CHAPTER 6

Channel Islands National Marine Sanctuary:

Advancing the Science and Policy of Marine Protected Areas

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Abstract

A network of marine protected areas was established in the Channel Islands National Marine Sanctuary in April 2003. Geospatial modeling tools were used to advance the science and policy underlying the network design. Scientists used a modeling tool, SPEXAN, to develop and evaluate design options. This modeling tool was used to process a large amount of spatially explicit data and to produce a set of solutions to the complex problem of where to establish marine protected areas. Each solution generated by SPEXAN included all conservation targets identified by planners, such as important habitats and species. The most efficient solutions, comprised of many small patches with high conservation value, generally were not practical for maximum compliance and enforcement. Thus, solutions with fewer and larger reserves were presented to planners for discussion. One of the most useful outputs of the SPEXAN analysis was a map of conservation value showing the number of times each planning unit was included in a final solution. Planners used the map of conservation value to begin the discussion about where to establish marine protected areas in the Sanctuary. Another geospatial modeling tool, the Channel Islands Spatial Support and Analysis Tool (CI-SSAT) was developed by NOAA's Coastal Services Center specifically for the Channel Islands process. CI-SSAT was used primarily as a tool for visualization and querying of ecological and socioeconomic data. Planners developed design options in CI-SSAT and then used the tool to query the data to determine their potential benefits and impacts. Planners made adjustments to the design options in order to increase ecological benefits and decrease socioeconomic impacts. In June 2001, planners

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submitted two alternative designs to the California Department of Fish and Game and the Channel Islands National Marine Sanctuary. The network of marine protected areas established in 2003 was a compromise, developed by the agencies, between the two alternative designs. Throughout the process, geospatial modeling tools advanced the science and policy, eventually leading to the carefully considered management action.

Introduction

In April 2003, the California Fish and Game Commission established the largest network of marine protected areas (MPAs) in California state waters (Title 14, California Code of Regulations, Sections 27.82, 530, and 632). The network of MPAs is located within the California state waters of the Channel Islands National Marine Sanctuary. The eight Channel Islands are located off of southern California. Five of the islands (San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara islands) are located within the Channel Islands National Marine Sanctuary. The network of marine protected areas includes 10 no-take marine reserves and 2 marine conservation areas, which allow limited take of certain fisheries[1] (Fig. 6.1). The design of the MPA network was based on scientific and socioeconomic data assembled by experts, and policy developed by a working group of local stakeholders and agency representatives (California Department of Fish and Game, 2002).

The group of local stakeholders and agency representatives (working group) was appointed by the Channel Islands National Marine Sanctuary Advisory Council in July 1999. The formation of the working group was driven by growing pressure from local communities to improve local ocean management[2]. The working group included representatives from fisheries, kelp harvesting, recreational industries,

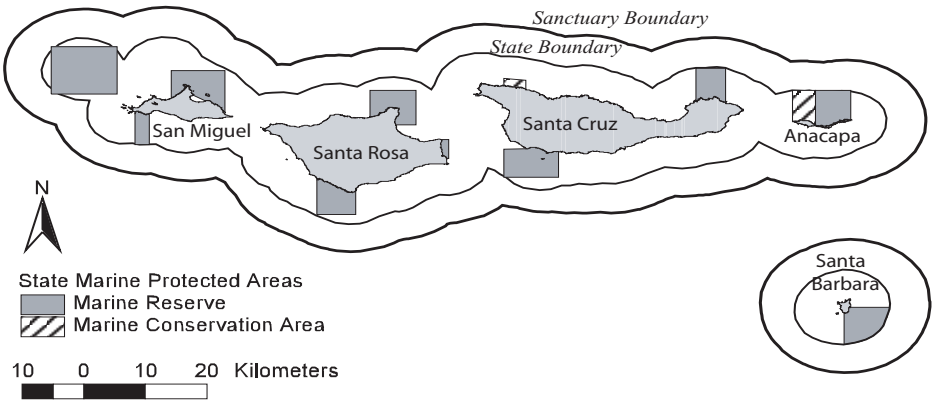


Figure 6.1. Network of state marine protected areas in the Channel Islands National Marine Sanctuary, established April 9, 2003. Solid polygons represent no-take marine reserves. Hatched polygons represent limited-take marine conservation areas.

Table 6.1. Goals for marine reserves developed by the Marine Reserves Working Group (Jostes and Eng 2001).

Biodiversity conservation	To protect representative and unique marine habitats, ecological processes, and populations of interest.
Sustainable fisheries	To achieve sustainable fisheries by integrating marine reserves into fisheries management.
Socioeconomic viability	To maintain long-term socioeconomic viability while minimizing short-term socioeconomic losses to all users and dependent parties.
Natural and cultural heritage	To maintain areas for visitor, spiritual, and recreational opportunities which include cultural and ecological features and their associated values.
Education	To foster stewardship of the marine environment by providing educational opportunities to increase awareness and encourage responsible use of resources.

and conservation organizations as well as state and federal agencies. The working group was given the task of considering the use of MPAs for management within the Channel Islands National Marine Sanctuary. The working group determined by consensus that no-take reserves should be used to conserve biodiversity, help sustain fisheries, contribute to opportunities for education and research, and preserve natural and cultural heritage (Table 6.1; Jostes and Eng, 2001). The working group agreed to design a network of no-take reserves to achieve these goals, with the minimum social and economic impacts to the community of users. The primary objectives of the design process were to conserve marine biodiversity and habitats in a network of reserves at a minimum cost in terms of area, boundary length, and economic impacts.

Two advisory panels were appointed by the Sanctuary Advisory Council to assist the working group with acquisition and evaluation of information. The science advisory panel, a body of seventeen marine scientists, was given the task of developing ecological criteria and options for reserve design based on the goals for biodiversity conservation and sustainable fisheries. The science advisory panel also evaluated potential ecological impacts of alternatives developed by the working group. The socioeconomic advisory panel included two economists from the National Oceanic and Atmospheric Administration (NOAA) and four contractors with expertise in economic and social sciences. The socioeconomic advisory panel was given the task of gathering data and evaluating potential social and economic impacts of marine reserves.

Table 6.2. Conservation targets for marine reserves, developed by the science advisory panel to the Marine Reserves Working Group.

Coastline characteristics
Sandy beach
Rocky coast (low exposure)
Rocky coast (high exposure)
Substrate type and depth
Soft sediment (0-30 m)
Hard sediment (0-30 m)
Soft sediment (30-100 m)
Hard sediment (30-100 m)
Soft sediment (100-200 m)
Hard sediment (100-200 m)
Soft sediment (>200 m)
Hard sediment (>200 m)
Additional features
Emergent rocks
Submerged rocky features (pinnacles, ridges, seamounts)
Submarine canyons
Dominant plant communities
Giant kelp
Surfgrass
Eelgrass

[1]Conservation goals listed in Airamé et al. (2003).

The ecological criteria, which guided the design of reserves, were based on the goals established by the working group and the scientific literature. To achieve objectives for biodiversity conservation, marine reserves must include representative habitats in each biogeographic region of the study area (Roberts et al., 2003a). Reserve design also should consider species (or populations) of particular interest, such as endangered or threatened species and species of economic importance (Roberts et al., 2003a). Additional criteria are necessary to address the question of sustainable biodiversity and fisheries. To be sustainable, reserves must be large enough to protect viable habitats and populations of interest. To contribute to sustainable fisheries, reserves must include a portion of the critical habitats and vulnerable life-history stages of targeted species. Connectivity among reserves must be considered in the design of reserves if they are expected to contribute to fisheries through spillover and export. In addition, the design of reserves must consider the distribution of human and natural threats, which could prevent reserves from achieving their objectives (Allison et al., 2003). Using these criteria, a set of conservation targets was identified (Table 6.2) to guide reserve design.

Historically, protected areas have been established using ad hoc approaches on a case by case basis. Geospatial modeling has made it possible to develop more systematic approaches to designing protected areas. As a tool for design, geospatial models help decision-makers find solutions that include all targets through a process that is transparent and defensible (Pressey et al., 1996; Margules and Pressey, 2000).

Methods

Two geospatial tools were used to evaluate the available data and advance the design process. The science advisory panel used SPEXAN (Version 3.1; Ball and Possingham, 1993), to evaluate spatial data and develop options for MPA design. SPEXAN (SPatially EXplicit ANnealing) utilizes several algorithms for selecting reserves, including simulated annealing, which was used in the Channel Islands process. The program runs within the framework of ArcView 3.2 (Environmental Systems Research Institute, Redlands, California), allowing easy visualization of data and solutions. Versions of this tool[1] have been applied to locate terrestrial reserves for The Nature Conservancy and marine reserves in Australia (Lewis et al., 2003), Canada (Ardron, 2002), Mexico (Sala et al., 2002), and Florida (Leslie et al., 2003).

There are a large number of solutions to the complex problem of reserve design. SPEXAN applies a process known as "simulated annealing" to identify sites within the study areas that contribute to management goals (Possingham et al., 2000). To begin the process, the algorithm adds sites until a set of conservation goals are met. Sites are added randomly, but sites that do not contribute to the goals can be rejected. With each change, the algorithm selects the solution that meets the greatest number of goals established by the user (Possingham et al., 2000). During the initial runs of the model, the algorithm explores a broad range of possibilities, including suboptimal solutions. As the analysis proceeds, the algorithm becomes more selective, leading to a final solution that meets the conservation targets at a minimum cost. In the Channel Islands process, the program repeated 1,000,000 annealing iterations per run.

SPEXAN requires the division of a study area into a set of planning units, each with a unique identification number. Planning units can be added together to produce a reserve and subsets of planning units may be aggregated into a network of reserves. Planning units may be regular, as in a grid of squares (Leslie et al., 2003) or hexagons (Ardron et al., 2002). Alternately, planning units may be irregular polygons that reflect natural barriers, such as watersheds or habitat types. Lewis et al. (2003) utilized a combination of regular and irregular polygons of different sizes to describe the Great Barrier Reef Marine Park. Large hexagons (30 km^2) were used offshore where homogeneous habitats were prevalent. Smaller hexagons (10 km^2) were used closer to shore in

non-reef areas. In reef areas, the actual boundaries of the reefs were used as planning units.

Leslie et al. (2003) varied the size of planning units in an analysis of the Florida Keys National Marine Sanctuary. They divided the study area into planning units of 1 km^2 and 100 km^2. Leslie et al. (2003) concluded that the small planning units were on the scale of the habitat patches themselves and that solutions based on analysis with large planning units contained considerably more area (and were less efficient) than solutions based on small planning units.

The size of the planning unit should be at the same scale as the management effort. In the state of California, waters are divided into 10 x 10 square n.m. "fish blocks." Data on fishery landings are collected by the Department of Fish and Game at the scale of fish blocks. Because of their large size, fish blocks were not useful planning units for marine zoning in the Channel Islands National Marine Sanctuary. Discussions about where to establish marine reserves, at a scale of 10 x 10 n.m., would likely break down in conflict over different resources within a single fish block. Smaller planning units that better approximate the scale of resource heterogeneity may facilitate more efficient solutions because they allow a more detailed representation of the biophysical environment. In the Channel Islands planning process, fish blocks were divided into 100 1 x 1 square n.m. planning units (Fig. 6.2). Within the Sanctuary boundary, 1,535 planning units were defined. All of the ecological and economic data were scaled to 1 x 1 square n.m. planning units or, if new data were collected, they were gathered at this scale.

During the process of simulated annealing, the algorithm seeks the minimum cost to achieve all conservation targets. The cost of marine reserves can be identified in various ways, including area and boundary length, or the opportunity or management cost incurred by establishing reserves (Leslie et al., 2003). The demands of conservation goals and minimum cost can be resolved by minimizing the following objective function.

$$\text{Objective Function (t)} = \text{BLM x Boundary(t)} + \sum\left(Penalty[i]\right) + \text{Cost(t)}$$

(Eqn. 1) where t is time as the algorithm proceeds, BLM is the Boundary Length Modifier (discussed below), Boundary(t) is the length of the outer boundary of the selected sites at time t, and Penalty(i) is the penalty for not meeting conservation goal i. Penalty(i) is zero when the conservation goal for target i is included in the reserve network. Cost(t) is the cost value, in terms of area or boundary length and/or missed opportunity, of all sites included in the network at time t (Ball and Possingham, 1999).

The boundary length modifier, BLM, determines the relative importance placed on minimizing the boundary length relative to

minimizing area. A network of reserves of minimum area may be highly fragmented because the algorithm selects only the planning units that contribute to the conservation goals. A fragmented network of reserves may be undesirable from the perspectives of management, enforcement and monitoring. The boundary length modifier is introduced in order to cluster the reserves. The boundary length modifier forces the algorithm to consider the relationship between the perimeter and area of the reserves.

As the boundary length modifier increases, the importance of minimizing the perimeter of the reserve system also increases. If the boundary length modifier is 0, then the algorithm selects the subset of planning units to meet conservation targets at a minimum total cost. If the boundary length modifier is greater than 0, the algorithm selects the subset of planning units to both meet conservation targets and reduce the ratio of boundary length around the network of reserves to total area in reserves. The larger the boundary length modifier, the more aggregated the planning units within individual reserves. In the Channel Islands process, the boundary length modifier was set at a range of values (0, 0.2, and 1) to explore the behavior to the model. The science advisory panel selected a boundary length modifier of 1, in which the perimeter and area of the reserves in the network were jointly minimized, to generate a set of alternatives for consideration by the working group.

SPEXAN provides an opportunity for users to input the "cost" of each planning unit. The cost may be equal to the total value of commercial and recreational activities within the planning unit. Alternatively, the cost may be the sum of relative contributions of each unit to each commercial and recreational activity, thus normalizing the scale so that activities that generate low revenue are valued equally

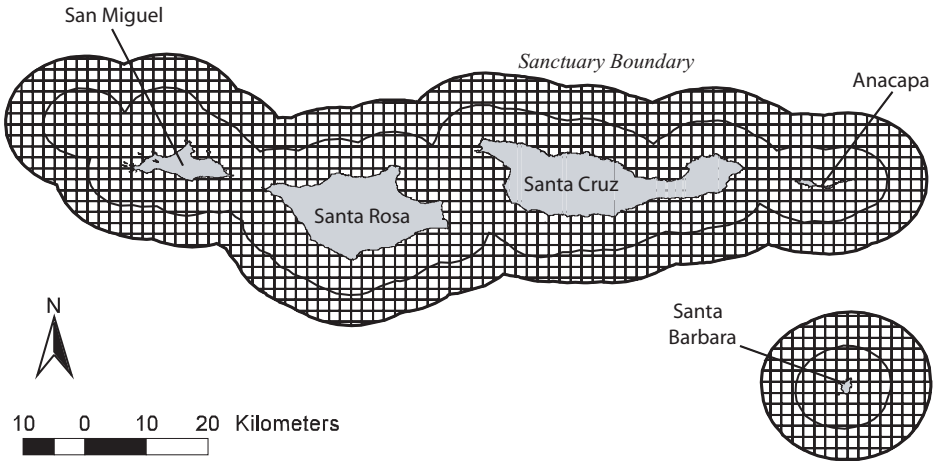


Figure 6.2. Planning units (1 x 1 square nautical mile) within the Channel Islands National Marine Sanctuary.

with activities that generate high revenue. If no cost is included in the dataset, then the cost function defaults to the area of each planning unit. In the Channel Islands case, the default cost function was used in the SPEXAN analysis and the cost of each planning unit was equal to its area.

