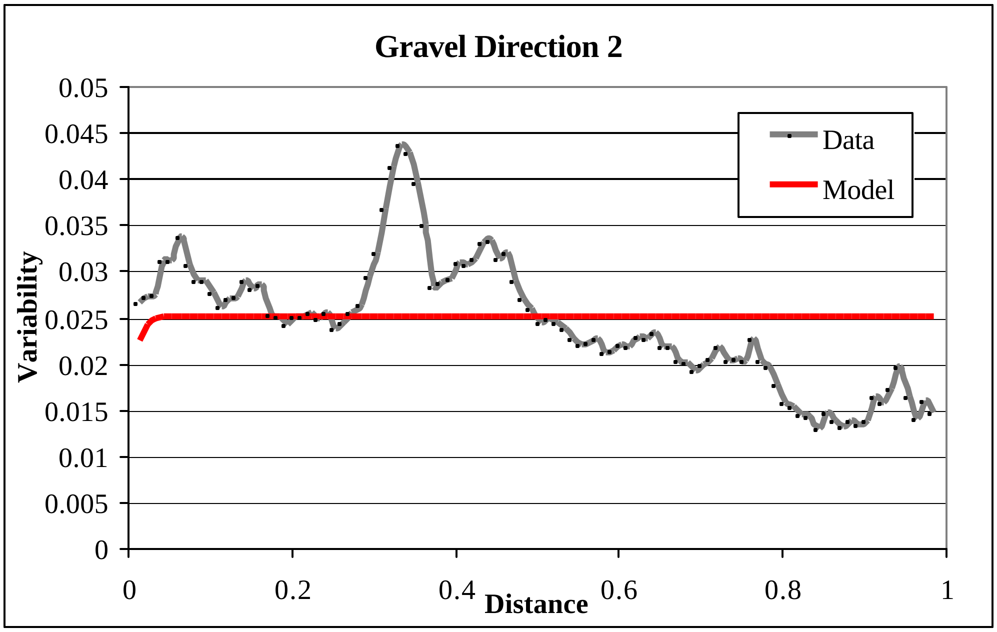
Shells semi-variogram model for 45°



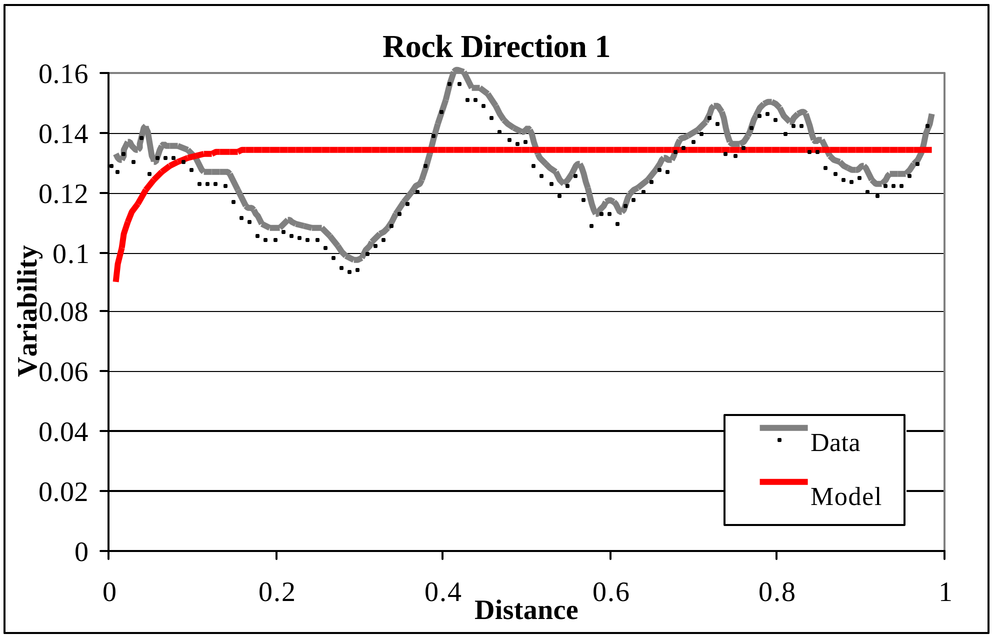
Shells semi-variogram model for 135°



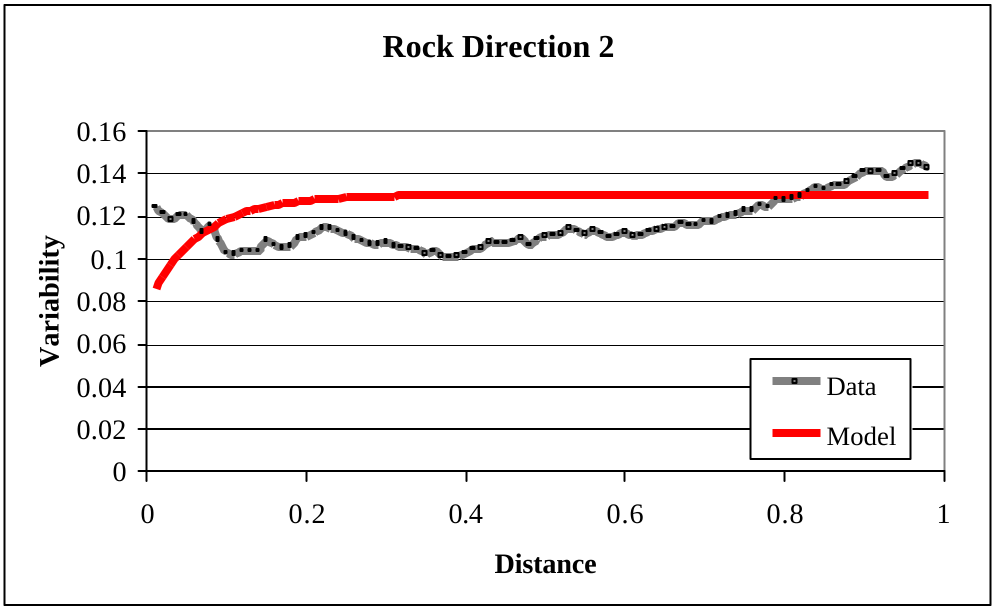
Gravel semi-variogram model for 45°



Gravel semi-variogram model for 135°



Rock semi-variogram model for 90°



Rock semi-variogram model for 45°

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