CHAPTER 3 – BIOGEOGRAPHY OF MACROINVERTEBRATES

Randy Clark, Wendy Morrison, M. James Allen, Larry Claflin

Several hundred species of invertebrates inhabit the mainland shelf and slope of southern California. Many of these species are abundant in southern California and have biogeographic breaks near Point Conception and CINMS. Others are more transient and have population centers north or south of the region (Figure 1.1.5). Providing an ecological assessment of all invertebrate species within the region of interest is beyond the scope of this chapter. This chapter examines the potential areas of habitat suitability for important commercial, ecological, and recreational species as determined by the CINMS. Additionally, fisheries independent monitoring data were analyzed to explore macroinvertebrate community structure on the southern California continental shelf.

3.1 SINGLE SPECIES HABITAT SUITABILITY MODELS (HSM)

Data and Methods

Habitat suitability modeling (HSM) is a tool for predicting the adequacy of habitat for a given species or assemblage of species. Models are constructed as a mathematical expression to provide an index of habitat quality as a function of one or more environmental variables. Model development can range from qualitative to quantitative, and is wholly dependent on the type of data being used to model the species in question (Brown *et al*., 2000; Clark *et al*., 2004). These mathematical expressions can then be mapped in a geographic information system (GIS) to portray areas of potential distribution for a given species.

Table 3.1.1. Invertebrate species of interest for the CINMS biogeographic assessment.

Common Name	Scientific Name
rock crabs	*Cancer* spp.
black abalone	*Haliotis cracherodii*
red abalone	*Haliotis rufescens*
white abalone	*Haliotis sorenseni*
California market squid	*Loligo opalescens*
sheep crab	*Loxorhynchus grandis*
spot shrimp	*Pandalus platyceros*
ridgeback rock shrimp	*Sicyonia ingentis*
California spiny lobster	*Panulirus interruptus*
California sea cucumber	*Parastichopus californicus*
warty sea cucumber	*Parastichopus parvimensis*
red sea urchin	*Strongylocentrotus franciscanus*
purple sea urchin	*Strongylocentrotus purpuratus*

In this chapter, deterministic models of habitat suitability were developed based on published ranges of bathymetry, preference for benthic substrate types, and latitudinal gradients for 15 macroinvertebrate species (Table 3.1.1). Where information was adequate, species distributions were mapped using a qualitative measure of suitability: high, medium, and low. For example, the distribution of the black abalone (*Haliotis cracherodii*) was reported to occur primarily from the shallow intertidal to 10 m on hard substrate (Leet *et al*., 2001). Based on these data, high suitability was assigned to hard substrate between 0-10 m, moderate suitability over hard substrates between 10-30 m, and all other habitats and depth zones were considered low suitability. Areas of high habitat suitability for each species were examined relative to the six boundary concepts using the Optimal Area Index (OAI). While there are many invertebrate species distributed throughout southern California (Chapter 1.3), the species listed in Table 3.1.1 were determined by project staff to have a significant commercial, ecological, and/or recreational importance within the southern California region.

Benthic substrate suitability was based on preferences for hard or soft substrates found in scientific literature combined with expert opinion. Preferred bathymetric ranges were rounded to the nearest 10 m interval to integrate with the GIS bathymetry data. The GIS bathymetric layer was developed using various sources and mapped at 10 m increments for the entire west coast of the U.S. Data extend from the shoreline to approximately 4,000 m. Refer to Chapter 2.10 for a more complete description of these data. For some species, information on latitudinal range was not available in the literature and expert opinion was used to provide information on latitudinal breaks.

Typically, fisheries independent monitoring data are used to validate habitat suitability model results (Rubec *et al*., 1999; Clark *et al*., 2004); however, such data were unavailable for invertebrates at the extent and scale needed. Thus, commercial fisheries data (Commercial Master File, CMASTR) provided by California Department of Fish and Game (CDFG) Marine Region GIS Lab were mapped and superimposed over suitability maps for comparison. These provided monthly summaries of abundance or total weight of landings within 10x10 nautical mile grids (Figure 3.1.1). CMASTR data were used for validating models for black, red, and white abalone, purple and red sea urchins, and ridgeback prawn. CMASTR data are landings information (in pounds) recorded at processing docks. Commercial trawl and trap logs recorded by commercial fishermen were used to validate models for California spiny lobster, California and warty sea cucumbers, ridgeback and spot prawns, and rock crabs. Validation data were ranked by 33rd percentile and classified as high, medium, and low to be consistent with model results. Mapped model results were presented at a workshop during May 2004 and reviewed by a panel of invertebrate biologists from CDFG and the University of California, Santa Barbara.

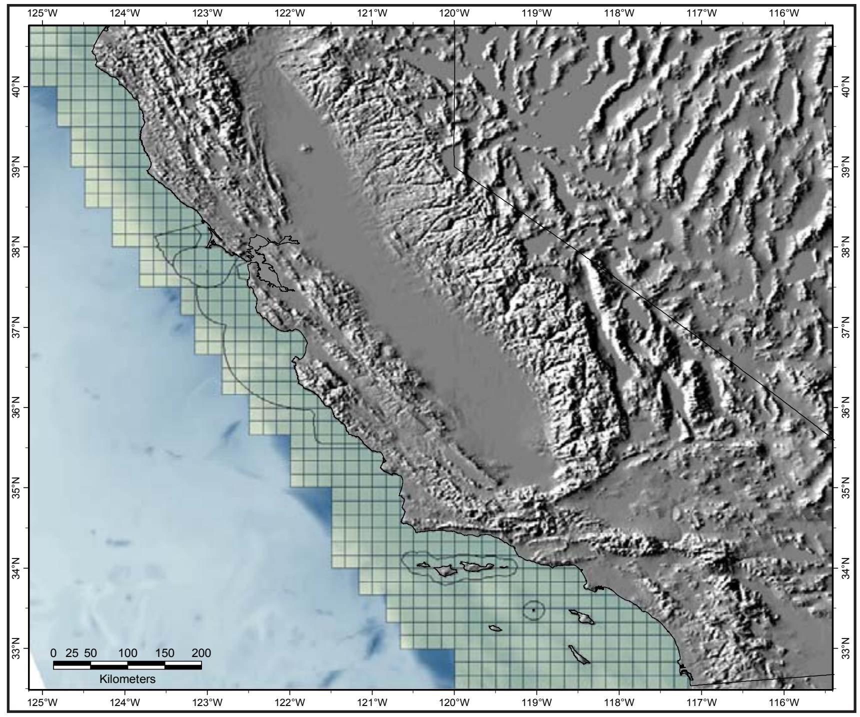

Figure 3.1.1. CDFG commercial 10x10 nm fishery landings grids. Mean monthly landings (pounds) were reported within designated grids from 1996-2002.

Rock crabs *(Cancer* spp.*)*

Three species of rock crab (brown, red, and yellow) were modeled together because their distribution and habitat preferences are reported to be similar (Carroll and Winn, 1989; Leet *et al*., 2001). The brown rock crab occurs from Washington to central Baja California, whereas the red rock crab occurs from Alaska to central Baja California, and the yellow rock crab is found from Humboldt Bay to Magdalena Bay, Baja California. Rock crab abundance is highest from low intertidal levels to subtidal depths (1-60 m), and occur over both hard and soft substrates (Morris *et al*., 1980; Winn, 1985). Red and brown rock crabs are found to depths of 100 m (Schmidt, 1921; Winn, 1985) and the yellow rock crab's depth range may extend to 140 m (Garth and Abbott, 1980; Winn, 1985). Although these species occur together throughout much of their range, brown rock crabs are more abundant in central California, red rock crabs dominate in northern California, and yellow rock crabs are most abundant in southern California (Carroll and Winn, 1989). Migration patterns are not described, though they are known to range randomly over several kilometers. Rock crabs are predators (feeding on a wide variety of invertebrates) and scavengers. Longevity is estimated to be 6 years or more (Leet *et al.,* 2001).

Large-scale commercial harvest of rock crabs using traps began in 1950. Santa Barbara and the Channel Islands represent major fishery areas. A minor sport fishery, using hoop nets and star traps, exists. Rock crab landings through 1991 have steadily increased since the fishery opened, with some fluctuation. Other sources of mortality include predation by fishes, octopus, sea stars, and sea otters. Rock crab populations in the study area have not specifically been assessed; however, experimental trapping has shown that catches are lower in commercially exploited areas (Gotshall and Laurent, 1979; Morris *et al.,* 1980; Leet *et al.,* 2001).

Broad-scale Patterns

High suitability was determined to occur over hard and soft substrate types in waters between 0-60 m. Habitats between 60-90 m were classified as moderately suitable. Habitats at depths between 90-140 m were considered low suitability and habitats at depths greater than 140 m were considered outside the species range and unsuitable. High and moderately suitable habitats are abundant throughout California waters and, when combined, comprise a large portion of the continental shelf (Figure 3.1.2). Considerable amounts of highly suitable habitat were observed within Gulf of the Farallones, Monterey Bay, and Channel Islands National Marine Sanctuaries. Commercial data from CDFG CMASTR landings were limited and model validation was not conducted.