Conservation Targets for Reserve Design

To generate a suite of reserve designs, SPEXAN requires continuous data, a list of explicit conservation targets, and goals for representation of each target. In the Channel Islands case, scientists organized ecological data according to biogeographic patterns. Three primary regions were identified based on sea surface temperature (The Institute for Computational Earth System Science (ICESS) at the University of California, Santa Barbara, unpublished data) and composition of marine communities. The northwestern Channel Islands, including San Miguel and Santa Rosa islands, are bathed in the cool waters of the California Current. The species in this region are similar to those found along the west coasts of California, Oregon, and Washington. The eastern Channel Islands, including Anacapa and Santa Cruz islands, are influenced by the California Countercurrent, which carries warmer waters north along the coast. The species in the region influenced by the countercurrent are similar to those along the coast of Baja California. The two currents collide in the Channel Islands region, mixing in a transition zone around Santa Barbara Island and southern Santa Rosa and Santa Cruz islands. The species composition of the transition zone is a unique blend of the communities from the northern and southern biogeographic provinces.

Because of the uniqueness of each of the biogeographic regions, the SPEXAN model was used independently within each of the three regions to identify potential reserves. The science advisory panel used information on average sea surface temperature and bathymetry to draw working boundaries for the biogeographic regions. In the areas of sharpest transition in temperature, the boundaries were drawn along the deepest bathymetric contours (Airamé et al., 2003). The science advisory panel acknowledged that the locations of the boundaries vary over time with climate. During El Niño cycles, the northern boundary of the California Countercurrent may shift tens of miles to the north, retreating during La Niña conditions. The dynamic zone of advance and retreat was classified as a transition between two biogeographic regions and was evaluated as a unique region.

The biogeographic regions are not distributed equally throughout the Channel Islands National Marine Sanctuary. Most of the northern Channel Islands are bathed in the cool, nutrient-rich waters that characterize the California Current. Only Anacapa and east Santa Cruz islands are situated within the warmer waters of the California Countercurrent. Because the biogeographic regions differ in size, the SPEXAN analysis could not be applied in the same way to each region.

Instead, the number of runs of the model was proportional to the size of each bioregion and varied from 300 to 800. By adjusting the number of runs for the total area within each region, the opportunity for selecting a planning unit for a reserve was relatively equivalent across biogeographic regions. The results across all three biogeographic regions were pooled for the purposes of visualization and discussion.

Scientists identified conservation targets of different habitats and species in each biogeographic region (Table 6.2). Conservation targets included coastline characteristics, substrate type and depth, unique physical features, dominant plant communities, seabird colonies, and pinniped haul-out sites (Airamé et al. 2003). In the Channel Islands region, approximately 70% of the coastline is rocky whereas 30% is sandy. About 40% of the benthic substrate in shallow subtidal zone (0-30 m) is rocky. Giant kelp (*Macrocystis pyrifera*) is the dominant alga in shallow subtidal rocky habitats. Surfgrass (*Phyllospadix* spp.) is common in shallow rocky subtidal habitats. In a few sheltered locations, shallow sandy substrate supports populations of eelgrass (*Zostera* spp.). In deeper waters on the continental shelf, the sediment is primarily sand, silt or unconsolidated rock with only a few rocky features scattered throughout the area. A deep submarine canyon divides the southern edges of Santa Rosa and Santa Cruz islands. Initially, all submerged rocky features were identified as unique. However, this classification of submerged rocky features constrained the reserve options identified by SPEXAN because each unique habitat was selected as a potential reserve area in every run of the model. Some flexibility was introduced by generalizing the habitat classification to include broader groups, such as emergent rocks, submerged pinnacles, and submarine canyons, rather than identifying each individual feature.

The choice of a particular habitat classification scheme can significantly influence the outcome of the model (Leslie et al., 2003). A simple habitat classification was developed for the Channel Islands process, based on available data and ecological differences between habitats. Ecological communities were characterized by sediment type and bathymetry. Benthic sediments were divided into two groups: soft (mud, silt, sand, cobble, and unconsolidated rock) and hard (boulders, rocky reefs, and bedrock). Bathymetry was divided into four groups: (1) the euphotic zone (0-30 m depth), (2) the shallow continental shelf (30-100 m depth), (3) the deep continental shelf (100-200 m depth), and (4) the continental slope (>200 m depth). The outer boundary of the Sanctuary falls near the continental shelf break, and therefore, most of the Sanctuary is in depths shallower than 200 m. For case studies in much deeper waters, additional depth zones should be specified. Dominant algae and plant communities, including giant kelp, surfgrass, and eelgrass, also were considered important conservation targets because these species provide shelter and food for distinct marine communities. The conservation targets are summarized in Table 6.2.

Table 6.3. Selected species of interest in the Channel Islands National Marine Sanctuary (from Airamé et al. 2000).

Breeding seabirds	*Scientific Name*
California Brown Pelican	*Pelecanus occidentalis californicus*
Pelagic Cormorant	*Phalacrocorax pelagicus*
Double-crested Cormorant	*Phalacrocorax auritus*
Brandt's Cormorant	*Phalacrocorax penicillatus*
Common Murre	*Uria aalge*
Pigeon Guillemot	*Cepphus columba*
Xantus's Murrelet	*Synthliboramphus hypoleucus*
Rhinoceros Auklet	*Cerorhinca monocerata*
Cassin's Auklet	*Ptychoramphus aleuticus*
Leach's Storm-petrel	*Oceanodroma leucorhoa*
Ashy Storm-petrel	*Oceanodroma homochroa*
Black Storm-petrel	*Oceanodroma melania*
Black Oystercatcher	*Haematopus bachmani*
Snowy Plover	*Charadrius alexandrinus*
Western Gull	*Larus occidentalis*
Pinnipeds	*Scientific Name*
California sea lion	*Zalophus califonianus*
Northern fur seal	*Callorbinus ursinus*
Northern elephant seal	*Mirounga Angustirostris*
Harbor seal	*Phoca vitulina*

In addition to developing the habitat classification, the science advisory panel assisted the working group with the identification of species of interest in the Channel Islands (Airamé et al. 2000). The list of species of interest includes species of economic and recreational importance; keystone or dominant species; candidate, proposed, or species listed under the Endangered Species Act; species that have exhibited long-term or rapid declines in harvest and/or size frequencies; habitat-forming species; indicator or sensitive species; and important prey species. The list excludes species that are incidental, at the edge of their ranges, or highly migratory.

Distributions of breeding seabirds and haul-out sites for pinnipeds also were utilized as conservation targets for the process of locating potential reserves (Table 6.3). Fifteen species of seabirds, including the endangered California brown pelican (*Pelecanus occidentalis californicus*) and Western snowy plover (*Charadrius alexandrinus nivosus*), roost and nest along the coastline of the Channel Islands. Important locations for breeding seabirds include Anacapa and Santa Barbara islands, Prince Island (off of San Miguel Island), Arch Rock (off of northeastern Santa Cruz Island), and Sutil Island (off of Santa Barbara Island).

Five pinniped species, including the California sea lion, northern elephant seal, harbor seal, and northern fur seal, commonly haul out

Table 6.4. Selected species of commercial importance in the Channel Islands National Marine Sanctuary (from Leeworthy and Wiley 2000).

	Scientific Name	*Average Value (1996-1999)*
Top invertebrate fisheries		
Market squid	*Loligo opalescens*	$11,249,837
Sea urchin	*Strongylocentrotus franciscanus*	$5,265,233
California spiny lobster	*Panulirus interruptus*	$922,098
Prawn	*Pandalus platyceros*	$703,186
Abalone (historical)	*Haliotis* spp.	$178,027
Crab	*Cancer, Loxorhynchus* spp.	$343,664
Sea cucumber	*Parastichopus* spp.	$167,700
Top commercial fisheries		
Rockfish	*Sebastes* spp.	$549,319
Anchovy and sardine	*Engraulis mordax, Sardinops sagax*	$234,367
California sheephead	*Semicossyphus pulcher*	$235,928
Flatfish	Pleuronectidae, Bothidae	$183,871
Mackerel	*Auxis, Scomber Trachurus* spp.	$67,119
Sculpin and bass	*Leptocottus, Icelinus, Paralabrax, Stereolepis, Atractoscion*	$60,327
Tuna	*Thunnus, Katsuwonus, Sarda, Euthynnus*	$205,884
Swordfish	*Xiphias gladius*	$39,090
Shark	Chondrichthyes	$34,751
Other commercial activities		
Kelp harvesting	*Macrocystis pyrifera*	$5,000,000

on beaches in the Channel Islands. San Miguel Island is the most important haul-out for pinnipeds, supporting populations of up to 80,000 California sea lions and 50,000 northern elephant seals (DeLong and Melin, 1999). Harbor seals are found throughout the Channel Islands region.

Information about the distribution and abundance of fishes and invertebrates in the Channel Islands region was available primarily from fisheries records. Fisheries data were not used as a part of the design process because of the potential conflict between conservation targets and fisheries interests. To meet conservation goals, the network of reserves must include all species of interest, including those that are fished. To minimize the impact on commercial and recreational activities, the reserves must not overlap the areas of greatest use. If fisheries data are used to define species distributions, then these goals will conflict during the process of locating potential reserves. The fisheries data were excluded from the SPEXAN analysis in order to produce a suite of

alternative solutions that were clearly responsive to the conservation goals. Fisheries data (Table 6.4) were used in a separate economic impact analysis to evaluate potential costs of reserve designs (Leeworthy and Wiley, 2002).

Conservation Goals for Reserve Design

The science advisory panel used SPEXAN to explore scenarios for reserve networks that represent the conservation targets efficiently with respect to both the total area and perimeter of the network. To run SPEXAN, the user must specify conservation goals, or fractions of each conservation target that must be represented in the final set of reserve sites. In some cases users may weight conservation targets on the basis of ecological importance, rarity, or vulnerability/threatened status. For example, Sala et al. (2002) required that 100% of the coral communities, seagrass beds and spawning aggregations be included in a network of reserves in the Gulf of California. Other habitats, such as rocky or sandy substrate, were included at levels of 20% or more. Another approach is to set aside conservation targets in proportion to their abundance in the study area (Roberts et al., 2003a). This approach is used when no information is provided about the relative importance of different targets. In the Channel Islands process, the science advisory panel established conservation goals in proportion to the abundance of each target in the study area.

Different conservation goals produce solutions that differ in their spatial extent and potential locations of reserves. To explore the model's behavior, conservation goals were set at three different levels: 30, 40, and 50%, based on an evaluation of the total reserve size needed to achieve goals established by the working group (Airamé et al., 2003).

Evaluation of Reserve Designs

As standard output, SPEXAN produces an evaluation of each solution. The evaluation indicates the degree to which a particular design meets conservation goals. The best solution is the one with the lowest value of the objective function (Eqn. 1), which balances conservation goals with a weighted sum of area and boundary length. For each solution, the program provides information about the total area of the network of reserves, the area of each conservation target within reserves, and the proportion of the target met. In some cases, particularly if the conservation target is common, it may be overrepresented in the network because of constraints imposed by rare targets.

After solutions were generated and evaluated, the science advisory panel conducted an "irreplaceability analysis" (Leslie et al., 2003) to determine how many times each planning unit was included in a final solution. The program generated this information as a list of summed solutions indicating the number of times planning units were included

in a final solution. The summed solutions were normalized to the percent of the total number of runs and converted to a map showing the percent use of each planning unit in the portfolio of final solutions.

From the hundreds of alternatives generated using SPEXAN, the science advisory panel identified similar designs using a clustering program, PRIMER v.4, Plymouth Routines in Mulitvariate Ecological Research (Clarke and Warwick, 2001). The 100 top ranking solutions were selected from the total runs for each biogeographic region and the Bray-Curtis similarity between solutions was calculated. Clusters of solutions were grouped together at 60% similarity, creating five clusters of solutions for each biogeographic region at each conservation goal. If the grouping algorithm produced more than five groups, the group with the lowest high score was removed from the analysis. From each cluster, scientists selected those that included the greatest number of habitats and species of interest, represented in patches of adequate size, in the most efficient configuration (or smallest boundary length and area). The set of solutions, which all met conservation goals and provided a range of spatial options, were delivered to the working group for consideration.

Application of CI-SSAT to Reserve Design

Members of the working group contributed their own expertise to modify designs or generate alternatives to the designs developed by the science advisory panel. The working group utilized a geospatial tool, known as the Channel Islands Spatial Support and Analysis Tool (CI-SSAT; Killpack et al., 2000), to advance the policy discussion. The tool was designed by NOAA's Coastal Services Center to facilitate interaction between working group members and provide a platform to conduct spatial analysis (Killpack et al., 2000). CI-SSAT provided a common framework for visualization, manipulation, and analysis of data for the purpose of designing marine reserves. CI-SSAT was tested during this process and the tool will be refined for general use.

CI-SSAT is a computer-based environment for viewing and evaluating information (Killpack et al., 2000). The tool was developed with Environmental Systems Research Institute (ESRI) ArcView 3.2 and Microsoft Visual Basic 6.0 software. The user interface resembles a geographic information system (GIS) with spatially explicit data relevant to the problem. Data can be selected or hidden by checking a box beside the data label. Once the data have been selected, the user can zoom in or out to obtain broader or more detailed views.

In the Channel Islands process, CI-SSAT contained both ecological and socioeconomic data. The map of conservation "hotspots," generated by irreplaceability analysis in SPEXAN, was included in the CI-SSAT. Other ecological data, including distributions of sediments, giant kelp, seagrasses, seabirds, and marine mammals, were available for viewing and basic querying. Ten options for marine reserves, generated by

SPEXAN, were available for purposes of comparison. The tool also contained maps showing revenue gained from the most important commercial industries and usage by various recreational activities. Proprietary data describing the economic value of each planning unit to each fishery was not released. However, maps of the revenue for aggregate fishing, squid fishing and kelp harvesting were included in the tool (Leeworthy and Wiley, 2002). Additionally, the tool contained maps of usage by recreational fishing and diving industries and private recreational fishers and divers. Ethnographic data showing the distributions of habitats and species, based on interviews with local citizens who lived, worked, and recreated around the Channel Islands for many years, also were included (Kronman et al., 2000). Anecdotal descriptions of declines or increases in abundance and shifts in distribution of species of interest also were captured in the dataset.