Analysis of Boundary Concepts

Within the current sanctuary boundary approximately 655 km^2 was considered highly suitable habitat for rock crabs (Figure 3.1.3). This area was comprised of nearshore waters around the northern Channel Islands to 70 m. A similar ratio of area was considered to be moderately suitable, while the majority of the area within the current boundary was determined to be low suitability. No additional highly suitable habitat was observed within the

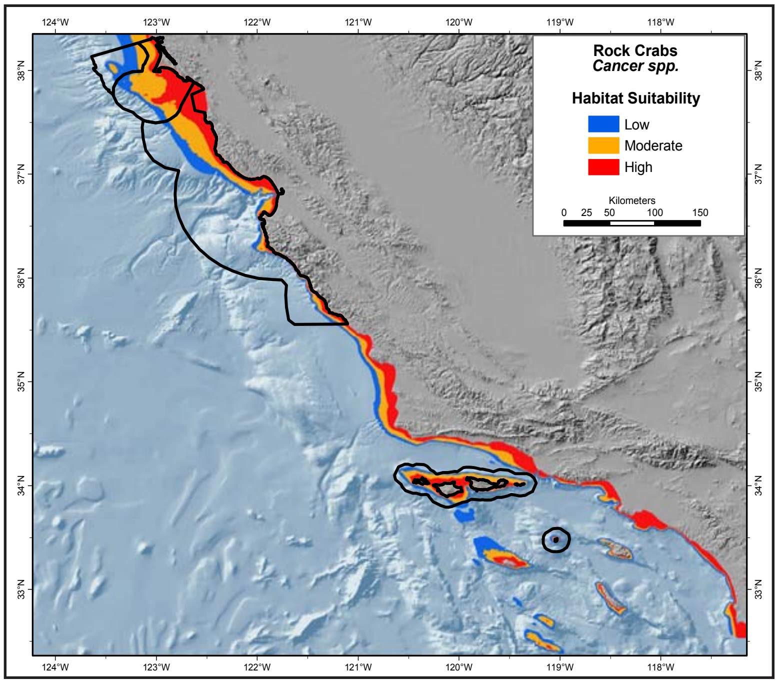

Figure 3.1.2. Rock crab (*Cancer* spp.) habitat suitability off central and southern California.

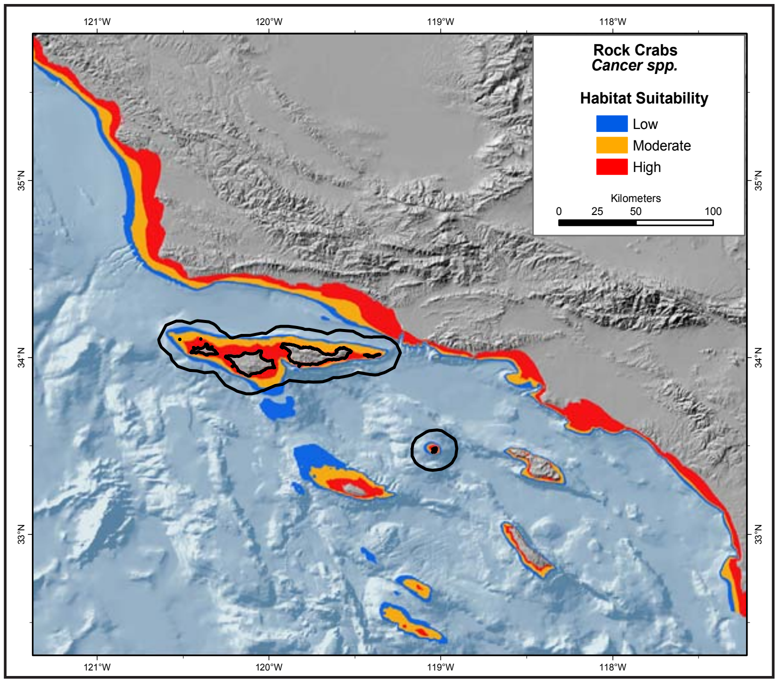

Figure 3.1.3. Rock crab (*Cancer* spp.) habitat suitability off southern California.

larger boundaries of Concepts 4 and 5. A 10% relative increase of highly suitable habitat was seen within Concept 3 as the northern boundary extended partially to the mainland. Significant increases were observed within Concepts 1, 1a, 2 and the Study Area as the northern boundaries contained vast amounts of shallow nearshore waters along the mainland (Figure 3.1.4). Analysis of the absolute OAI calculations for the predicted distribution of highly suitable habitat for rock crabs indicate that the Study Area yielded the greatest increase of highly suitable habitat relative to the increase in area from the No Action Concept (NAC; Table 3.1.2); however, this boundary is not under consideration. Therefore, Concepts 1 and 1a ranked highest for the OAI statistic.

Summary

• Brown, red, and yellow rock crabs share similar habitat preferences; highly suitable habitat was defined to occur over hard and soft substrates between 1-60 m.

• Of the six boundary concepts being considered, Concepts 1 and 1a provide the optimal proportional change of suitable habitat/total area relative to the NAC.

Table 3.1.2. Analysis of rock crab habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km²)	High Suitability Area (km²)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	732	-	-	-
5	4538	**739**	21.12	0.96	0.05
4	7981	**739**	113.11	0.96	0.01
3	9044	**812**	141.50	10.93	0.08
2	13736	**1363**	266.78	86.20	0.32
1	22613	**2150**	503.82	193.72	0.38
1a	22591	**2150**	503.23	193.72	0.38
SA	*17093*	***2150***	*356.42*	*193.72*	*0.54*

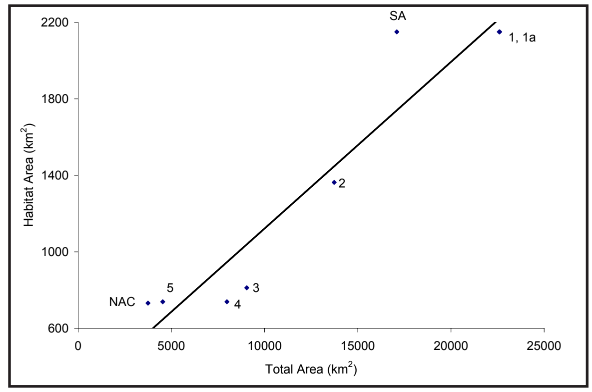

Figure 3.1.4. Regression of highly suitable habitat area for rock crabs and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Black abalone *(Haliotis cracherodii)*
Black abalone inhabit mid-low intertidal levels to depths of 6 m from Oregon to southern Baja California (Morris *et al*., 1980). They are readily identified by dark, bluish-black coloration, a smooth shell with 5 to 7 open respiratory holes, and relatively small size (5 to 20 cm as adults). Black abalone are relatively sedentary and typically found clustered in wet crevices, under boulders, or on the walls of surge channels along exposed shores. Black abalone are typically found within the intertidal to mid-intertidal zone (1-10 m) and a few may be found at depths of 20 m (Ault, 1985). *H. cracherodii* compete with sea urchins and other crevice-dwellers for space and food (Miller and Lawrence-Miller, 1993; Taylor and Littler, 1979). Where abundant, abalone may be stacked on top of each other, reaching densities of more than 100/m^2 (Douros, 1987; Richards and Davis, 1993). Black abalone are slow-growing and long-lived, with recruitment being low and variable (Morris *et al*., 1980; Van Blaricom *et al*., 1993). Growth rates depend on animal size, location, food availability, reproductive condition, and other factors. Absolute longevity has not been determined, but ages greater than 30 years appear likely based on tagging and other population studies (e.g., Van Blaricom *et al*., 1993).

Although once an important fishery resource throughout the study area, landings peaked in 1973 and declined thereafter (Leet *et al*., 2001). Sport and commercial black abalone fisheries have been closed since 1993. *H. cracherodii* populations in southern California suffered catastrophic declines since the mid-1980s that have resulted in a nearly complete disappearance of black abalone along mainland shores south of Point Conception (Miller and Lawrence-Miller, 1993), as well as at many of the Channel Islands (Lafferty and Kuris, 1993; Richards and Davis, 1993). Mortality was associated with withering syndrome (WS), in which the foot shrinks and weakened individuals lose their grip on rock surfaces (Antonio *et al*., 2000; Friedman *et al*., 1997; Gardner *et al*., 1995). WS has spread to populations north of Pt. Conception in recent years (Altstatt *et al*., 1996). Other sources of mortality include smothering by sand, dislodgment by storm waves, and predation by octopus, sea stars, fishes, and sea otters (Morris *et al*., 1980; Van Blaricom *et al*., 1993). Impacts from oil are little known, but North *et al*. (1965) reported black abalone mortality following a spill in Baja California. Because of low recruitment, slow growth, and already decimated reproductive populations, additional mortality from oil spills would be devastating, and recovery prospects long-term at best. It is important to note that results of the HSM described below do not capture these types of information, rather they identify habitats that are potentially suitable for particular species.

Broad-scale Patterns
Highly suitable habitat for black abalone was determined to occur in nearshore waters ranging from 0-10 m on hard substrates and low on hard substrates between 10-20 m. All habitats at depths greater than 20 m were considered unsuitable. As such, highly suitable habitat for black abalone was limited to nearshore rocky habitats along the mainland and islands of California, especially around the Channel Islands (Figure 3.1.5).

Commercial statistics for black abalone were available from CDFG CMASTR landings data during 1990-1993 (Figure 3.1.6). The majority of landings occurred in southern California, most notably around San Miguel, Santa Rosa, and San Nicolas islands. These data were not sufficient for statistical comparisons with the predicted HSM results however, six of the nine commercial grids that were ranked as high overlapped areas of high habitat suitability, and six of eight grids that were ranked as moderate overlapped high and moderately suitable habitats.

Analysis of Boundary Concepts

Highly suitable habitat for black abalone within the CINMS was spread throughout the islands comprising 66 km^2 (Figure 3.1.5). An additional 99 km^2 of area was considered moderately suitable. No additional highly suitable habitat was gained within Concepts 4 and 5. Highly suitable habitat increased within the remaining concepts that have boundaries which include mainland shoreline (Figure 3.1.7). OAI results indicate that Concept 2 provides the greatest proportional change of suitable habitat/total area relative to the NAC (Table 3.1.3).

Summary

• Black abalone have a narrow range of habitat distribution. Highly suitable habitat occurs over hard substrates at depths between 0-10 m.

• Sport and commercial fisheries for black abalone are currently closed.

• Of the six boundary Concepts being considered, Concept 2 provides the optimal proportional change of suitable habitat for black abalone/total area in relation to the NAC.

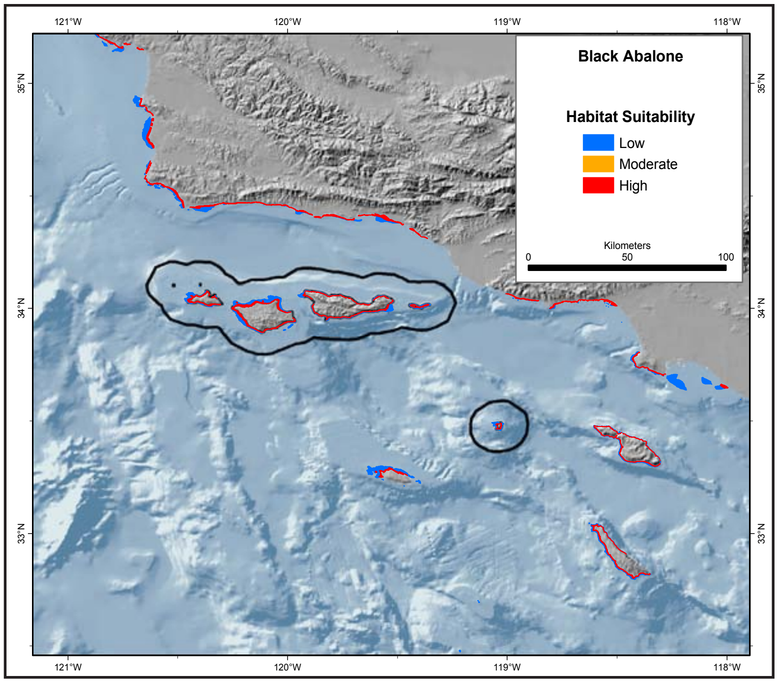

Figure 3.1.5. Black abalone habitat suitability off southern California.

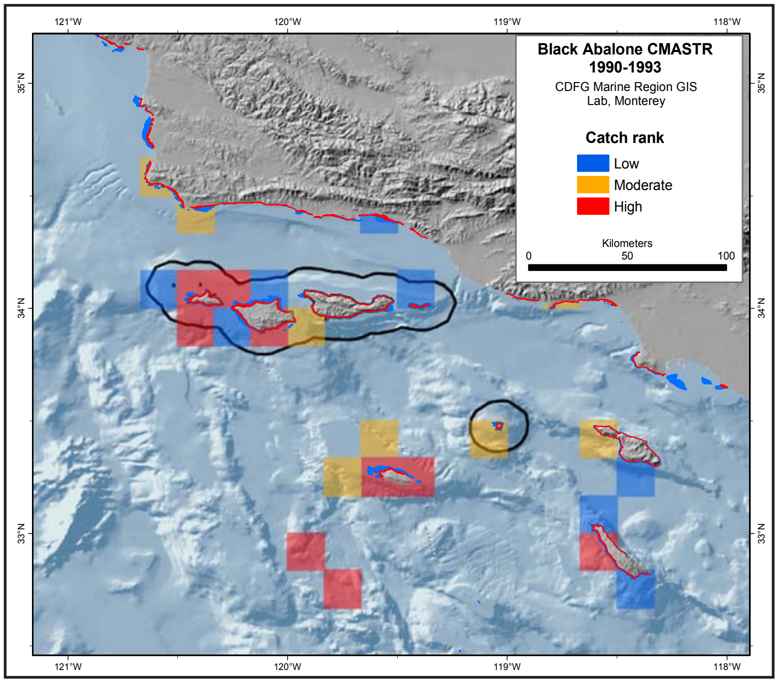

Figure 3.1.6. Black abalone commercial landings data from CDFG CMASTR database, 1990-1993, superimposed over predicted habitat suitability.

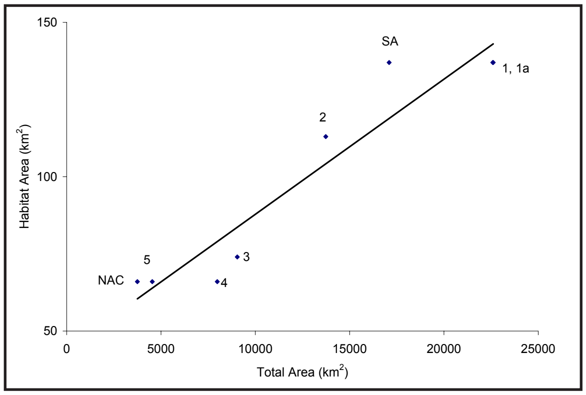

Figure 3.1.7. Regression of highly suitable habitat area for black abalone and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Red abalone *(Haliotis rufescens)*

Red abalone prefer to inhabit low intertidal and subtidal rocky substrates to depths of 30 m from Oregon to southern Baja California (Morris *et al*., 1980). In southern California, red abalone are most abundant from the intertidal zone to 30 m with a depth limit of 50 m (Leighton, 1968). This colder-water abalone is relatively sedentary on reef tops or in crevices. They feed on drift algae and, especially when young, on microscopic algal films. This species may live 20 years (Leet *et al*., 2001). Red abalone were once an important fishery in California, with landings peaking in 1967 and steadily declining thereafter (Leet *et al*., 2001). They were common or abundant in the study area, especially along the northwestern islands, but now are uncommon except for areas at Santa Rosa and San Miguel Islands. The red abalone commercial and sport fishery is currently closed, except for sport take by free divers in northern California. Other sources of mortality include predation by crabs, octopus, sea stars, fishes, and sea otters.

Table 3.1.3. Analysis of black abalone habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km²)	High Suitability Area (km²)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	66	-	-	-
5	4538	66	21.12	0.00	0.00
4	7981	66	113.11	0.00	0.00
3	9044	**74**	141.50	12.12	0.09
2	13736	**113**	266.78	71.21	0.27
1	22613	**137**	503.82	107.58	0.21
1a	22591	**137**	503.23	107.58	0.21
SA	*17093*	*137*	*356.42*	*107.58*	*0.30*

Broad-scale Patterns

High suitability habitat for red abalone was determined to consist of hard substrates at depths between 0-30 m. Hard substrates between 30-40 m were classified as moderate and low to 50 m. While these high and moderately suitable habitats are intermittently located throughout the nearshore waters of California, it is difficult to display them from a state-wide scale. Thus, results for southern California are displayed in Figure 3.1.8. Warmer waters from the south reduce suitability at locations east of the midpoint of Santa Cruz island (approximately 119.8° W; Barsky, K. pers. comm.), where suitability was defined as moderate on hard substrates between 0-30 m and low at depths between 30-50 m. In southern California, considerable amounts of highly suitable habitat are situated along the mainland west of Santa Barbara and around San Miguel, Santa Rosa, and Santa Cruz Islands. Moderate suitability in the nearshore mainland extends east of Point Mugu and around the southern Channel Islands.

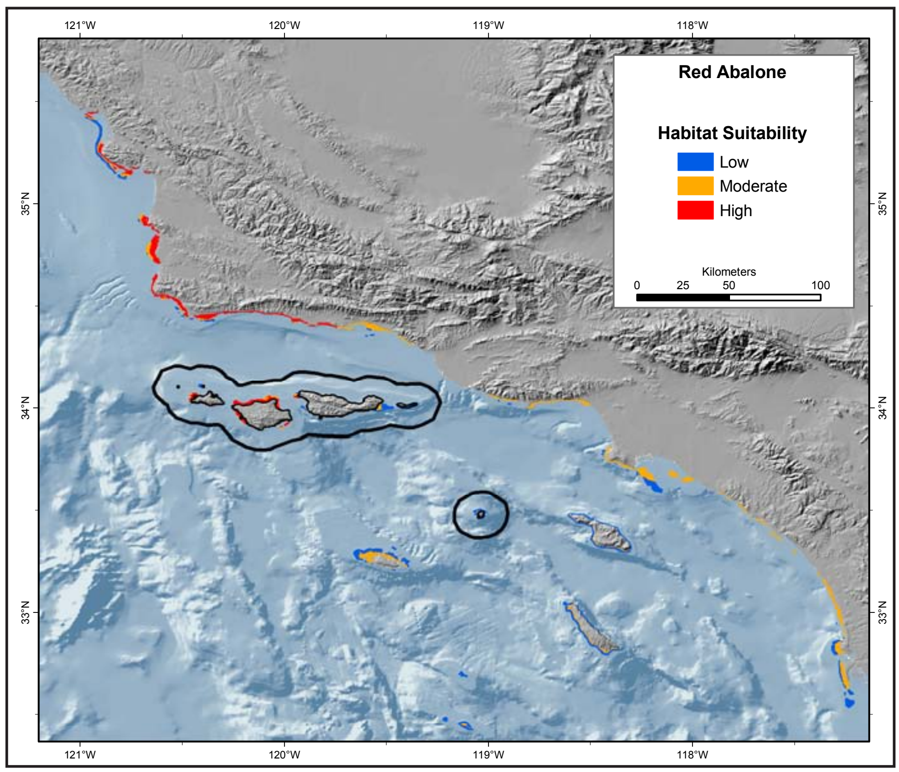

Figure 3.1.8. Red abalone habitat suitability off southern California.