All datasets were referenced to a common base map consisting of a 1 x 1 square n.m. grid. These planning squares were used as the common units for all the data layers and the SPEXAN analysis. The data were displayed in raster format in CI-SSAT.

Selection and Weighting of Criteria

CI-SSAT offers the opportunity for users to weigh various criteria for reserve design (Fig. 6.3). In the Channel Islands process, the criteria were based on goals established by the working group. The tool offered two primary criteria: ecological and socioeconomic. In CI-SSAT, these conceptual criteria were tied to a dataset for evaluation ("evaluation layer"). Each evaluation layer is a synthesis of many individual datasets representing the probability that a particular goal will be met in a particular area. Each planning unit in the evaluation layer uses a common ranking unit that describes how well that unit satisfies a

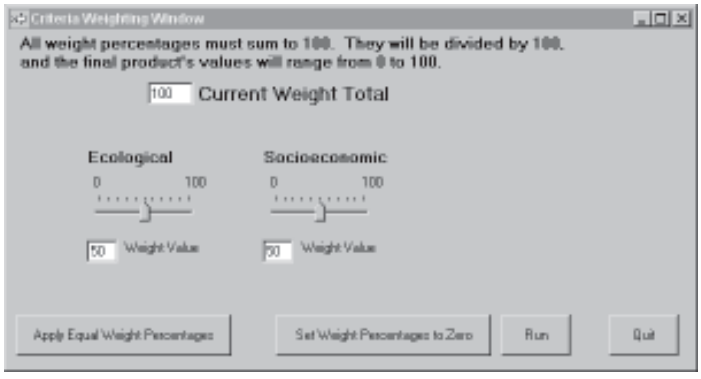


Figure 6.3. Dialog box for the criteria weighting tool for CI-SSAT. Two criteria were provided for the Channel Islands process: ecological and socioeconomic. The weights for all criteria must sum to 100%. The user may adjust the weight of a particular criterion by moving the slider bar to the desired percent.

particular goal. The probability values range between 0 and 100, where 100 is the highest rank for a particular criterion.

The science advisory panel developed the ecological criterion layer using SPEXAN (see earlier discussion). The ecological criterion layer was the map of conservation value resulting from the irreplaceability analysis (Fig. 6.4). The ecological evaluation layer input to CI-SSAT therefore utilized all of the ecological data and conservation targets considered in SPEXAN analysis.

The socioeconomic criterion layer was based on revenue and usage (Fig. 6.5). For some commercial industries, including squid fishing and kelp harvesting, the total revenue per species fished was available at a scale of 1 x 1 square n.m. For other commercial industries and all recreational activities, the total usage was estimated in person-days per year for each planning unit. Because industry values were represented in different units, it was not possible to calculate a straight summation of the total revenue per planning unit. Instead, each individual socioeconomic dataset was normalized from 0 to 100 and the values for different commercial industries and recreational activities were summed. Normalization of the summed data created a relative ranking of planning units based on revenue or usage. Areas of high revenue or usage were identified as undesirable locations for marine reserves. Locations of low revenue or usage were ranked highly in the section of marine reserves. Thus, a value of 100 for the socioeconomic

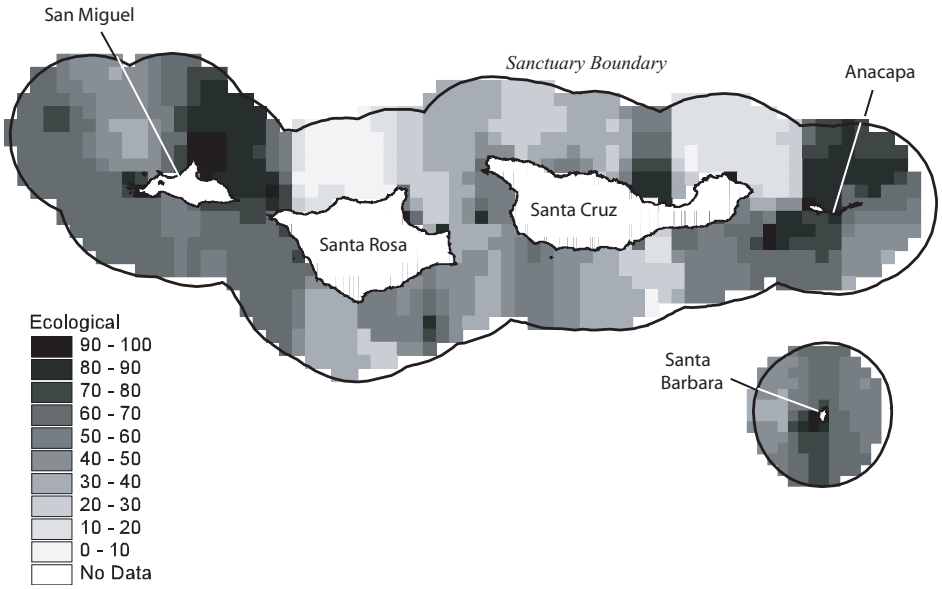


Figure 6.4. Ecological criterion layer for CI-SSAT. The data were derived from the irreplaceability analysis in SPEXAN. The grayscale represents the conservation value, or the number of times each planning unit was included in a final solution. Areas shaded in black or dark gray were included more often than areas shaded in light gray or white.

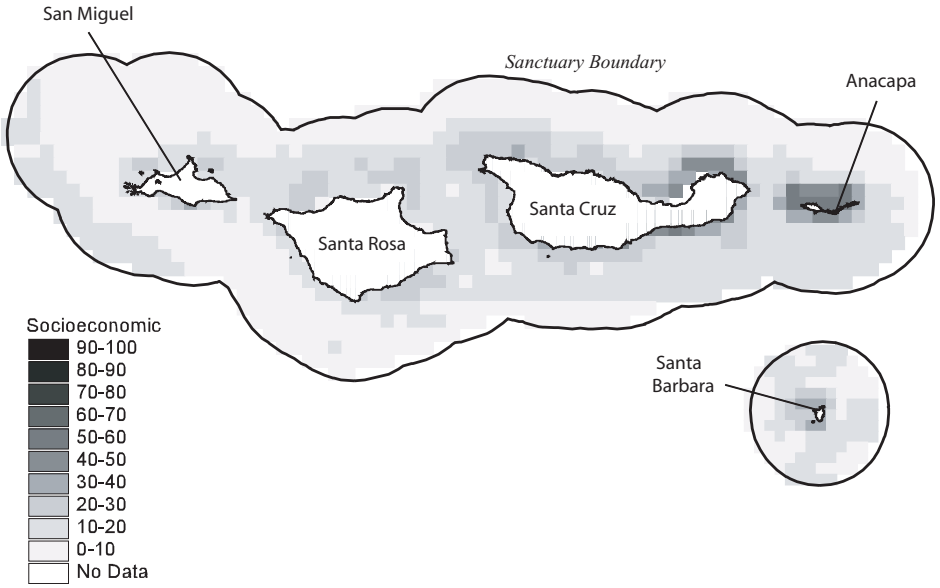


Figure 6.5. Socioeconomic criterion layer for CI-SSAT. The data were derived from the economic impact analysis conducted by Leeworthy and Wiley (2000). The grayscale represents the relative economic value estimated as a percentage of each of the commercial and recreational activities conducted in the Channel Islands National Marine Sanctuary. Areas shaded in black or dark gray are more valuable, in terms of commercial and recreational activity, than areas shaded in light gray or white.

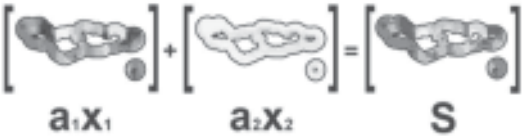


Figure 6.6. Criteria weighting analysis in CI-SSAT. Each criterion data layer (x_n) is weighted (a_n) according to user values and added to other weighted criterion data layers to produce a base map (S).

evaluation layer in CI-SSAT represents a planning unit with the highest probability of minimizing potential socioeconomic impacts.

CI-SSAT performs a simple algorithm to rank the suitability of various locations for marine reserves (Fig. 6.6). The algorithm, which is usually known as simple additive weighting or weighted linear combination, combines the criteria layers according to Eqn 2,

$$a_1x_1 + a_2x_2 + a_3x_3 + \ldots a_nx_n = S$$

where a_n is the weight value ($\_ a_n = 1$), x_n is the criterion values for the planning unit bearing a value between 0 and 100, and S is the resultant outcome data cell value ranking between 0 and 100. A high value represents a suitable area for a marine reserve based on the chosen weights and criteria (Killpack et al., 2000).

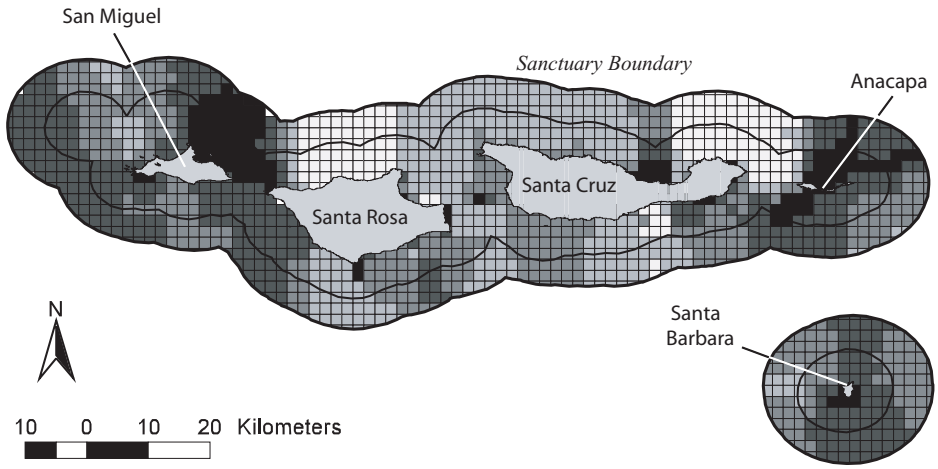


Figure 6.7. Results of the criteria weighting analysis in CI-SSAT. Each criterion data layer (x_n) is weighted (a_n) according to user values and added to other weighted criterion data layers to produce this base map (S). In this example, the ecological and socioeconomic criteria were weighted, each at 50%, to produce the resulting base map. High values (shaded in dark gray) represent suitable areas for reserves based on the chosen weights and criteria.

Each weighting process is unique and based on values held by the user. If the user desires to produce a zoning plan based entirely on ecological criteria, the analysis will reflect only ecological data and the conservation "hotspots" will be identified based on habitat heterogeneity, species diversity, rare habitats and species, or other criteria identified in the ecological evaluation. If the user desires to minimize economic impact of a zoning plan, then the CI-SSAT analysis selects areas that have low overlap with existing commercial and recreational consumptive activities. If the user desires to balance ecological with economic criteria, the areas of conservation value will be selected in the sites that minimize economic impacts.

The user selects a number between 0 and 100 to represent the weighting for each criterion, with the sum of all weights no greater than 100. For purposes of analysis, these values are divided by 100 to standardize to values between 0 and 1. Then, the weight value and criteria data grid are multiplied and all weighted criteria grids are summed together using raster addition (Fig. 6.6). The resulting values for each planning unit, ranging between 0 and 100, indicate the potential of each planning unit to achieve the desired outcome based on user specifications. The results of the weighting process are displayed as a raster or grid map with high numerical values representing areas that meet the criteria and the weighting scheme of the user.

Once the analysis is completed, the user can use the output layer as a base map (Fig. 6.7) to develop a plan for marine zoning. The base map indicates the relative value of each planning unit for a reserve, based on the compromise among different criteria weighted by the user. In the Channel Islands case, the working group decided not to use the CI-SSAT function to weight criteria. Members of the working group agreed that the criteria should be weighted equally, but they were unwilling to work from a compromised map. Thus, CI-SSAT was more useful for visualization, exploration, and comparison of zoning plans developed by working group members.

Exploration and Comparison of Options in CI-SSAT

The user also has the ability to query some of the data in CI-SSAT. The tool contains two predefined query functions. Ecological queries focus on information provided by the science advisory panel and on habitat types. Data such as kelp habitat, surfgrass, eelgrass, coastline geomorphology, benthic sediments, and bird and mammal densities were available for query. The socioeconomic queries focus on the consumptive industries operating in the waters near the Channel Islands. Revenues from aggregate commercial fishing, squid fishing and kelp harvesting were available for query. Usage of recreational fishing and diving industries, and private recreational fishing and diving also were available for query.

Queries begin by identifying a particular location in the study area. Simple drawing features in CI-SSAT allow users to create rectangles, circles, or irregular polygons to represent potential reserves. Additionally, the user may indicate an area that should be excluded from further analysis. Examples include areas that already are protected in reserves, areas of particularly high commercial or recreational value, or areas that are particularly vulnerable to human threats or natural disturbances (Allison et al., 2003). If the exclusion areas are located in a GIS shapefile, they can be integrated easily with the data in CI-SSAT. Once exclusion areas have been identified, the data within those areas will be excluded from further analysis.

Once the user has located a potential reserve, a quick evaluation provides the user with (1) information about the amount of each habitat or portion of species' range captured within the reserve boundaries; and (2) the potential impact of the reserve on major commercial industries and recreational activities. The query window returns a table of values for the analyzed area and compares these values with the total Sanctuary area.

By allowing the user to iteratively adjust the boundaries to include more of a particular habitat or species, or to reduce the impact to a particular industry or activity, CI-SSAT facilitates development of a marine zoning plan to meet the user's criteria. The tool supports rapid

modification and real-time evaluation of alternatives. The analysis facilitates negotiation among users by providing quantitative information to supplement personal knowledge.

In the Channel Islands process, the working group utilized CI-SSAT to visualize and query data. The working group used the tool at public meetings on several occasions to develop and evaluate alternative designs. Initially, the working group divided into four subgroups to consider alternatives to satisfy the collective goals of the group. Each subgroup was charged with the task of creating three alternatives. A technical facilitator was assigned to each subgroup to assist with computer operations so that the subgroups would not be distracted by the complexity of the support tool. Each group considered three standard weighting schemes to begin their analysis: (1) 50% ecological and 50% socioeconomic; (2) 75% ecological and 25% socioeconomic; and (3) 25% ecological and 75% socioeconomic (Killpack et al., 2000). However, the weighting process was discarded due to concerns that results from the criteria weighting analysis were compromised. Working group members expressed strong conviction that all goals should be considered equally and that compromises should be avoided, if possible. The working group proceeded with development of designs by using the data viewing and querying functions in CI-SSAT. Some working group members drew alternatives on paper maps. If paper maps were used, a technical facilitator recreated the design concepts in CI-SSAT for further evaluation. All maps were evaluated and results returned to working group members for discussion (Killpack et al., 2000).