Commercial information for red abalone were available from CDFG's CMASTR landings data from 1990-1999. Although landings occurred from Point Reyes through southern California, viewing the overlap with model results was difficult. Therefore, landings from southern California superimposed over model results are shown in Figure 3.1.9. Chi-square analysis indicated a significant correlation between CDFG landings data and predicted habitat suitability.

Analysis of Boundary Concepts

Highly suitable habitat for red abalone comprises 123 km² within the current CINMS boundary (NAC). Although Concepts 4 and 5 increased in size, no additional highly suitable habitat was included. Within these boundaries, areas of high and moderate suitability were found primarily around San Miguel, Santa Rosa, the western half of Santa Cruz, and along the mainland west of Santa Barbara (Figure 3.1.8). Regression analysis revealed significant increases of highly suitable habitat within Concepts 1, 1a, 2, and the Study Area boundary compared to the smaller concepts (Figure 3.1.10). Although Concepts 1 and 1a contained the greatest amount of red abalone habitat, OAI results indicated that Concept 2 offers the most beneficial proportional change of suitable habitat/total area relative to the NAC (Table 3.1.4).

Summary

• Highest habitat suitability for red abalone occurs over hard substrate within 0-30 m.

• Red abalone distribution throughout southern California is broadly dispersed throughout the Channel Islands and along the mainland.

• The commercial fishery for red abalone closed in 1997.

• Of the six boundary concepts being considered, Concept 2 provides the optimal proportional change of suitable habitat for red abalone/total concept area relative to the NAC.

White abalone *(Haliotis sorenseni)*

Historically, adult and juvenile white abalone were most abundant at depths ranging from 20-60 m in warm waters from southern California to southern Baja California (Morris *et al*., 1980; Leet *et al*., 2001; Lafferty *et al*., 2004). Longevity has been estimated to be 25 years (Gotshall and Laurent, 1979; Davis *et al*., 1996). White abalone are sedentary, inhabiting open, exposed deep-water reefs with a kelp understory. Adults consume drifting and attached macroalgae. Juveniles are cryptic, hiding in crevices and beneath rocks where they feed on microalgal films (Davis *et al*., 1996).

The white abalone fishery developed late due to their preferred depth range (with the first reported commercial landings in 1968). Historically, abundance was highest along the southern and northeastern Channel Islands. Peak landings occurred in 1972 and decreased thereafter (Leet *et al*., 2001). Average density during periods of peak harvest in the 1970s was one abalone/m^2. Density has dramatically decreased since then with recent surveys in the study area suggesting that density has decreased to 0.0001/m^2 (Davis *et al*., 1998). Females must be within a few meters of a male during spawning for fertilization to occur. Present population densities in the study area apparently preclude successful spawning. Although some sections of the white abalone fishery have been closed since 1977 and the entire fishery has been closed since 1993, densities have continued to fall (Davis *et al*., 1998;

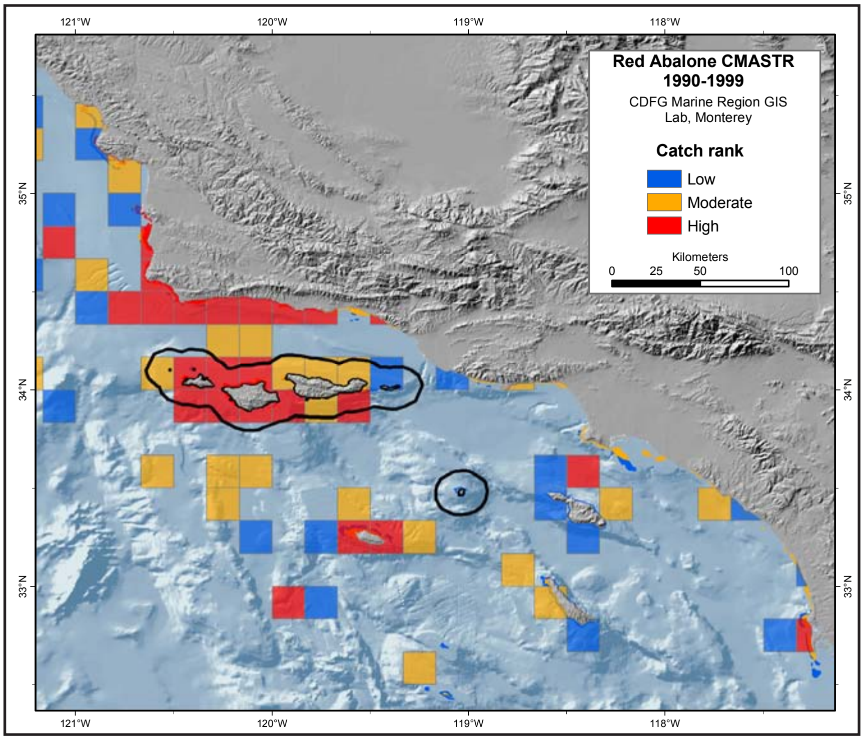

Figure 3.1.9. Red abalone commercial landings data from CDFG CMASTR database, 1990-1999, superimposed over predicted habitat suitability.

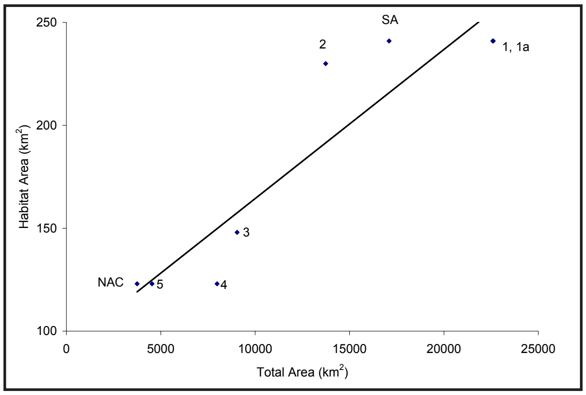

Figure 3.1.10. Regression of highly suitable habitat area for red abalone and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.4. Analysis of red abalone habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	123	-	-	-
5	4538	123	21.12	0.00	0.00
4	7981	123	113.11	0.00	0.00
3	9044	**148**	141.50	20.33	0.14
2	13736	**230**	266.78	86.99	0.33
1	22613	**241**	503.82	95.93	0.19
1a	22591	**241**	503.23	95.93	0.19
SA	*17093*	***241***	*356.42*	*95.93*	*0.27*

Carlton *et al*., 1999). Subthreshold breeding density and continued predation (e.g., fish, octopus, and sea stars) suggest that recovery without significant human intervention is unlikely. White abalone are currently a candidate species for protection under the Environmental Species Act. Submersible surveys are being carried out to further evaluate population status and to explore possibilities for collection of specimens for a captive breeding program.

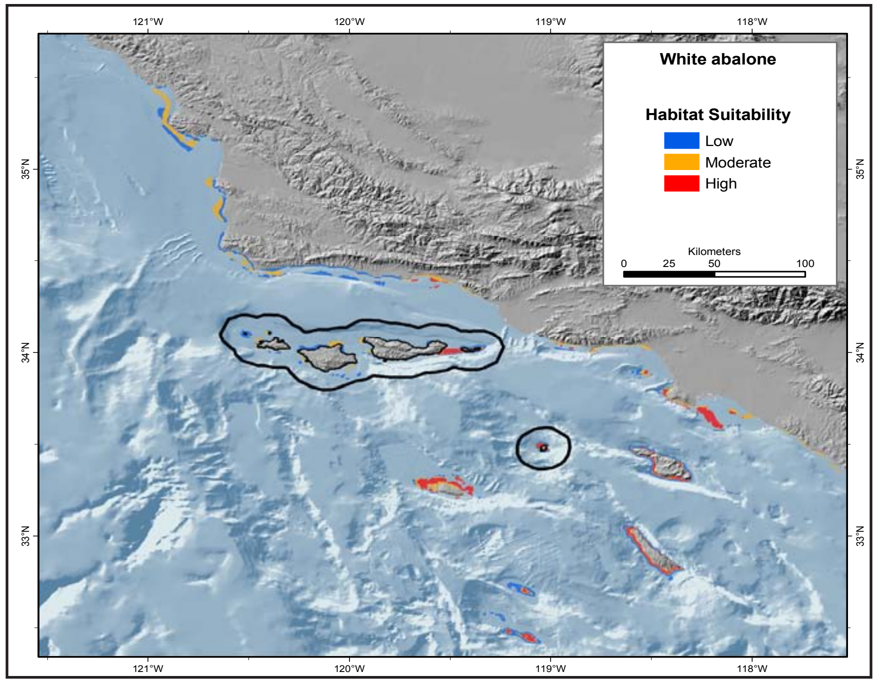

Figure 3.1.11. White abalone habitat suitability off southern California.

Broad-scale Patterns

Since white abalone prefer warm waters, their distribution is almost the transpose of that for red abalone. Highly suitable habitats occur east of Point Mugu (approximately 119.8°W) over hard substrates between 20-60 m. Hard substrates at depths less than 20 m and between 60-70 m were considered moderate, while hard substrates between 70-80 were low suitability. Hard substrates at depths between 20-70 m west of Santa Barbara were classified as moderate and low at depths from intertidal to 20 m and 60-80 m. The distribution of white abalone are limited to southern California, thus habitats above 35.5°N were considered to be low suitability. Accordingly, 565 km^2 is considered highly suitable for white abalone in southern California (Figure 3.1.11). These habitats are generally found just off the mainland from Santa Barbara to the U.S.-Mexico border. Other areas of high suitability encompass the southern Channel Islands (Santa Catalina, San Clemente Islands, and San Nicolas), Anacapa Island, the eastern half of Santa Cruz Island, and portions of Tanner and Cortez Banks.

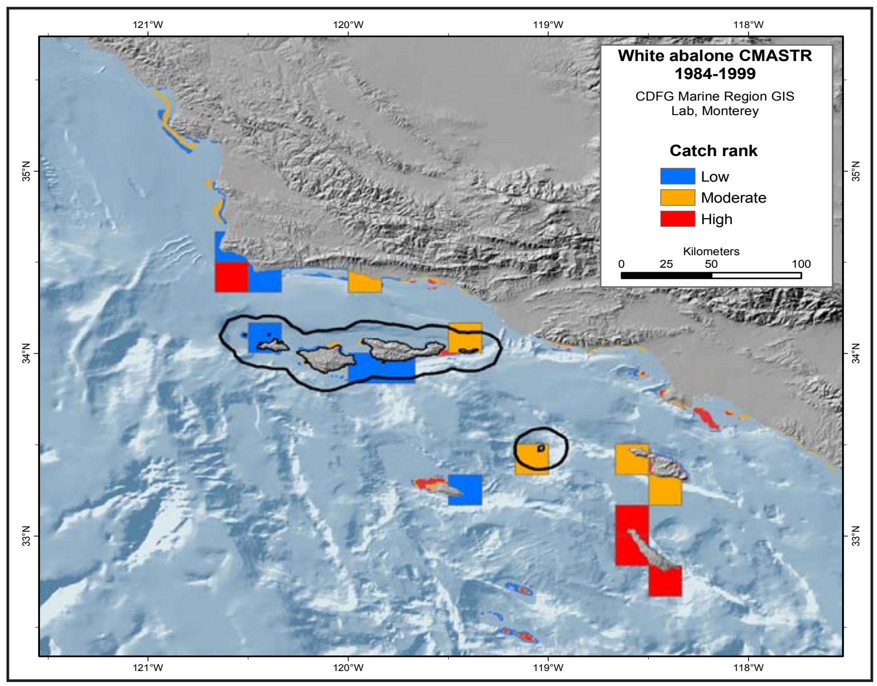

Figure 3.1.12. White abalone commercial landings data from CDFG CMASTR database, 1984-1999, superimposed over predicted habitat suitability.

CDFG's CMASTR landings data from 1984-1999 were compared with HSM results to provide a measure of model validation (Figure 3.1.12). The data were insufficient for statistical analysis; however, visual observation indicates that catch patterns generally agree with model results.

Analysis of Boundary Concepts

Approximately 52 km^2 of habitat was considered highly suitable for white abalone within the current CINMS boundary (NAC). No additional highly suitable habitat was gained within Concepts 2, 3, 4 or 5. Highly suitable habitats located on the mainland east of Santa Barbara were gained within Concepts 1, 1a, and the Study Area (Figure 3.1.13). Most of the habitat classified as highly suitable were located further south and are not included in any of the boundary concepts (Figure 3.1.11). Despite this, OAI results indicate that Concepts 1 and 1a offer the best proportional change in highly suitable habitat area/total area gained relative to the NAC (Table 3.1.5).

Summary

• White abalone is a candidate species under the Endangered Species Act.

• Suitable habitat for white abalone was determined to occur over hard substrate within 20-60 m. The majority of highly suitable habitat occurs south of the proposed boundary concepts.

• Of the six boundary concepts being considered, Concepts 1 and 1a provide the optimal proportional change of suitable habitat for white abalone/total area in relation to the NAC.

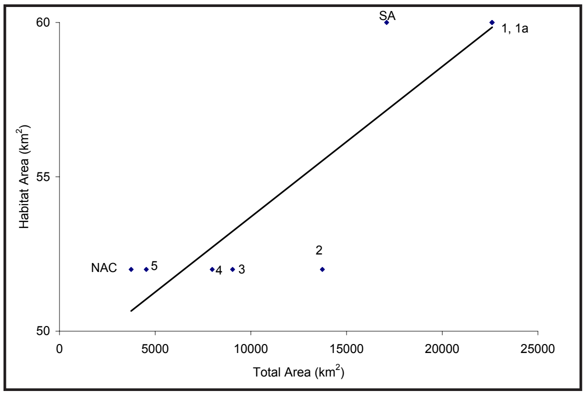

Figure 3.1.13. Regression of highly suitable habitat area for white abalone and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.5. Analysis of white abalone habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	52	-	-	-
5	4538	52	21.12	0.00	0.00
4	7981	52	113.11	0.00	0.00
3	9044	52	141.50	0.00	0.00
2	13736	52	266.78	0.00	0.00
1	22613	**60**	503.82	15.38	0.03
1a	22591	**60**	503.23	15.38	0.03
SA	*17093*	***60***	*356.42*	*15.38*	*0.04*

California Market Squid *(Loligo opalescens)*

The California market squid occurs off southern Alaska to central Baja California. The market squid is pelagic, inhabiting coastal waters to 800 m (PFMC, 1998). Large numbers of squid gather to spawn in semi-protected bays, usually over a sand bottom with rocky outcroppings. Spawning often occurs from October through May in the study area among squid that are from 1 to 3 years of age; however, spawning may occur at other times in some years (Leet *et al.*, 2001). Spawning may occur in deep waters (Roper *et al.*, 1984). Eggs are deposited on the bottom in clusters, with juveniles emerging within approximately one month. Adults die after spawning. The diet of squid consists of small pelagic crustaceans, fishes, and benthic worms.

Market squid have been harvested in California since 1863. The California fishery shifted its emphasis to southern California in 1961, where it is currently centered. The fishery has been marked by large-scale fluctuations in landings, with no apparent overall trend. The present status of populations in the this region is unclear and is presently being evaluated by the California Department of Fish and Game. Squid are important prey for numerous fishes, birds, and marine mammals and their eggs are eaten by benthic echinoderms (Morris *et al.*, 1980, Leet *et al.*, 2001). The market squid is one of the principal diet items of Dall's and Risso's dolphins, pilot whales, sea lions, and elephant seals (Bonnell and Dailey, 1993).

Broad-scale Patterns

Habitat suitability for market squid was considered to be high from 0-200 m, moderate between 201-500 m, and low at depths between 500-800 m. Since market squid are pelagic, suitability for substrate types was not considered. Thus, mapped suitability based on bathymetry results in extensive areas along the continental shelf of California and around the islands in the south (Figure 3.1.14). Smaller areas of moderate suitability extend seaward of high suitability habitats, followed by a broad area of low suitability in deeper (<800 m) waters. Based on the model, approximately 28,000 km^2 of highly suitable habitat occurs off the coast of California.

National Marine Fisheries Service (NMFS) trawl samples from 1999-2002 (N=1,096) were superimposed over the predicted habitat suitability map to test model performance. Suitability values were extracted at the trawl sample location (Figure 3.1.15) and compared using correspondence analysis. A positive relationship was observed with NMFS trawl catches and HSM results (X^2<0.0001, r^2=0.17). High and moderate catches from the NMFS data were more correlated with high suitability, while low catches were correlated with moderate and low suitability. Some biases must be considered when interpreting these results. The data used for this comparison were taken from NMFS otter trawls, where sampling was not equivalent throughout the bathymetric range of the study area. Also, otter trawls may not effectively capture squid; purse seines are typically used in the squid commercial fishery (NMFS, 1998).

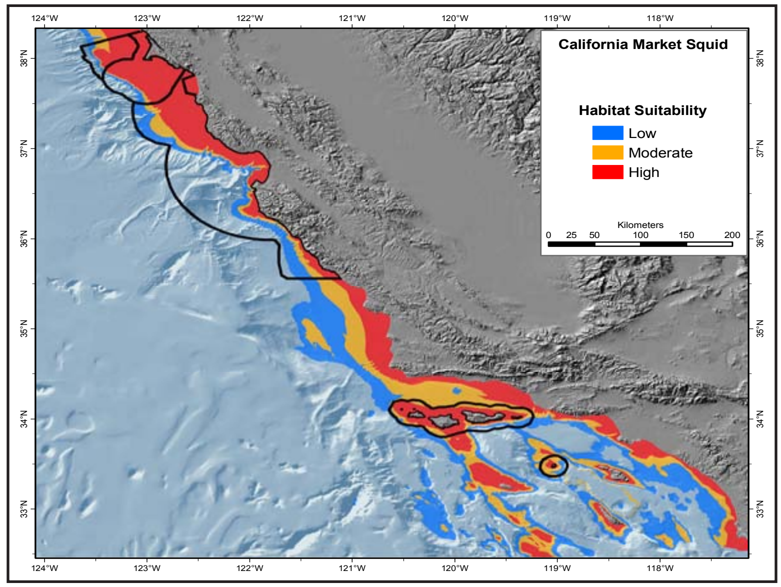

Figure 3.1.14. California market squid habitat suitability off central and southern California.