Results from SPEXAN

The science advisory panel utilized SPEXAN to evaluate ecological data for reserve design. Different scenarios were run to explore the behavior of the model. Changes in the boundary modifier (at conservation goals of 30% of each target) affected the spatial configuration of the network of reserves (Fig. 6.8). Application of SPEXAN with no boundary modifier resulted in highly fragmented network (Fig. 6.8a). Without a boundary length modifier, the final solutions generally are so highly fragmented that they would be impossible to implement and enforce. Increases in the boundary modifier to 0.2 and 1 contributed to clustering of potential reserve sites (Fig. 6.8b and 6.8c). The science advisory panel selected a boundary length modifier of 1 to produce solutions that were more likely to meet standards for management, enforcement, and monitoring as described in Roberts et al. (2003a).

The most efficient reserve system (BLM=0) at a conservation goal of 30% of each target included 404 planning units. A change in the boundary length modifier from zero to 0.2 resulted in an increase of twelve planning units and a decrease in the total perimeter of the best reserve system. Further increasing the boundary length modifier to 1 resulted in an increase of forty-one planning units to the area of the

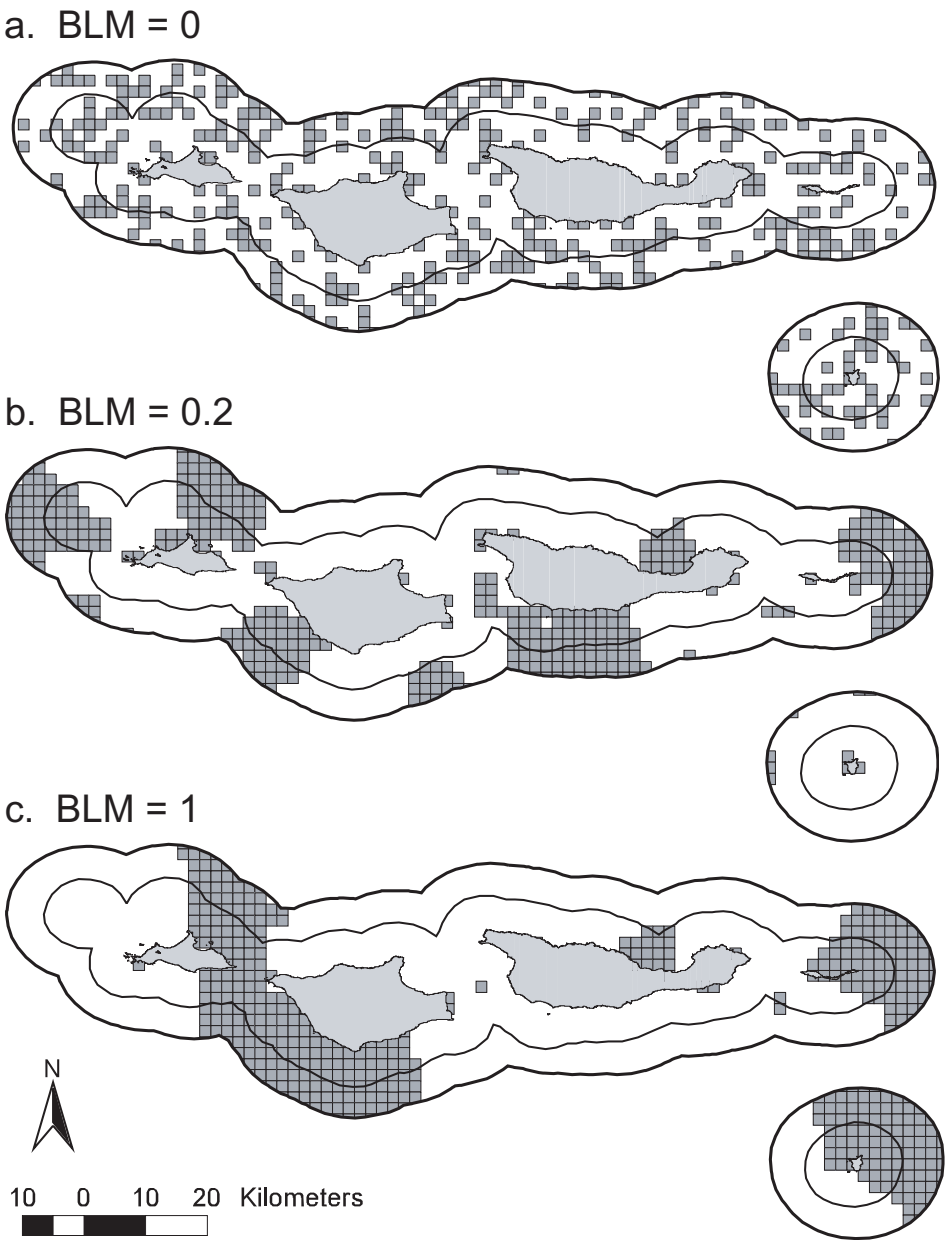


Figure 6.8. Changes in the boundary modifier allow the analyst to control the spatial configuration of the network of reserves. Application of SPEXAN with no boundary modifier results in a highly fragmented network (a). Increases in the boundary modifier contribute to clustering of potential reserve sites (b and c).

network and a further decrease in the perimeter (Table 6.5). The most highly connected networks (BLM = 1) had just 10% of the total perimeter of solutions generated without regard to spatial clustering (BLM = 0). The increase in the boundary length modifier resulted in a more clustered set of reserves (Fig. 6.8c).

A change in the conservation goal for each target affected the total area and perimeter of the network of reserves. Figure 6.9 shows the total network size and perimeter for conservation goals of 30, 40, and 50% of each target. The most connected reserve system (BLM=1) at a conservation goal of 30% of each target included 457 planning units. A change in the conservation goal from 30 to 40% resulted in an increase of 152 planning units and a decrease in the total perimeter of the best reserve system. Further increasing the conservation goal to 50% resulted in an increase of 146 planning units to the area of the network and a further decrease in the perimeter (Table 6.6). The conservation goals were met in all scenarios because no constraints were placed on the total area of the network of marine reserves. With an increase in the conservation goal for each target, the total area and perimeter of the network increased (Fig. 6.9).

Through the process of evaluating different conservation goals, the science advisory panel determined that larger conservation goals generated solutions with more flexibility in potential locations of marine reserves than smaller conservation goals. Analyses conducted at the lowest conservation goals produced the least amount of flexibility about potential sites. At low conservation goals, the algorithm always selected the rarest conservation targets for core locations for marine reserves. The analyses conducted at the highest conservation goal produced the greatest number of alternative locations for reserves. In the process of developing a bigger network of marine reserves, the algorithm compared hundreds of similar planning units that contained common habitats or species. The map of conservation value not only highlighted the areas where rare habitats or species were found, but also indicated alternatives for protecting more common habitats and species in a variety of locations (e.g., not just in the area adjacent to rare habitats).

Table 6.5. Reserve system solutions generated by simulated annealing at three different levels of clustering with conservation goals of 30 percent of each target.

BLM	*Best Area (PU)*	*Min Area (PU)*	*Max Area (PU)*	*Best Perimeter (n.m.)*	*Minimum Perimeter (n.m.)*	*Maximum Perimeter (n.m.)*
0	404	403	409	1089.8	990	1165.4
0.2	416	409	422	246.9	236.3	427.5
1	457	435	483	102.7	89.6	196.3

BLM, Boundary Length Modifier; PU, Planning Units; n.m., nautical miles

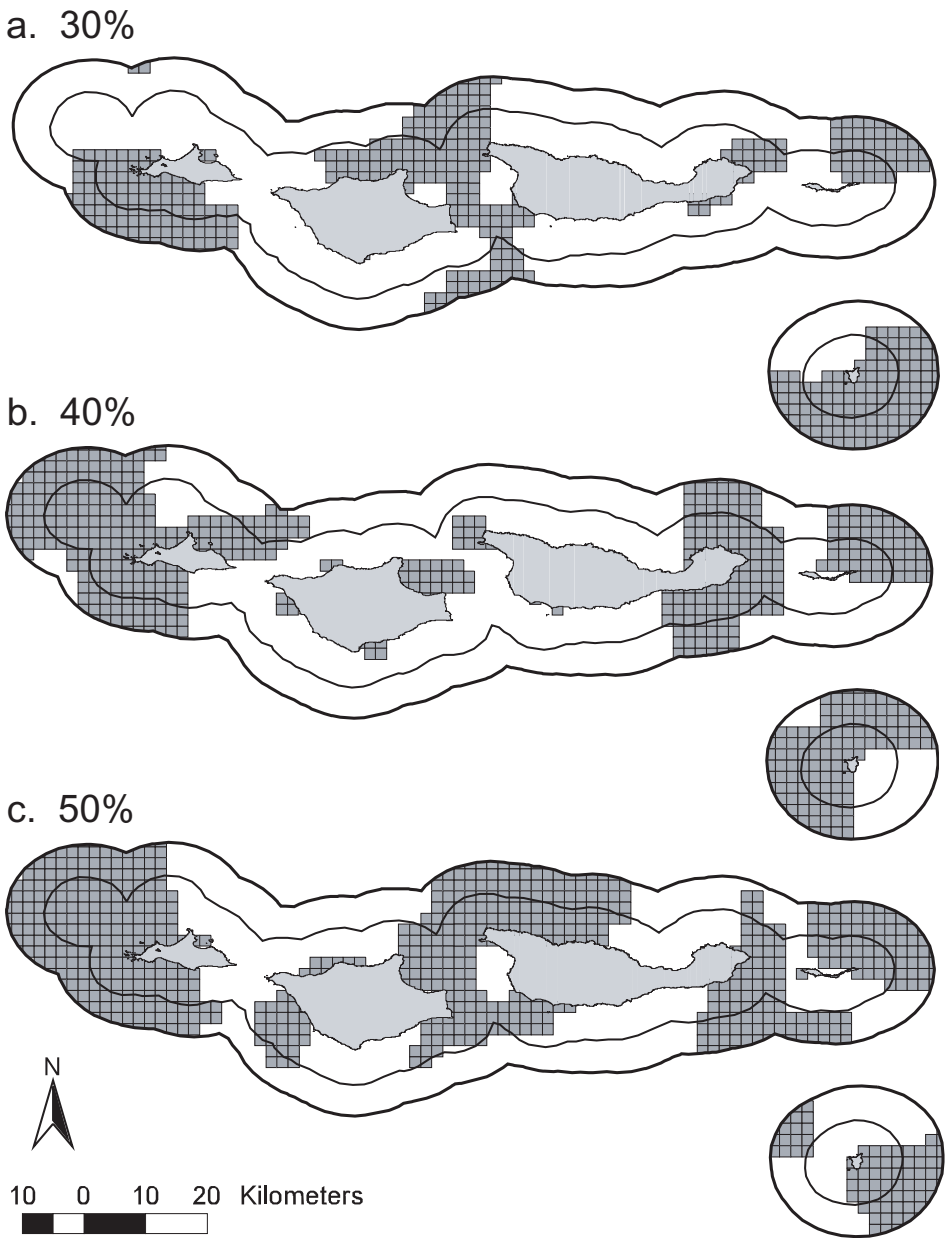


Figure 6.9. Changes in the conservation goals alter the spatial extent of reserves. Conservation goals were set at (a) 30%, (b) 40%, and (c) 50%. Increasing the conservation goals altered the spatial extent and configuration of reserves.

Rarity of conservation targets constrains the potential locations of reserves, particularly at low conservation goals. If a conservation target is rare, but required in the solution, the algorithm has no choice but to select a portion of the rare target. If the conservation goal is small and the total reserve size is minimized, common targets (e.g., soft benthic substrate) generally are added to reserves adjacent to rare targets.

In the Channel Islands process, eelgrass was one of the rarest habitats, found only in sheltered coves on sandy substrate (Engle, J., unpublished data). All of the final solutions from the model included a substantial portion of the eelgrass beds. Other—more common—conservation targets, such as soft benthic substrate, were added to reserves in the vicinity of the eelgrass beds in order to minimize the overall area and perimeter of the network of reserves.

With larger conservation goals, the selection process is more flexible. Rare habitats are included, but some common habitats may be included in areas that are not adjacent to the rare habitats. The flexibility of evaluating the problem with high conservation goals is useful in discussions about policy because users can select from a range of options rather than being constrained to the regions around the rarest habitats.

Using SPEXAN, the science advisory panel generated hundreds of solutions to the complex problem of reserve design. The solutions were sorted, using a cluster analysis in PRIMER v. 4 (Clarke and Warwick, 2001) and solutions were grouped at 60% similarity. By sorting the solutions, the science advisory panel was able to identify the range of geospatial alternatives that meet the same set of conservation goals. The most efficient solution from each cluster at 30, 40, and 50% was selected for consideration by the working group. Figure 6.10 shows the most efficient solutions, in which the SPEXAN objective function is minimized, from five different groups of solutions. Although these solutions differ in their geospatial coverage, all solutions include 30% of each conservation target.