Analysis of Boundary Concepts

Considerable amounts of highly suitable habitat were included within all boundary concepts and more than half of the total area within the current CINMS boundary (NAC) was considered highly suitable for market squid (Figure 3.1.17). Little additional habitat was gained within Concept 5 while an increase of 20% was observed within Concept 4. Significant gains were observed in the larger concepts as their northern boundaries contained habitats near the mainland. Although Concepts 1, 1a, and the Study Area contained greater amounts of highly suitable habitat, comparison of OAI values indicates that Concept 2 provides the optimal proportional change of highly suitable habitat/total area gained relative to that of the NAC (Table 3.1.6).

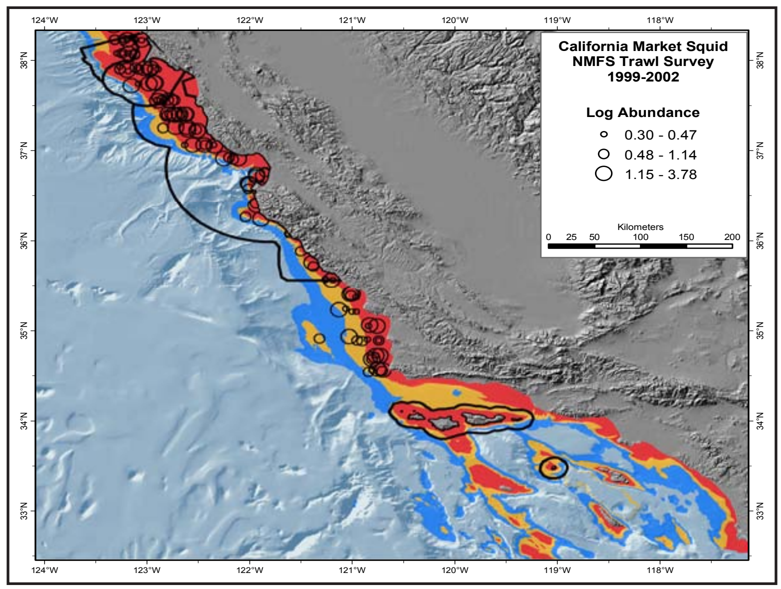

Figure 3.1.15. Location of NMFS trawls (1999-2002) and squid mean log abundance superimposed over predicted habitat suitability.

Summary

•California market squid is one of the most important commercial fisheries in California.

•Market squid are pelagic and highly suitable habitat occurs in waters between 0-200 m.

•Model performance tested well with NMFS trawl data.

•Of the six boundary concepts being considered, Concept 2 provides the optimal proportional change of highly suitable habitat for market squid/ total concept area relative to the NAC.

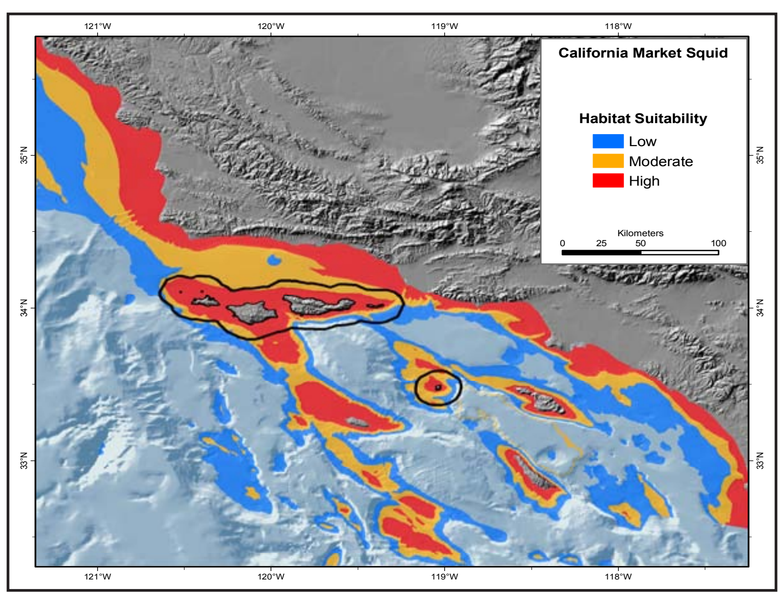

Figure 3.1.16. California market squid habitat suitability off southern California.

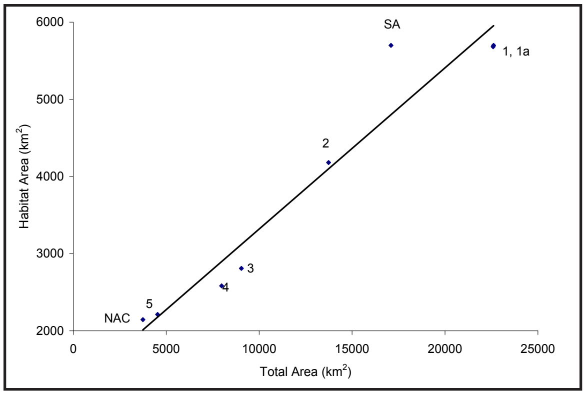

Figure 3.1.17. Regression of highly suitable habitat area for California market squid and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.6. Analysis of California market squid habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	2145	-	-	-
5	4538	**2212**	21.12	3.12	0.15
4	7981	**2583**	113.11	20.42	0.18
3	9044	**2809**	141.50	30.96	0.22
2	13736	**4181**	266.78	94.92	0.36
1	22613	**5699**	503.82	165.69	0.33
1a	22591	**5681**	503.23	164.85	0.33
SA	*17093*	***5699***	*356.42*	*165.69*	*0.46*

Sheep crab *(Loxorhynchus grandis)*
The sheep crab is the largest member of the California spider crabs, with an adult carapace length ranging from 4-9 inches. They range from Cordell Bank to Baja California in sand or rocky substrate at depths ranging from 3-124 m. Male crabs winter in deep water, but both sexes migrate onshore in early spring to mate (Leet *et al*., 2001).

The Santa Barbara Channel and waters offshore of the northern Channel Islands represent major fishery areas for the sheep crab. Large-scale commercial harvest of sheep crab whole body and claws began in 1984 and the fishery peaked in 1988, with retail values totaling $1.9 million/year. Landings declined after 1990 when the use of gillnets was banned in shallow water, and again in 1994 when gillnets were universally phased out (Leet *et al*., 2001).

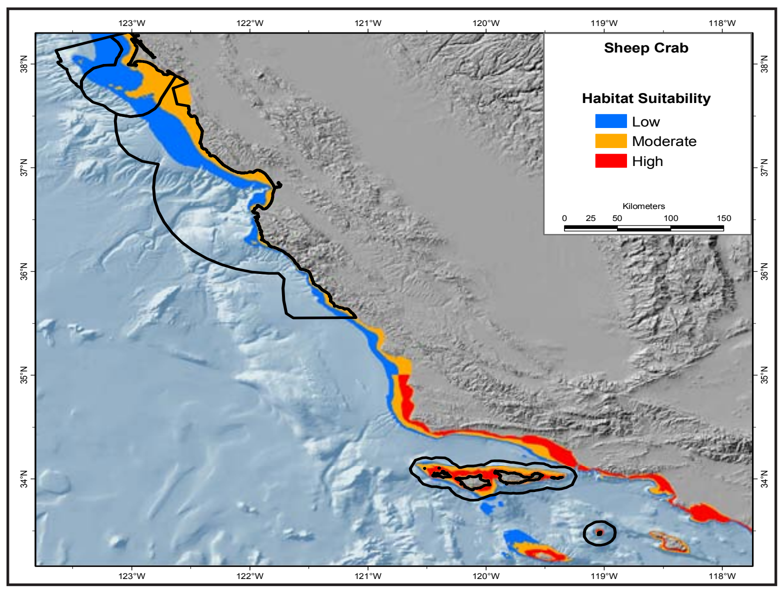

Figure 3.1.18. Sheep crab habitat suitability off central and southern California.

Broad-scale Patterns
Sheep crab suitability was defined as high for both hard and soft substrate at depths from 10-60 m. Moderate suitability extended from intertidal waters to 10 m and between 60-100 m. Habitat suitability was low at depths between 100-130 m. Sheep crabs are most abundant south of Point Conception, thus habitats in waters less than 60 m, above 35°N were considered moderate suitability while remaining habitat was defined as low. Suitability was considered low for all habitats north of Point Reyes. As such, highly suitable habitat is abundant throughout southern California waters, extending along the mainland from Point Conception south to San Diego, and encompassing the Channel Islands (Figure 3.1.18). Moderately suitable habitat extends northward through the central California sanctuaries.