The hundreds of solutions to the problem of reserve design were summarized by describing the number of times each planning unit was included in a final solution. The resulting map (Fig. 6.11) indicates the relative contribution (or "conservation value") of each planning unit to the conservation goals. Twenty-two planning units were chosen more than 75% of the time to meet goals of 30% of each conservation target. These sites were represented consistently in the solutions, suggesting that they may be priority sites for protection. In the Channel Islands case, the priority sites were located off the northeast coast of San Miguel Island, a highly productive region that supports numerous breeding seabirds and productive kelp forests; on the north side of Anacapa Island, and on the south side of Santa Barbara Island. A large number of planning units (576) were chosen less than 25% of the time, suggesting that these may not be suitable sites for reserves. Five planning units were never chosen during the runs. A planning unit that was not chosen

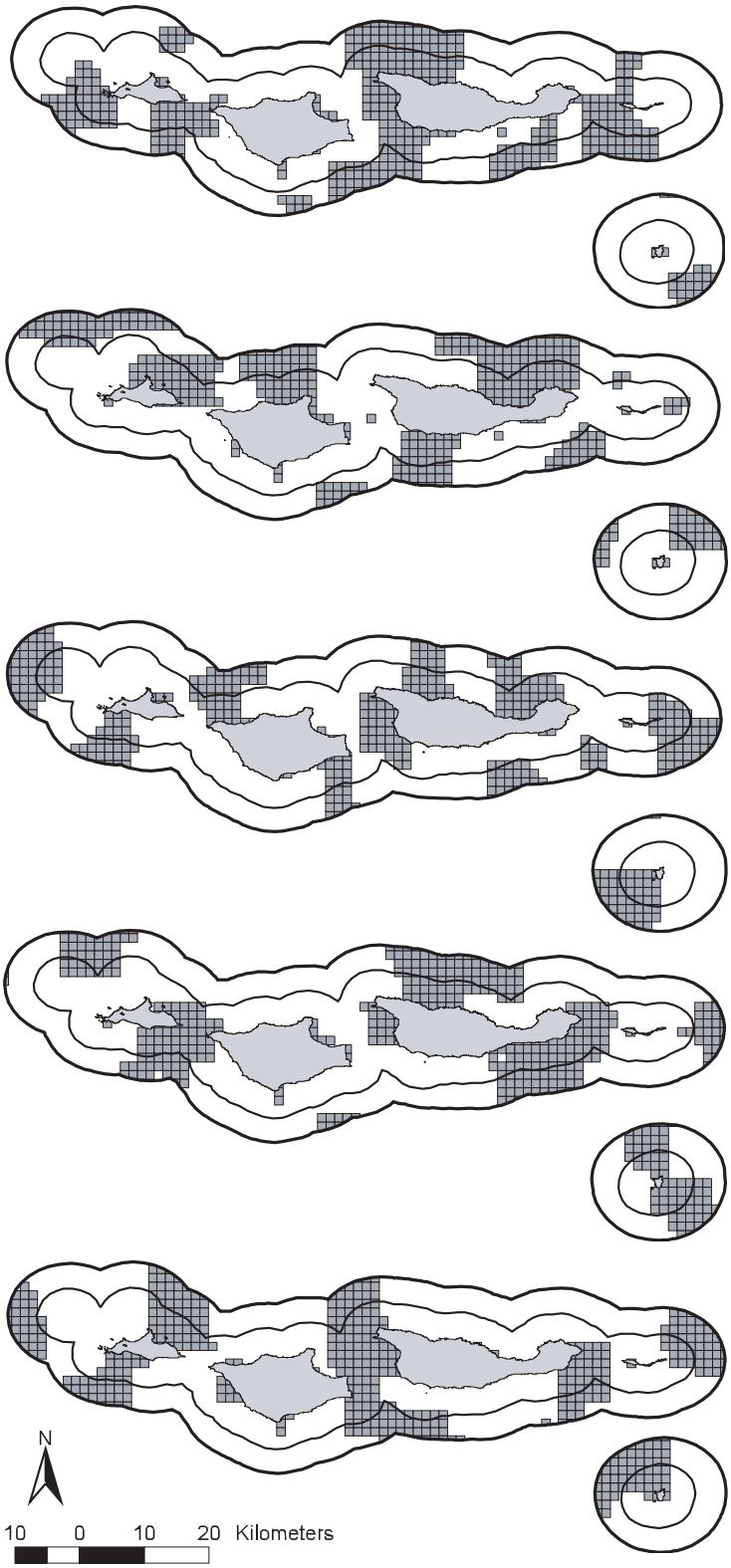


Figure 6.10. The model produced a large number of solutions to the complex problem of reserve design. Five solutions are shown for the goal of 30% representation of all conservation targets. All solutions meet the conservation goals, providing flexibility in the reserve design process.

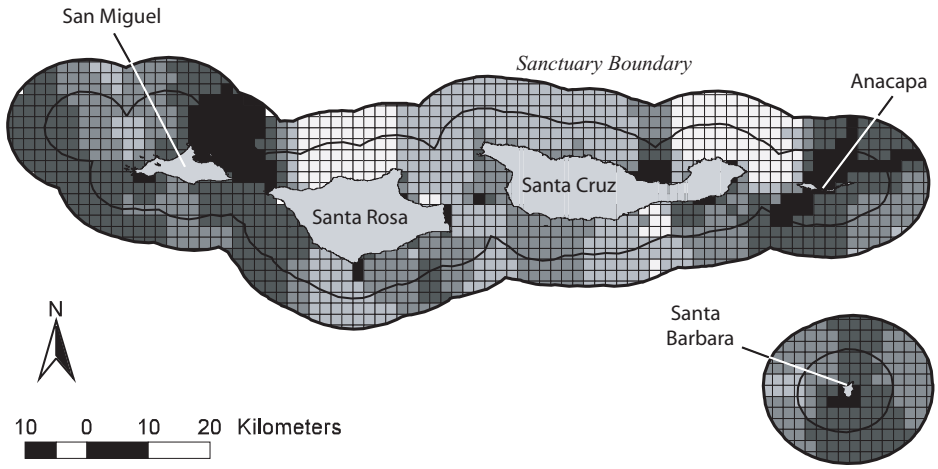


Figure 6.11. Conservation value of planning units in the Channel Islands National Marine Sanctuary. The conservation value is the number of times each planning unit was included in a solution. Black and dark gray areas were included in more than 75% of the solutions whereas light gray and white areas were included in less than 25% of the solutions.

in a final solution may not contain sufficient conservation targets to contribute to conservation goals. However, it is important to note that, even if a planning unit is not selected for a reserve, the planning unit may contain habitats and species of interest. Additional information may be gained by evaluating the raw data and consulting with experts who have information about the area in question. The map of conservation value (Fig. 6.11) was used as the ecological criterion data layer in CI-SSAT.

Results from CI-SSAT

In the Channel Islands process, the working group began their discussion about marine zoning with support of the CI-SSAT. The working group did not consider the locations of marine reserves during their first 12 months (July 1999 – Sept 2000). During the initial period, the working group considered the state of the marine ecosystem and goals for marine reserves. In May 2000, the science advisory panel delivered a suite of ecological goals for the design of marine reserves to meet goals of the working group. In August 2000, the science advisory panel delivered the initial results of the SPEXAN modeling process, including the map of conservation value from the irreplaceability analysis (Fig. 6.11) and 10 alternatives for marine reserves that achieved conservation goals (five of which are depicted in Fig. 6.10). In September 2000, the working group began deliberations about potential locations for marine reserves in the Channel Islands.

The working group met with the advisory panels to consider the ecological and socioeconomic data and begin the process of designing a

network of marine reserves for the Channel Islands National Marine Sanctuary. After reviewing information provided by the advisory panels, the working group divided into four subgroups. Each subgroup worked with a technical facilitator to access and query data using CI-SSAT. Most subgroups used pre-set queries in CI-SSAT to understand the potential impacts of their decisions.

Nine scenarios were produced at the conclusion of the September 2000 workshop. The scenarios ranged from 11 to 38% of the Channel Islands National Marine Sanctuary. Figure 6.12 shows the number of times each planning unit was included in one of the nine scenarios developed by the working group. All groups agreed that a reserve should be established in the waters on the northwest side of San Miguel Island. All but one scenario included a reserve around Gull Island off the southwest coast of Santa Cruz Island. Seven of nine scenarios included reserves off the southwest side of Santa Barbara Island and at the Footprint (offshore between Santa Cruz and Anacapa Islands). Less than half of the working group agreed that reserves should be located on the north side of Santa Rosa Island, at Scorpion Rock on the northeast side of Santa Cruz Island, and off the northern coast of Anacapa Island. Detailed ecological and economic analyses were provided to the working group, including the amount of each conservation target represented in each scenario and the potential impact of each scenario on commercial and recreational activities.

In October 2000, the working group convened to revise and refine the reserve scenarios. To vary the approach, the working group divided into five subgroups representing similar perspectives and each subgroup produced a single alternative reflecting the common views of the subgroup. From this exercise, the working group produced five

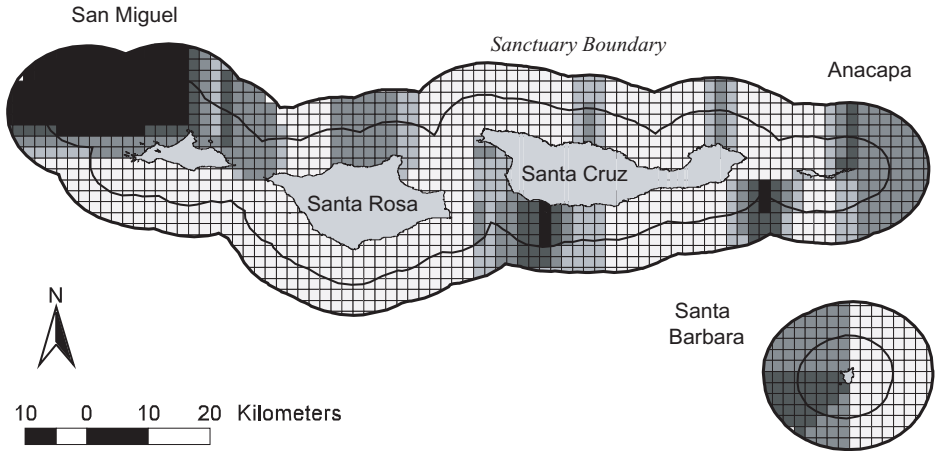


Figure 6.12. Results of the design workshop in September 2000. Nine scenarios were developed by the working group. Shading represents the number of scenarios that included each planning unit. Dark shaded areas were included in most of the scenarios whereas light shaded areas were not.

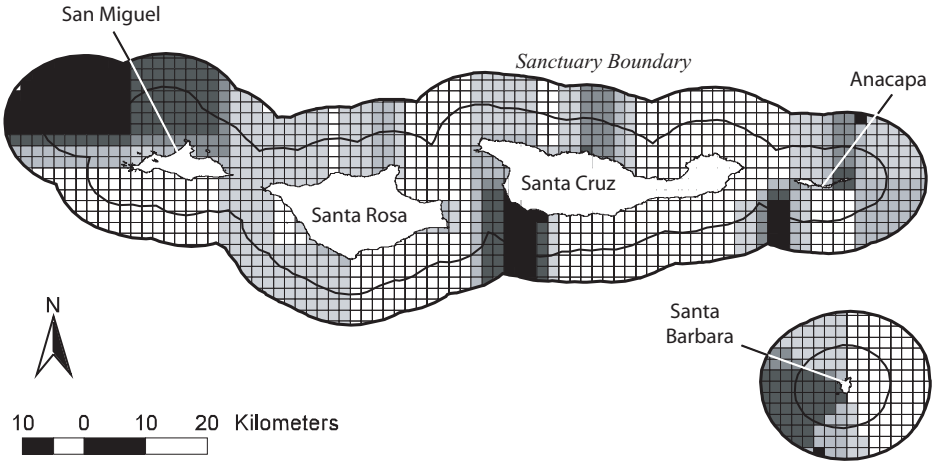


Figure 6.13. Results of the design workshop in October 2000. Five scenarios were developed by the working group. Shading represents the number of scenarios that included each planning unit. Dark shaded areas were included in most of the scenarios whereas light shaded areas were not.

alternatives representing the interests of commercial fishing, the environment, recreational users, government, and community. The working group achieved a greater degree of consistency through this exercise. Figure 6.13 shows the number of times each planning unit was included in one of the five scenarios developed by the working group in October 2000. Most groups agreed that reserves should be located in waters off the north side of San Miguel Island, around Gull Island off the southwest coast of Santa Cruz Island, at the Footprint, between Santa Cruz and Anacapa islands, and off the west coast of Santa Barbara Island. Three of five groups agreed that reserves should be located off the north coast of Anacapa Island whereas the other groups suggested placing reserves off the southeastern corner of the island. Detailed ecological and socioeconomic analyses were provided to the working group in November 2000.

With assistance from the advisory panels, the working group continued to refine the alternatives during subsequent meetings. By May 2001, the working group had developed over forty different designs for marine zoning and evaluated the ecological value and potential economic impact of each design. The working group selected two designs to represent the diverse views of the group (Fig. 6.14). All members of the working group agreed that some areas (known as the "areas of overlap") should be set aside in marine reserves. Some members of the working group did not agree that the areas of overlap, which totaled 12% of the Sanctuary, were sufficient to meet the conservation goals established by the working group. A second set of areas was proposed (known as "areas of non-overlap") to satisfy the concerns by some members of the working group that the areas of overlap were not sufficient to meet their goals. The combination of the areas of overlap

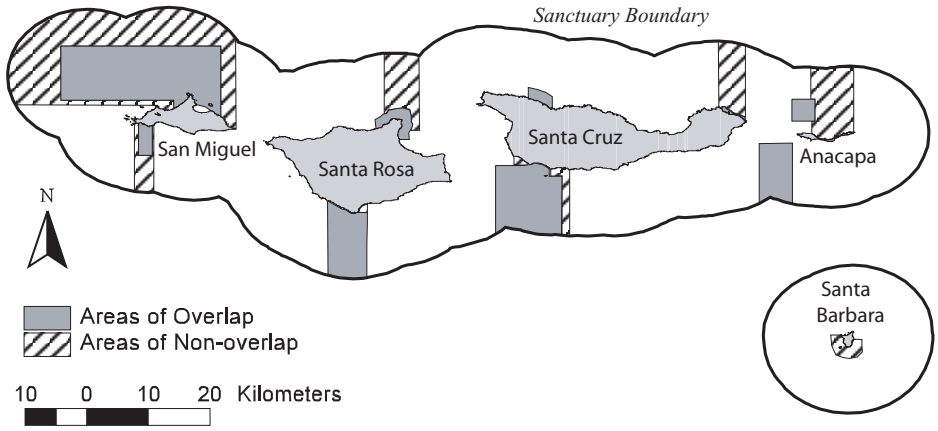


Figure 6.14. Two designs for networks of marine reserves developed by the working group using CI-SSAT. The solid polygons represent areas that all group members agreed to set aside in marine reserves. The hatched marks represent additional areas that some members of the group considered essential to meet conservation goals.

and non-overlap, totaling 28% of the Sanctuary, formed the network of marine protected areas proposed by some members of the working group.

These maps, together with policy, scientific, and economic information, were provided to state and federal agencies for consideration in June 2001. During the summer of 2001, the California Department of Fish and Game and the Channel Islands National Marine Sanctuary worked together to develop a compromise between the two maps. The proposed reserve area on the north side of San Miguel Island was divided into two smaller areas to protect specific targets at Harris Point and Richardson Rock. The southern boundaries of proposed reserves on the south sides of Santa Rosa and San Miguel islands were moved two and three nautical miles, respectively, inshore to reduce impacts to trawling and trapping industries. A small patch of coastline and shallow subtidal waters were removed from the proposed reserves to accommodate consumptive recreational divers. The boundary of the reserve proposed at Carrington Point on the north side of Santa Rosa Island was constrained within three nautical miles of shore to avoid conflicts with offshore set and gill net fisheries. The boundaries of the proposed reserve at Scorpion Rock on the northeast side of Santa Cruz Island were moved west to alleviate pressure on recreational fishers and divers. The west side of the proposed reserves on north Anacapa Island and at Painted Cave on the northwest side of Santa Cruz Island were opened to limited commercial and recreational fishing to reduce potential impacts to recreational fishers and commercial lobster fishers. The resulting network of marine reserves (Fig. 6.15) was a compromise between the perspectives represented on the working group.