Sheep crab landings data, recorded as mean pounds during 1996-2000, superimposed over HSM results are presented in Figure 3.1.19. During this time period, the commercial fishery was most active in southern California, most notably between the northern Channel Islands and Santa Catalina Island. Landings data were insufficient to compare statistically; however, upon further observation the landings data do not correlate well with HSM results. Landings data indicate that sheep crabs were harvested at depths deeper than that predicted as suitable.

Analysis of Boundary Concepts
Approximately 20% of the total area (739 km^2) within the current CINMS boundary was considered highly suitable

habitat for sheep crab (Figure 3.1.20). No highly suitable habitat was gained within the slightly larger Concepts 4 and 5. Concepts 1, 1a, 2, and the Study Area gained substantial amounts of highly suitable habitat with the inclusion of area near the mainland. Concepts 1 and 1a contained nearly three times the amount of highly suitable habitat than the NAC (Figure 3.1.21) and had the highest OAI value (Table 3.1.7).

Summary

• Sheep crab are most abundant from Point Conception south to Baja California; highly suitable habitat was considered to occur over hard and soft substrates at depths between 10-60 m.

• The commercial fishery for sheep crab primarily occurs in southern California.

• Of the six boundary concepts being considered, Concepts 1 and 1a provided the best proportional gain of highly suitable habitat/total area relative to the NAC.

Spot shrimp *(Pandalus platyceros)*

Spot shrimp occur on rocky substrates in deep water (45–487 m) from Alaska to San Diego (Leet *et al*., 2001). Adults are generally found at the deeper end of this range, while juveniles are typically found in shallower waters (Sunada, 1984). The diet of spot shrimp consists of small crustaceans, plankton, molluscs, polychaetes, sponges, and carcasses (O'Clair and O'Clair, 1998). This species may live for more than 6 years.

A commercial fishery using trawling gear and traps began in southern California in 1974 (Leet *et al*., 1992). Spot shrimp populations have not been well studied. Landings have fluctuated

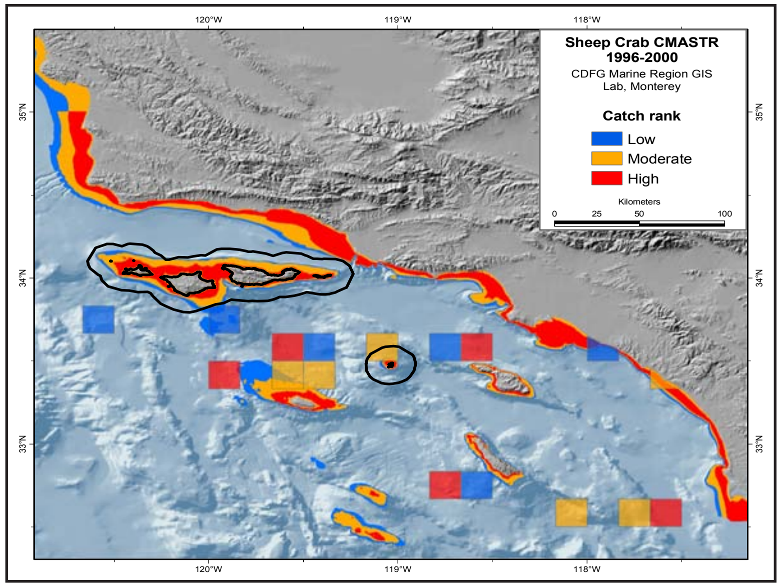

Figure 3.1.19. Sheep crab commercial landings data from CDFG CMASTR database, 1996-2000, superimposed over predicted habitat suitability.

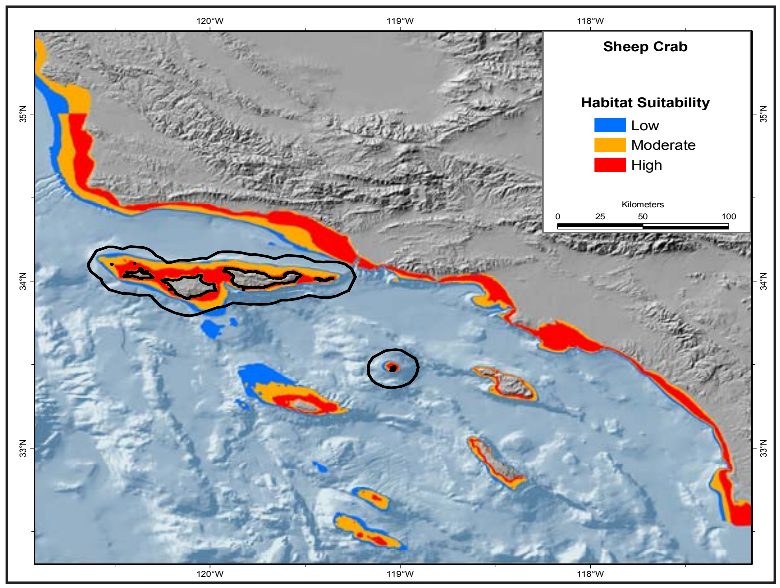

Figure 3.1.20. Sheep crab habitat suitability off southern California.

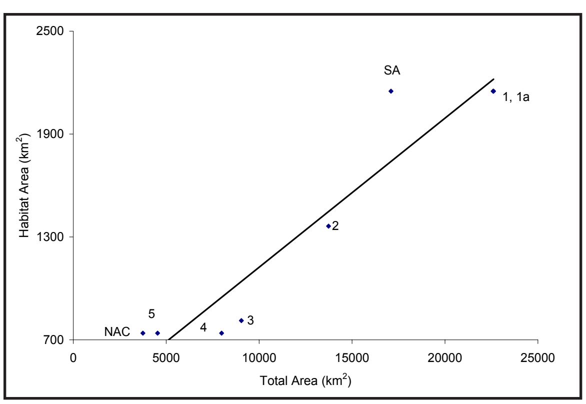

Figure 3.1.21. Regression of highly suitable habitat area for sheep crab and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.7. Analysis of sheep crab habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km²)	High Suitability Area (km²)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	739	-	-	-
5	4538	739	21.12	0.00	0.00
4	7981	739	113.11	0.00	0.00
3	9044	**812**	141.50	9.88	0.07
2	13736	**1363**	266.78	84.44	0.32
1	22613	**2150**	503.82	190.93	0.38
1a	22591	**2150**	503.23	190.93	0.38
SA	*17093*	***2150***	*356.42*	*190.93*	*0.54*

widely, with several good years followed by several poor years. Natural predators include octopus and fish. The northern portion of the Southern California Bight is one of the major population centers for this species (O'Clair and O'Clair, 1998; Leet *et al*., 2001).

Broad-scale Patterns

Highly suitable habitat for spot shrimp was determined to occur on hard and soft substrates within a wide bathymetric range (150-320 m). Moderate suitability extends from 40-150 m and 320-400 m. Low suitability extended from 400-490 m. As such, most of California's continental shelf is suitable habitat for spot shrimp (Figure 3.1.22), and is characterized by a narrow band of highly suitable habitat surrounded by extensive areas of moderate suitability. Considerable amounts of highly and moderately suitable habitat exist in southern California, most notably within the Santa Barbara Channel, the Santa Cruz Basin, and the offshore banks south of the Channel Islands. These areas correspond well with published areas of high abundance (Leet *et al*., 2001).

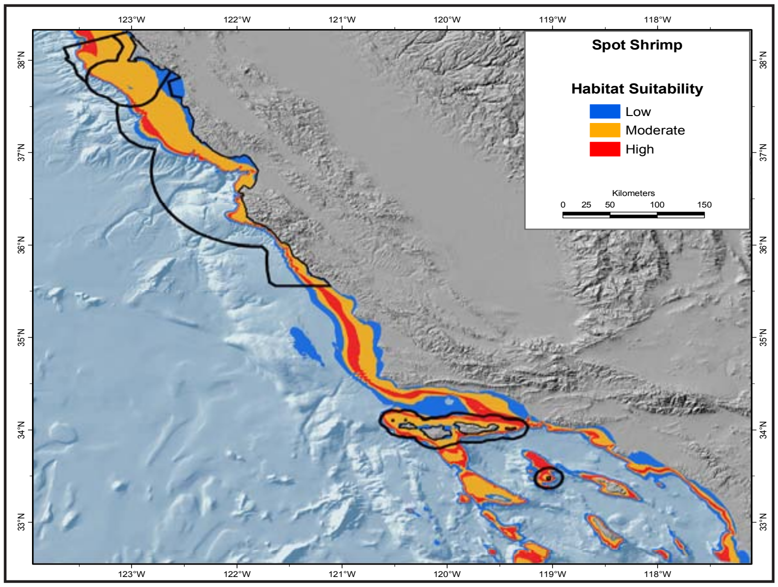

Figure 3.1.22. Spot shrimp habitat suitability off central and southern California.

Model performance was tested with CDFG's commercial trawl and trap logs from 1994-2001. CDFG commercial trap landings primarily occurred in southern California (Figure 3.1.23) around the Channel Islands and along the mainland. Landings in pounds were ranked similar to that for the HSM and compared using correspondence analysis. Chi-square analysis indicated a significant correlation (X^2=0.0072, r^2=0.07). Commercial trawl landings (Figure 3.1.24) were more ubiquitous than trap landings, and chi-square results displayed a statistically significant correlation with model results (X^2<0.0001, r^2=0.17).