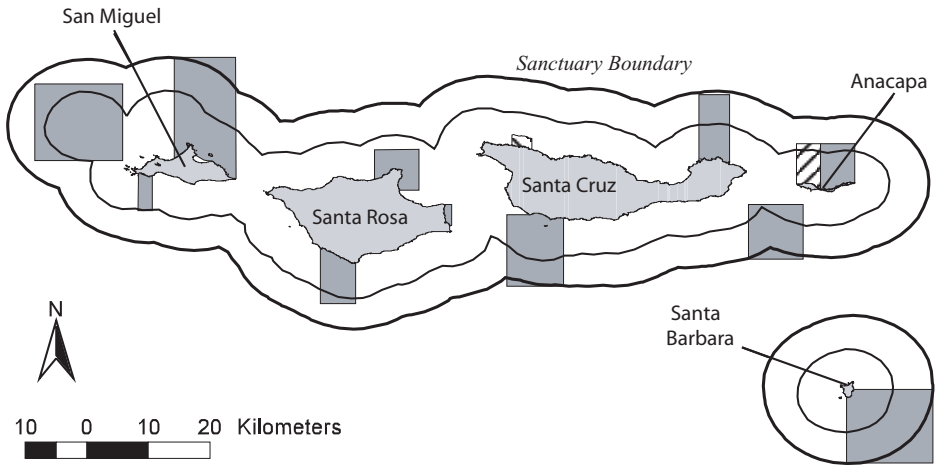


Figure 6.15. The design for a network of marine protected areas developed by the California Department of Fish and Game and the Channel Islands National Marine Sanctuary. The design is based on the two maps provided by the working group and the ecological and socioeconomic data gathered during the Channel Islands process. Solid shaded polygons represent no-take marine reserves; hatched polygons represent marine parks and conservation areas where limited commercial and recreational fishing is allowed.

In October 2002, the California Fish and Game Commission took action to protect marine ecosystems at the Channel Islands using network design based on the extensive information generated by the working group and advisory panels. Because its jurisdiction is limited to waters between the mean high tide and three nautical miles offshore, the Commission was not able to implement the entire network of marine protected areas. The Commission considered the proposed areas within state waters only. In April 2003, a network of state marine protected areas was established in the Channel Islands National Marine Sanctuary (Title 14, California Code of Regulations, Sections 27.82, 530, and 632).

Discussion and Conclusion

Geospatial modeling tools contributed substantially to the process of designing "no-take" marine reserves for the Channel Islands National Marine Sanctuary. SPEXAN was used by the science advisory panel to evaluate ecological information and provide a set of solutions to meet conservation goals established by the working group. CI-SSAT was used by the working group to view and query ecological and socioeconomic information and to evaluate the solutions produced during the SPEXAN analysis.

Both tools are displayed within a GIS, providing opportunities to view, display, and manipulate spatial information. During public meetings of the working group and advisory panels, both geospatial tools were used to display data and solutions (or alternatives).

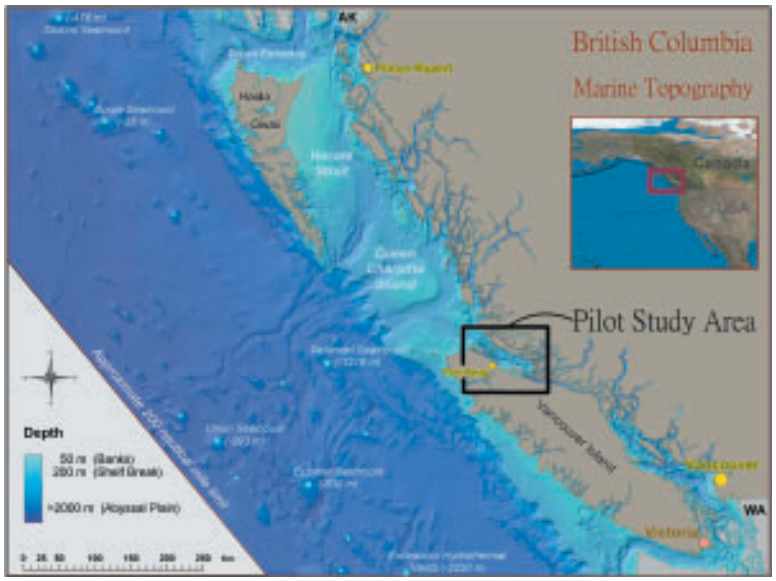


Figure 4.1. The study area is part of the southern Central Coast of British Columbia. It is approximately the extent of DFO Statistical Area 12. For our analysis, we excluded the inlets. The remaining sea area is approximately 2,400 square kilometres (931 sq. mi; 703 sq. nautical miles).

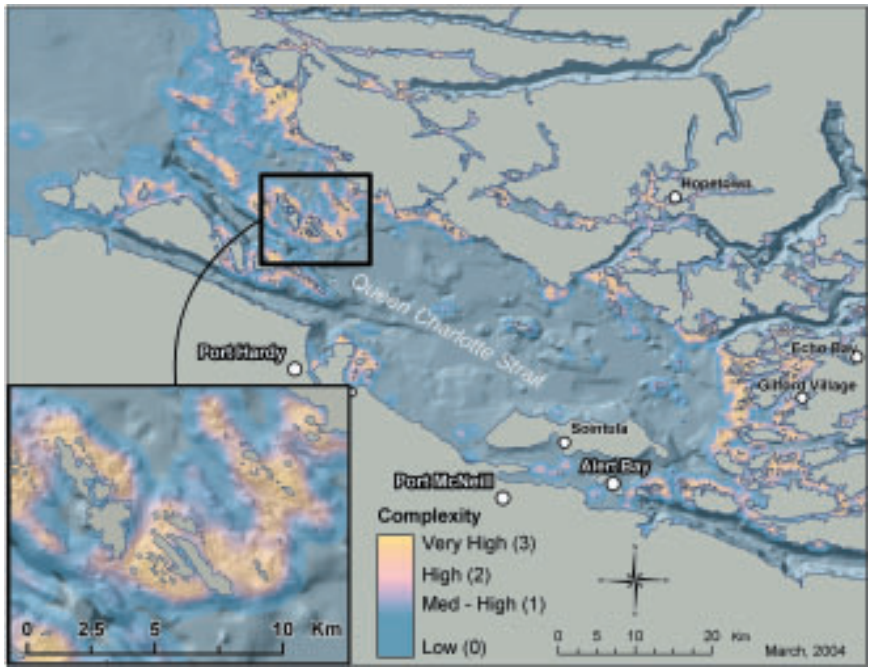


Figure 4.2. Benthic topographical complexity is a measure of how convoluted the sea floor is per given unit area. At this scale, it is a good method for identifying rocky reef habitat.

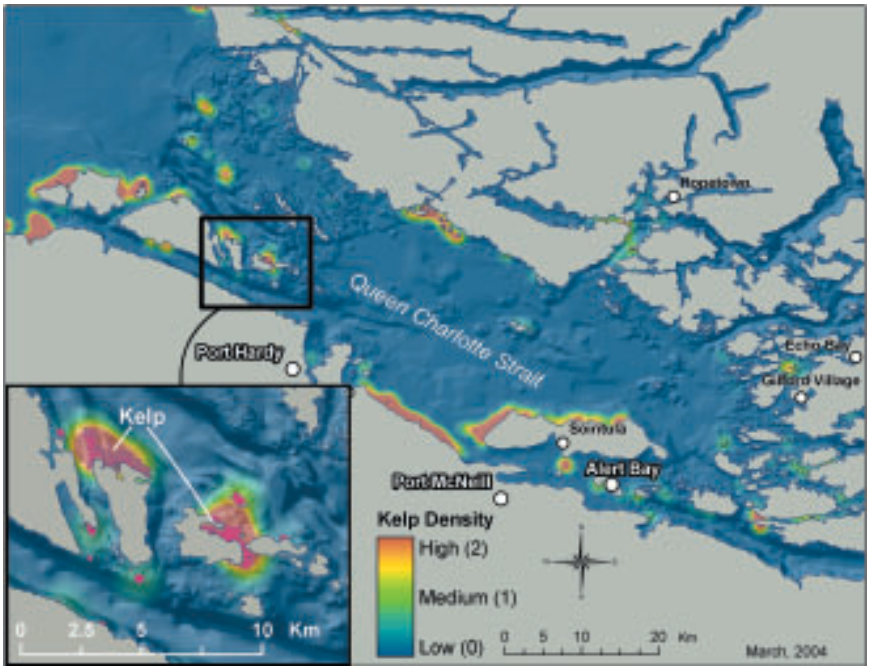


Figure 4.3. Kelp beds (Nereocystis luetkeana and Macrocystis intergrifolia) occur in varying sizes and distributions. We wanted to model proximity to complex areas, but realized that a buffer would exaggerate the influence of small beds. Thus, we performed a density analysis, and re-classed the results into either high (2) or medium (1).

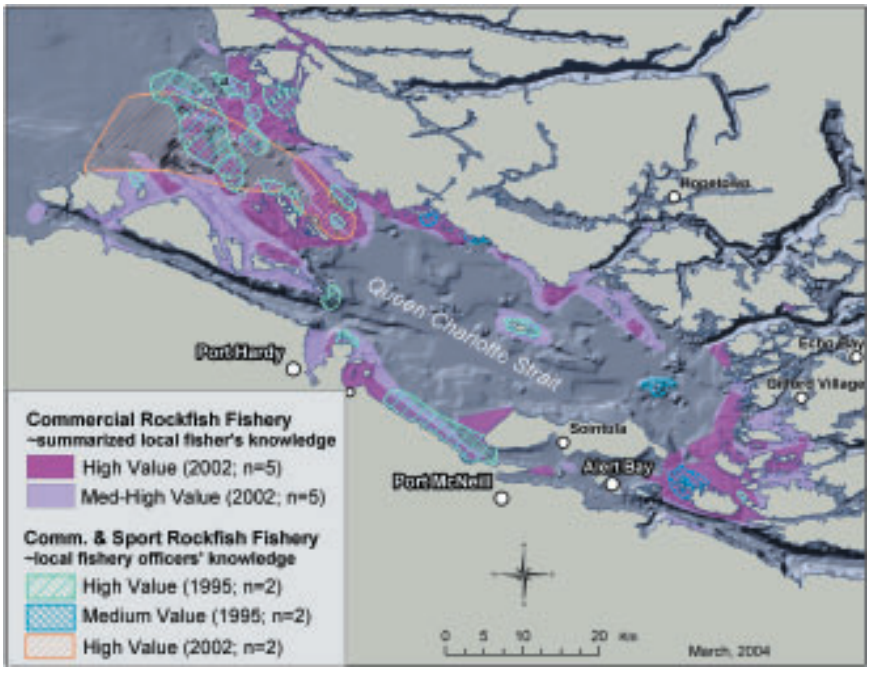
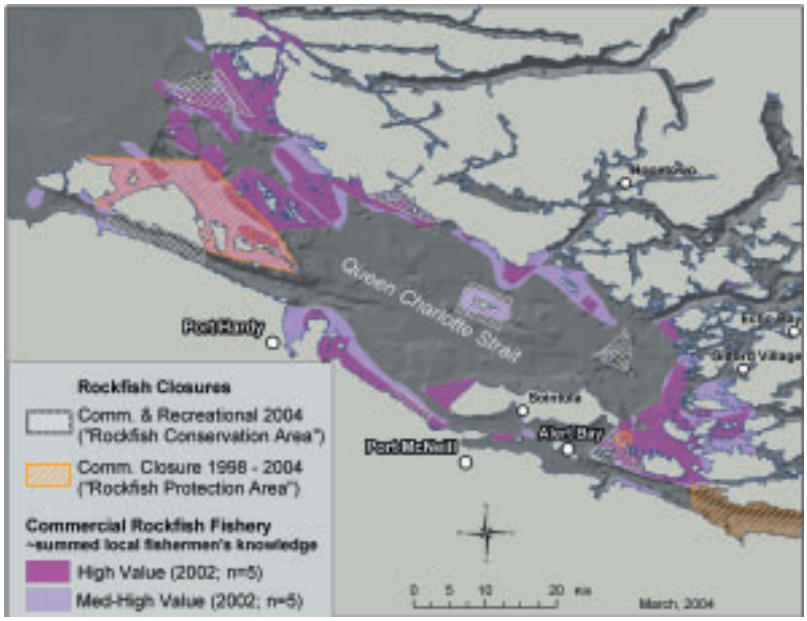


Figure 4.4. Known as "Area 12," Queen Charlotte Strait has several areas where commercial and recreational rockfish fishing occur. While there are areas of overlap, there are also discrepancies between the fishers' knowledge and that of the fishery officers and managers.



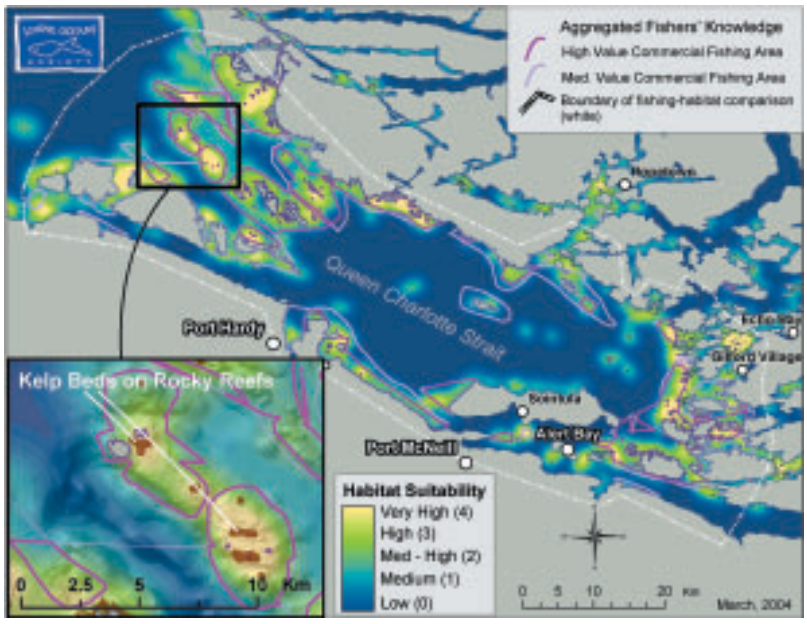


Figure 4.5. Previous experience with the commercial closures (orange hatching) had indicated that while some areas were known to harbour rockfish, others were not. When the commercial and recreational Rockfish Conservation Areas (white hatching) were tentatively first announced in 2003, it again appeared to be a portfolio of possibly mixed results. This prompted our analysis.

Figure 4.6. The model had a high degree of overlap with areas identified by commercial fishers as being important fishing areas. Note that the commercial fleet rarely fishes in the inlets. Thus to keep the comparison meaningful, we excluded the inlets (white dashed line). With only a few small exceptions, every high-value fishing area in the study area contains high or very high-value habitat identified by our model. While not every high-value habitat area is accompanied by a high-value fishing area, local anecdotal knowledge would indicate that most of these areas are also known fishing areas. (We are currently involved in expanding the data collection to include recreational fishers as well as more commercial fishers.)

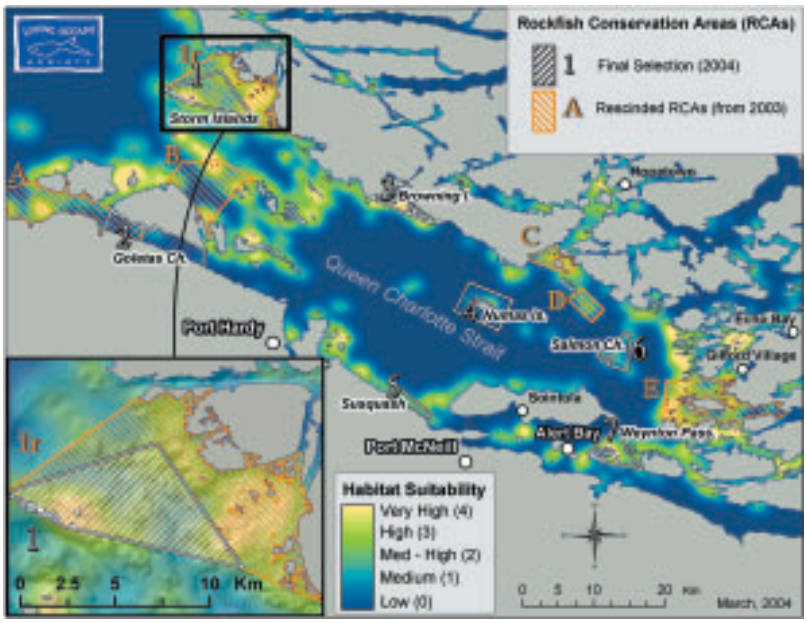


Figure 4.9. A number of rockfish conservation areas were initially proposed within the study area. Of those, some were finalized (black & white) and others were rescinded (orange). As can be seen, these RCAs overlap rockfish habitat to varying degrees, with the rescinded areas often being in what the model predicts to be quite good habitat (e.g., C, E, and 1r – inset).

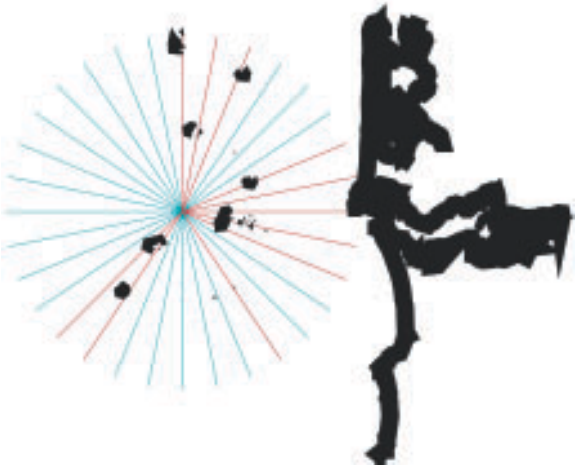


Figure 5.6. Areas where trawl activity would likely not occur. Untrawlable tow paths (red arcs) are removed.

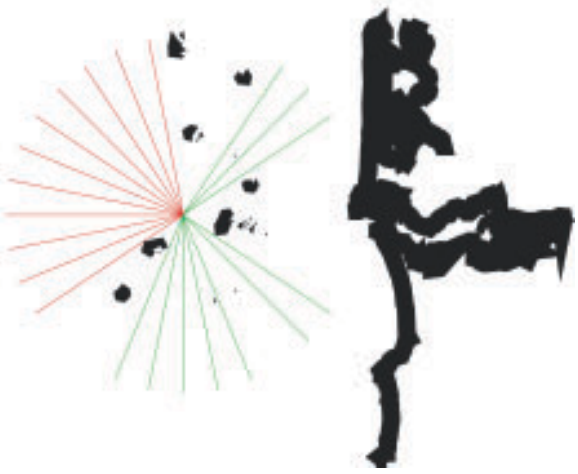


Figure 5.7. Removing tow paths in steep terrain (slopes greater than 1%). Red arcs are removed from analysis.

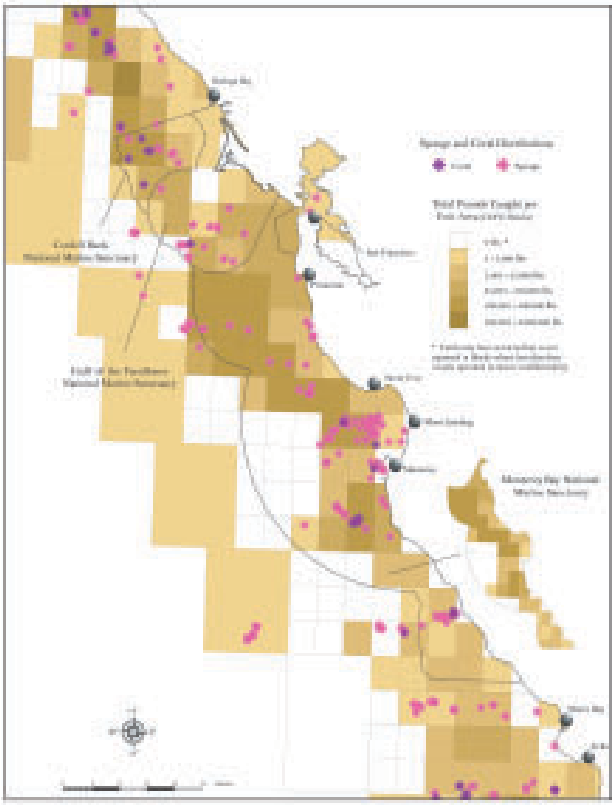


Figure 5.10. (a) Catch per area in the Monterey Bay National Marine Sanctuary.

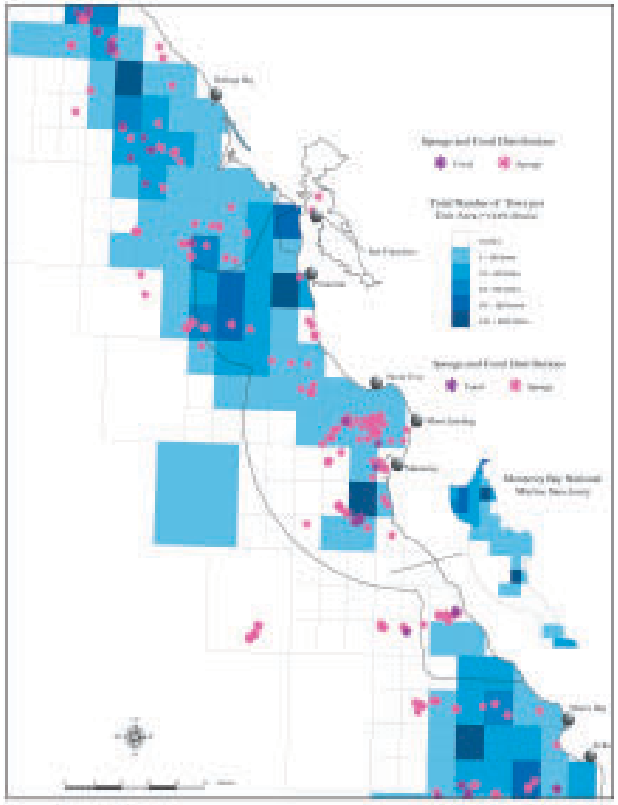


Figure 5.10. (b) Number of trawl tows in the Monterey Bay National Marine Sanctuary.

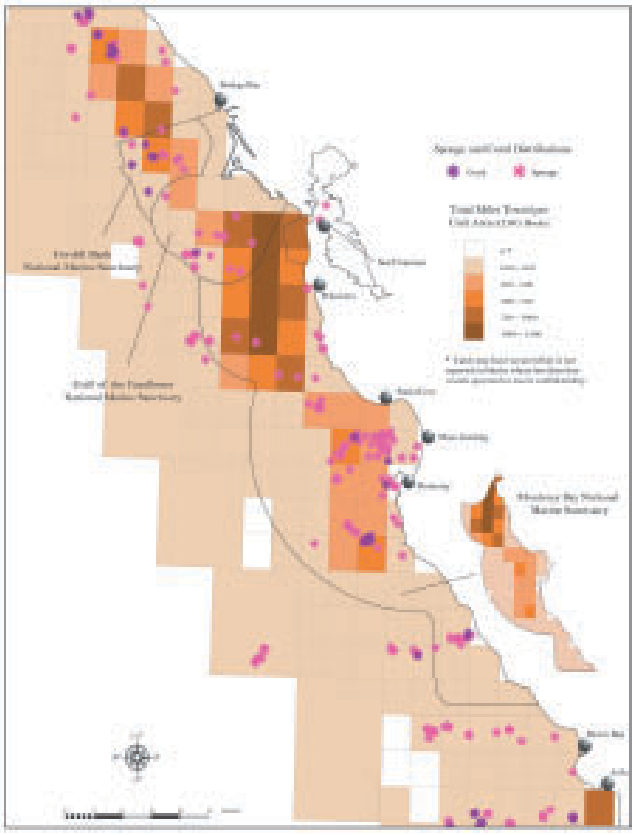


Figure 5.10. (c) Total miles towed in the Monterey Bay National Marine Sanctuary.

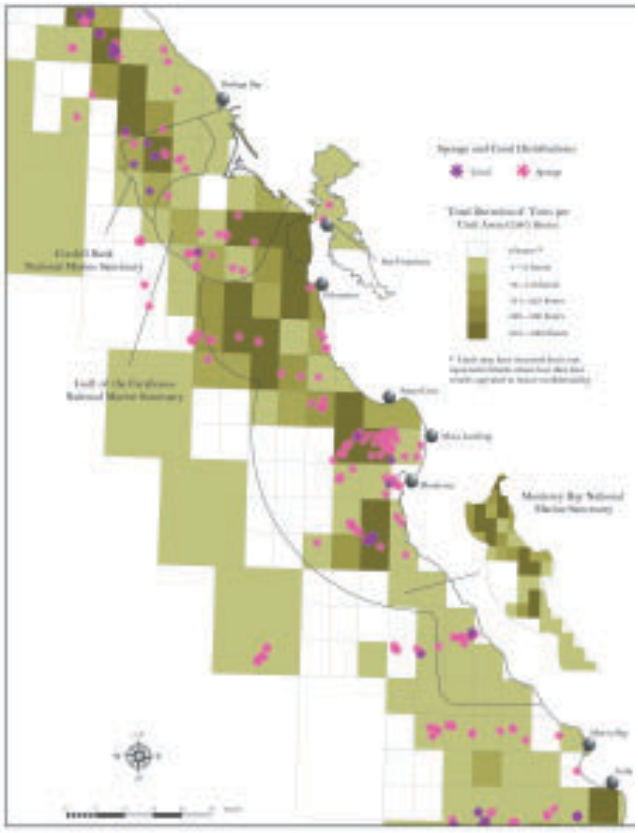


Figure 5.10. (d) Duration of tows in the Monterey Bay National Marine Sanctuary.

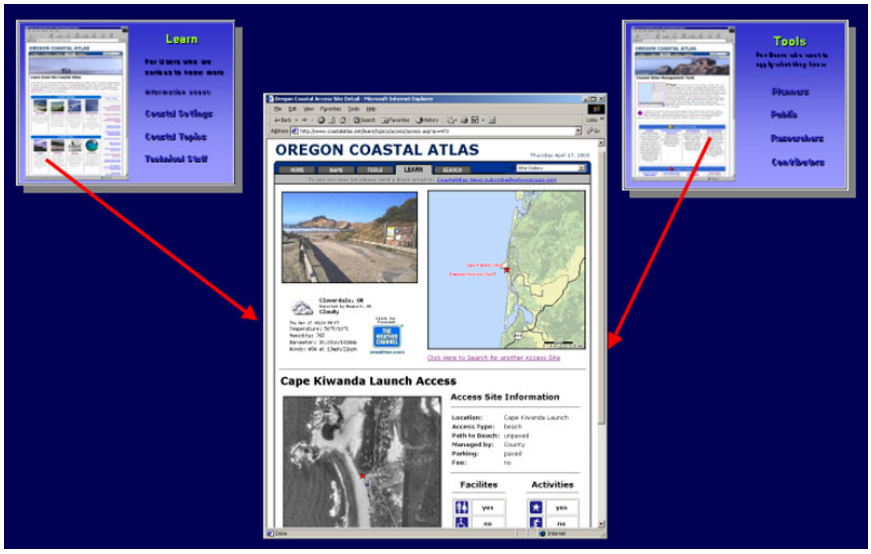


Fig. 7.3. Users may browse through a coastal encyclopedia within the Learn section of the OCA, and then focus on a coastal setting or topic by way of the online Coastal Access Information Tool containing location and inventory information about each of the access sites on the Oregon coast.

Figure 7.4. Opening page of the online Watershed Assessment Tool, a step-by-step GIS decision-making tool that provides guidelines, instructions, and then access to GIS data, and an Internet map service to aid the user in a watershed assessment process.

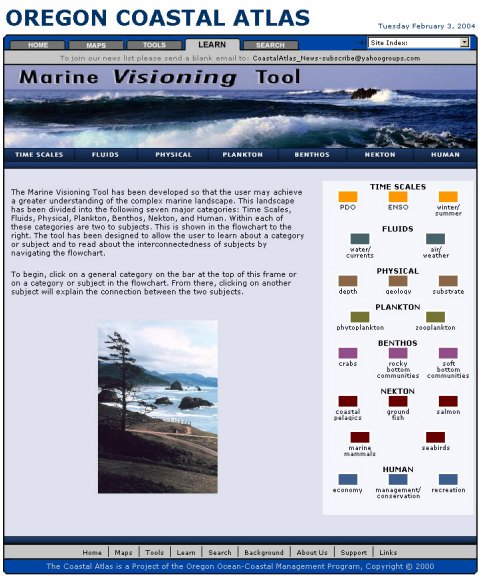


Figure 7.5. Opening page of the online Marine Visioning Tool, which allows the user to explore various topics about oceanographic processes, including time scales, fluids, physical parameters, benthic communities, pelagic communities, and human activities.

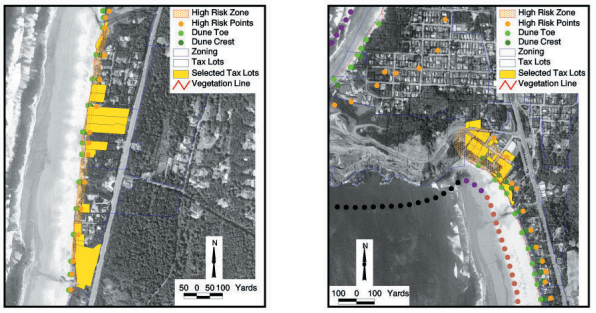


Figure 7.6. Two views that show the results of a GIS query to locate vacant parcels in private ownership within a high-risk zone.

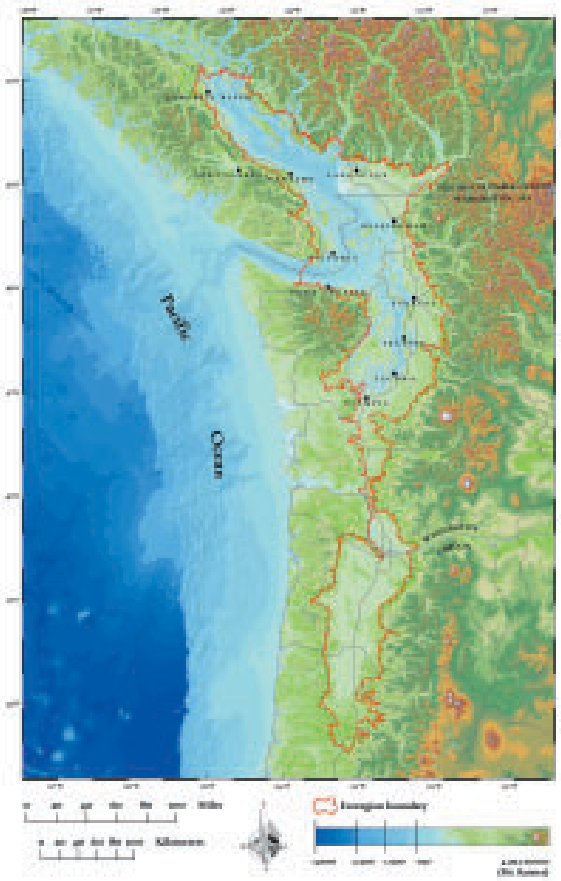


Figure 8.1. Willamette Valley-Puget Trough-Georgia Basin ecoregion of the Pacific Northwest

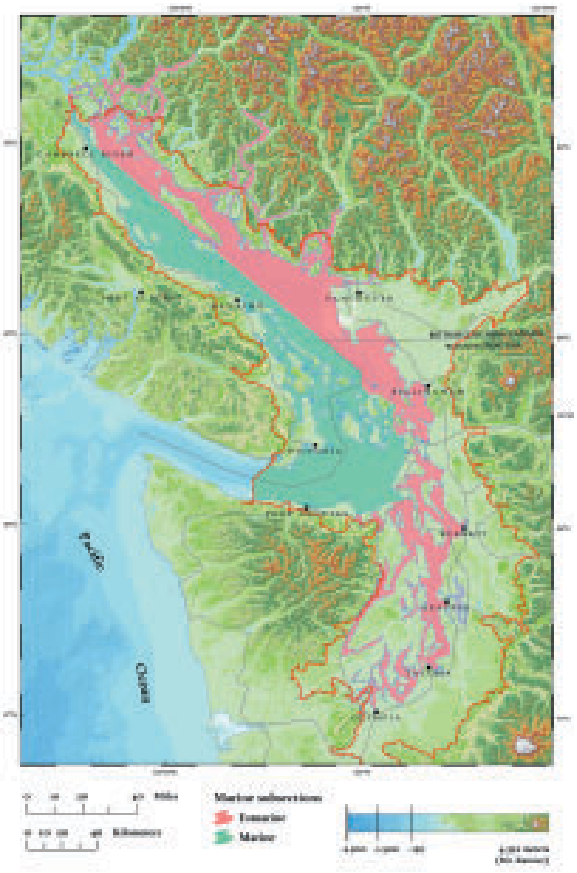


Figure 8.2. Marine technical teams separated the waters into subsections based on the dominance of freshwater outflow ("estuarine") and tidal conditions ("marine")

Information in the tools was projected onto a screen and members of the working group or advisory panels were able to discuss the information and make changes while others observed the process. The science advisory panel used their public meetings to review the effects of changing the boundary length modifier and the conservation goals in SPEXAN. Consideration of the results led the science advisory panel to recommended use of a boundary length modifier of 1 and conservation goals between 30 and 50%. Additionally, the science advisory panel reviewed results from SPEXAN to refine the data classification system, providing flexibility and repeatability of the analysis. The working group used CI-SSAT to view and query data in public meetings. Additionally, the working group generated, reviewed, and modified alternative designs for marine reserves, while the designs were projected on a screen in a meeting room.

The use of geospatial modeling tools bolstered public confidence in the reserve design process for the Channel Islands. In the case of SPEXAN, the tool provided the flexibility needed to address policy concerns within the framework of an analytical process that was repeatable and rigorous. Using simulated annealing, the science advisory panel explored the process of designing a network of marine reserves by considering the level of detail of habitat classification, the type of data in the analysis, and the overall conservation goals. After the working group established the overarching goals for the Channel Islands process, the science advisory panel developed a corresponding set of conservation targets to achieve the working group's goals. The flexibility in the model allowed policy-makers and scientists to evaluate the effects of different types of data, classification schemes, and goals on the model output.

Simulated annealing produced many good solutions that achieved conservation goals and minimized the area and perimeter of the network. More compact solutions, in spite of their greater area, were selected for consideration because of the relative ease of implementation, enforcement, and monitoring. The alternative solutions were particularly useful in the Channel Islands process because of the flexibility introduced to the discussion about where reserves should be located. From the SPEXAN analysis, it was clear that various configurations of marine reserves could satisfy the conservation goals. Given the range of solutions, the working group was able to identify constructive alternatives to establishing reserves in areas of high conflict among working group members.

The map of conservation values, generated from the irreplaceability analysis in SPEXAN, was particularly valuable for advancing discussions about marine zoning. Biodiversity "hotspots" were identified as planning units selected for a large number of solutions. In the Channel Islands process, the map of conservation values (Fig. 6.11) provided the foundation for discussions about reserve design. The network of state

marine protected areas, established in April 2003, includes many of the hotspots identified from the map of conservation values.

The ecological and socioeconomic information in CI-SSAT advanced the reserve design process in the Channel Islands. Working group members were concerned that each conservation target was represented in the network of reserves, with a minimum impact to commercial and recreational users. To advance the discussion about where reserves should be located, working group members drew potential reserves in CI-SSAT and used the built-in queries to investigate the potential benefits and impacts of the reserve. Before a design concept became a feasible alternative, adjustments were made to reduce potential impacts to commercial and recreational users and incorporate conservation targets. CI-SSAT supported this process of exploration of the data, thus facilitating the development of reserve designs.

In spite of the vast amount of information provided, the working group was unable to come to consensus on the size and location of potential reserves for the Channel Islands. One of the goals of the Channel Islands process was to bring together a diverse group of stakeholders and work together to develop a consensus view of the management needs, based on shared information. This approach was used by the Florida Keys National Marine Sanctuary during discussions that led to the creation of the Tortugas Marine Ecological Reserve (Florida Keys National Marine Sanctuary, 2000). In the Florida Keys process, the working group agreed to set aside a reserve that was outside the study area. In the Channel Islands process, the working group agreed on the problem and the goals of the process, but was unable to come to consensus on the size and location of reserves within the study area.

From the numerous designs generated during the Channel Islands process, it is clear that there was some agreement on locations of reserves, particularly at San Miguel Island, at Gull Island off the southwest coast of Santa Cruz Island, and at the Footprint area between Santa Cruz and Anacapa islands. Consensus eluded the Channel Islands process, in part, because diverse views represented on the working group reached their limits of acceptable compromise before a final solution was developed. A majority of working group members was willing to accept the combined areas of overlap and non-overlap (Fig. 6.14) as a network of reserves. However, a few minority views on both sides of the debate prevented the group from reaching full consensus. In such complex management problems, the lofty goal of consensus may not be a realistic target. To reach a solution, participants must either adjust their expectations to be satisfied with a compromise or make explicit policy decisions *a priori* to weight the contributions of different interests.

Acknowledgments

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Notes

1 Fisheries permitted within the state marine conservation areas include recreational fishing for pelagic species and recreational and commercial fishing for California spiny lobster (*Panulirus interruptus*).

2 In April 1998, the California Fish and Game Commission received a recommendation from the Channel Islands Marine Resources Restoration Committee to set aside 20% of the shoreline and waters out to 1 mile. The recommendation was criticized as the work of one stakeholder group representing a narrow range of perspectives. A public process was recommended by the California Fish and Game Commission to resolve the conflicts between stakeholders.

3 The geospatial tool SPEXAN (SPatially EXplicit ANnealing) was developed for the Nature Conservancy for the purpose of locating terrestrial reserves. Later, the geospatial tool was modified to more directly reflect biophysical principles and the new tool was named "MARXAN" (Ball and Possingham, 2000). A description and the program are available at the MARXAN Web site.

References

Airamé, S., Cassano, E., Pickett, M., Fangman, S., Hastings, S., Bingham, S., Walton, A., Waltenberger, B., Murray, M., Simon, M., Woodall, R., and Ugoretz, J., 2000. Species of Interest in the Channel Islands: For consideration by the Marine Reserves Working Group, Santa Barbara, California, Channel Islands National Marine Sanctuary.

Airamé, S., Dugan, J. E., Lafferty, K. D., Leslie, H., McArdle, D. A., and Warner, R. R., 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands, *Ecological Applications*, 13(1): Supplement S170-S1854.

Allison, G. W., Gaines, S. D., Lubchenco, J., and Possingham, H. P., 2003. Measuring persistence of marine reserves: Catastrophes require adopting an insurance factor, *Ecological Applications*, 13(1): Supplement 8-24.

Ardron, J. A., Lash, J., and Haggarty, D., 2002. Modelling a network of marine protected areas for the central coast of British Columbia. Version 3.1, Sointula, British Columbia, Canada, Living Oceans Society.

Ball, I. R., and Possingham, H.P., 1999. *SPEXAN Manual, version 3.1*, Adelaide, South Australia, Adelaide University, http://www.ecology.uq.edu.au/marxan.htm.

Beck, M. W., and Odaya, M., 2001. Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 11: 235-42.

California Department of Fish and Game, 2002. Final Environmental Document. Marine Protected Areas in NOAA's Channel Islands National Marine Sanctuary, Volume 1, October 2002, State of California, The Resources Agency, Department of Fish and Game.

Clarke, K. R., and Warwick, R. M., 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, 2nd edition, Plymouth, PRIMER-E Ltd.

DeLong, R. L., and Melin, S. R., 1999. Thirty years of pinniped research at San Miguel Island. Alolkoy, The Publication of the Channel Islands Marine Sanctuary Foundation, 12(2): 3.

Florida Keys National Marine Sanctuary, 2000. Tortugas Ecological Reserve, Final Supplemental Environmental Impact Statement/Draft Supplemental Management Plan, U.S. Department of Commerce, NOAA/NOS/Office of Ocean and Coastal Resource Management/Marine Sanctuaries Division.

Jostes, J. C., and Eng, M., 2001. Facilitator's Report: Regarding the Channel Islands National Marine Sanctuary Marine Reserves Working Group, Santa Barbara, California, Channel Islands National Marine Sanctuary Advisory Council, 27 pp.

Killpack, D., Waltenberger, B., and Fowler, C., 2000. Using the Channel Islands-Spatial Support and Analysis Tool to Support Group-based Decision Making for Marine Reserves, Charleston, South Carolina, NOAA Coastal Services Center, http://www.csc.noaa.gov/pagis/html/web_cissat_paper.pdf

Kronman, M., Airamé, S., and Simon, M., 2000. Channel Islands National Marine Sanctuary Ethnographic Data Survey, Santa Barbara, California, Channel Islands National Marine Sanctuary.

Leeworthy, V. B., and Wiley, P., 2002. Socioeconomic Impact Analysis of Marine Reserve Alternatives for the Channel Islands National Marine Sanctuary, Silver Spring, MD, U.S. Department of Commerce, NOAA National Ocean Service, Special Projects.

Leet, W. S., Dewees, C. M., Klingbeil, R., and Larson, E. J. (eds.), 2001. California's Living Marine Resources: A Status Report, State of California. The Resources Agency, The California Department of Fish and Game.

Leslie, H., Ruckelshaus, M., Ball, I. R., Andelman, S., and Possingham, H. P., 2003. Using siting algorithms in the design of marine reserves, *Ecological Applications* , 13(1): Supplement 185-98.

Lewis, A., Slegers, S., Lowe, D., Muller, L., Fernandes, L., and Day, J., 2003. Use of Spatial Analysis and GIS techniques to Re-Zone the Great Barrier Reef Marine Park, Coastal GIS Workshop, July 7-8, 2003, University of Wollongong, Australia.

Margules, C. R., and Pressey, R. L., 2000. Systematic Conservation Planning. *Nature* 405: 243-53.

McDonnell, M. D., Possingham, H. P., Ball, I. R. and Cousins, E. A., 2002. Mathematical methods for spatially cohesive reserve design, *Environmental Modelling and Assessment*, 7:107-14.

Possingham, H. P., Day, J., Goldfinch, M., and Salzborn, F., 1993. The mathematics of designing a network of protected areas for conservation, in Sutton, D., Cousins E., and Pearce, C. (eds.), Proceedings of the 12th Australian Operations Research Conference, Decision Sciences, Tools for Today, Adelaide, Australia, Australian Society for Operations Research, 536-45.

Possingham, H., Ball, I. and Andleman, S., 2000. Mathematical models for identifying representative reserve networks, in Ferson, S., and Burgman, M. (eds.), *Quantitative Methods for Conservation Biology*, New York, Springer-Verlag, 291-306.

Pressey, R. L., Possingham, H. P., and Margules, C. R., 1996. Optimality in reserve selection algorithms: When does it matter and how much? *Biological Conservation*, 76:259-67.

Roberts, C. M., Andelman, S., Branch, G., Bustamante, R. H., Castilla, J. C., Dugan, J., Halpern, B. S., Lafferty, K. D., Leslie, H., Lubchenco, J., McArdle, D., Possingham, H. P., Ruckelshaus, M., and Warner, R. R., 2003a. Ecological criteria for evaluating candidate sites for marine reserves, *Ecological Applications,* 13(1): Supplement 199-214.

Roberts, C. M., Andelman, S., Branch, G., Bustamante, R. H., Castilla, J. C., Dugan, J., Halpern, B. S., Lafferty, K. D., Leslie, H., Lubchenco, J., McArdle, D., Possingham, H. P., Ruckelshaus, M., and Warner, R. R., 2003b. Application of ecological criteria in selecting marine reserves and developing reserve networks, *Ecological Applications*, 13(1): Supplement 215-28.

Sala, E., Aburto-Oropeza, O., Paredes, G., Parra, I., Barrera, J. C., and Dayton, P. K., 2002. A general model for designing networks of marine reserves, *Science*, 298: 1991-93.