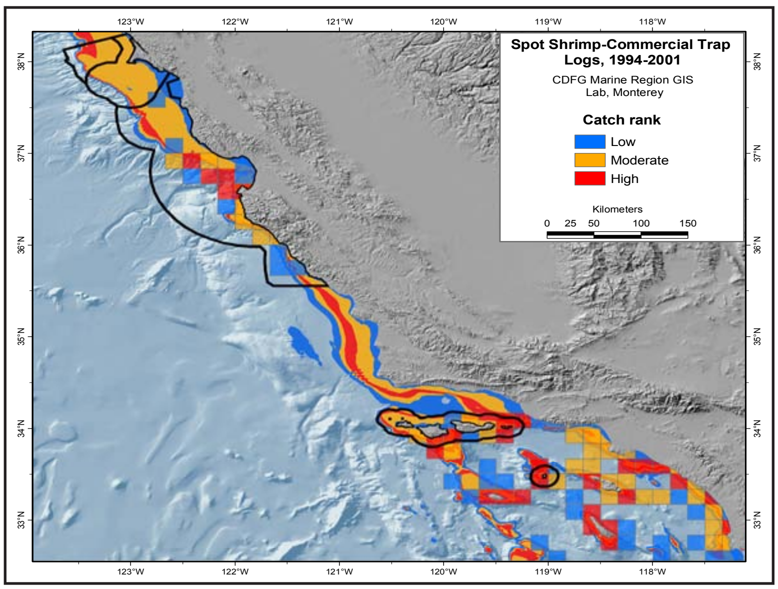

Figure 3.1.23. Spot shrimp commercial landings data from CDFG Commercial Trap Logs, 1994-2001, superimposed over predicted habitat suitability.

Analysis of Boundary Concepts

Approximately 979 km^2 of highly suitable habitat occurs within the current CINMS boundary (Figure 3.1.25). Highly suitable habitat increased relatively by 12% within Concept 5, 50% within Concept 4, and 70% within Concept 3. Significant gains of highly suitable habitat were observed within the large concepts which included areas in the northern portion of the Santa Barbara Channel and around Point Conception. Although Concepts 1 and 1a contained the largest amounts of highly suitable habitat (Figure 3.1.26), OAI results indicate that Concept 5 offered the optimal proportional change of suitable habitat gained/total area gained relative to the NAC (Table 3.1.8).

Summary

• Spot shrimp are typically a deep water species where highly suitable habitat occurs over hard and soft substrates at depths between 150-320 m .

• Comparisons of commercial data and habitat suitability were statistically significant.

• Of the six boundary concepts being considered, Concept 5 provided the optimal proportional change of highly suitable habitat for spot shrimp/total concept area relative to the NAC.

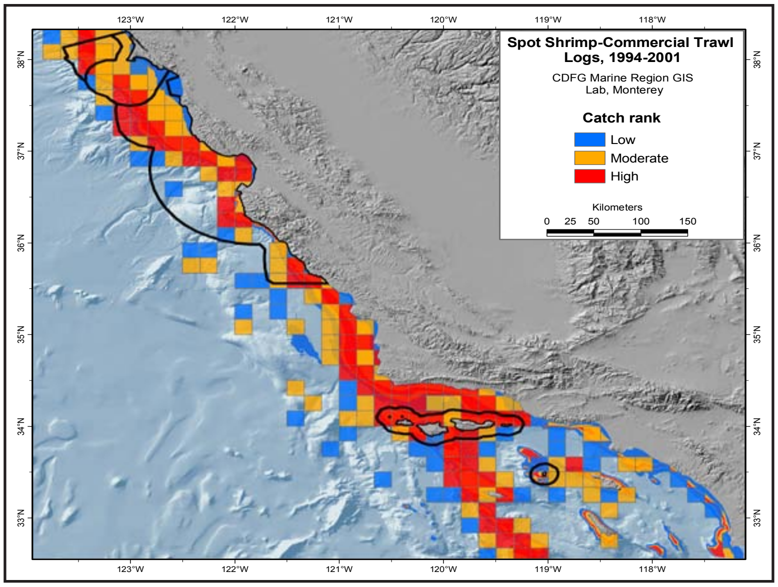

Figure 3.1.24. Spot shrimp commercial landings data from CDFG Commercial Trawl Logs, 1994-2001, superimposed over predicted habitat suitability.

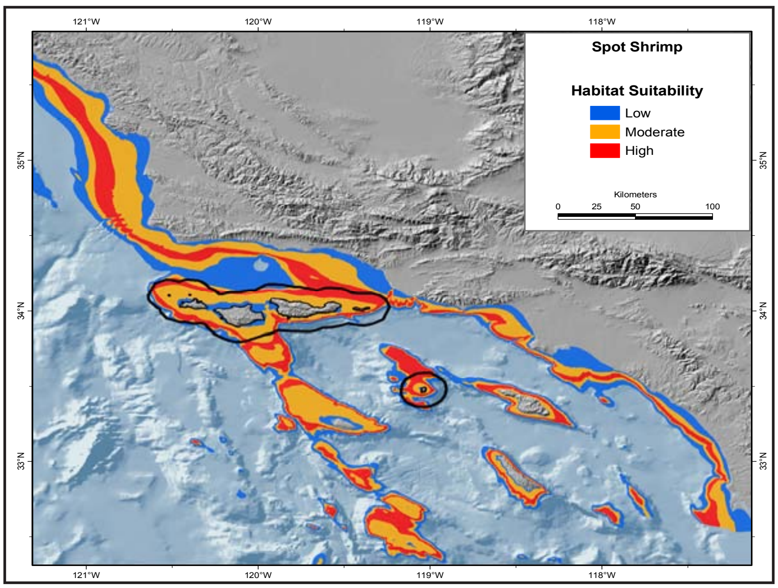

Figure 3.1.25. Spot shrimp habitat suitability off southern California.

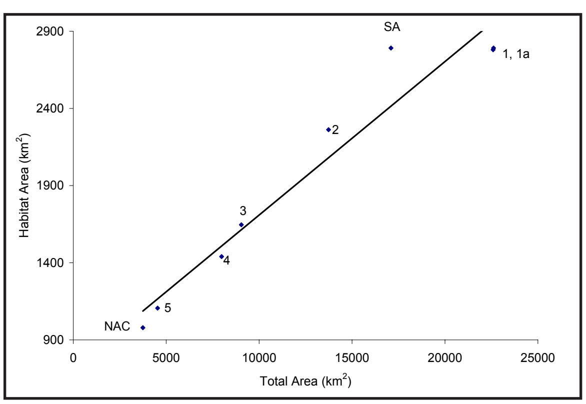

Figure 3.1.26. Regression of highly suitable habitat area for spot shrimp and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.8. Analysis of spot shrimp habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	979	-	-	-
5	4538	**1106**	21.12	12.97	0.61
4	7981	**1440**	113.11	47.09	0.42
3	9044	**1646**	141.50	68.13	0.48
2	13736	**2262**	266.78	131.05	0.49
1	22613	**2791**	503.82	185.09	0.37
1a	22591	**2780**	503.23	183.96	0.37
SA	*17093*	***2791***	*356.42*	*185.09*	*0.52*

Ridgeback rock shrimp *(Sicyonia ingentis)*
Ridgeback rock shrimp occur in subtidal depths (5-307 m) from Monterey Bay to central Mexico (Perez-Farfante, 1985). In the Southern California Bight, they are most abundant between 40-160 m (Sunada, 1984). Preferred substrates are sand, shell, and mud (Sunada, 1984; Leet *et al*., 2001). The diet is not well known, though it is suspected to be a detritus feeder as are related species. This species may live about 5 years.

A commercial fishery using trawling gear began in 1966. Landings decreased dramatically from 1985 to 1991 (Leet *et al*., 2001). Surveys by the California Department of Fish and Game confirmed population declines since 1985. The study area includes one of the major population centers for this species (Leet *et al*., 2001).

Broad-scale Patterns
High habitat suitability was determined to occur over hard and soft substrates between 40-160 m. All substrates between 20-40 m and 160-250 m were considered moderate, while substrates at depths between 0-20 m and 250-310 m were defined as low suitability. Leet *et al*., (2001), state that ridgeback rock shrimp distribution begins near Monterey Bay and extends through Mexico and abundance is greater south of Point Conception. Therefore, suitability is higher below 35°N and extends southward. The distribution of high and moderately suitable habitat is similar to that of spot prawn by covering a wide region of the continental shelf and encompassing the Channel Islands (Figure 3.1.27). Highly suitable habitat is also found on the southern offshore banks.

Model performance was tested with trawl data collected by Southern California Coastal Water Research Project (SCCWRP) during 1994 and 1998. During these two years, 520 stations were sampled throughout southern California at depths to 200 m (Figure 3.1.28). Catches were ranked and compared to HSM results using chi-square analysis. Model results and catch rankings grouped well, although moderate catches were more closely correlated with high HSM rankings. Despite this, the comparison was statistically significant (X^2<0.0001, r^2=0.20).

Analysis of Boundary Concepts
Highly suitable habitat for ridgeback rock shrimp follows the contour of the continental shelf and encompasses a broad area around the Channel Islands (Figure 3.1.29). Approximately 30% of the area within the current CINMS boundary (1,138 km^2) was considered highly suitable habitat for

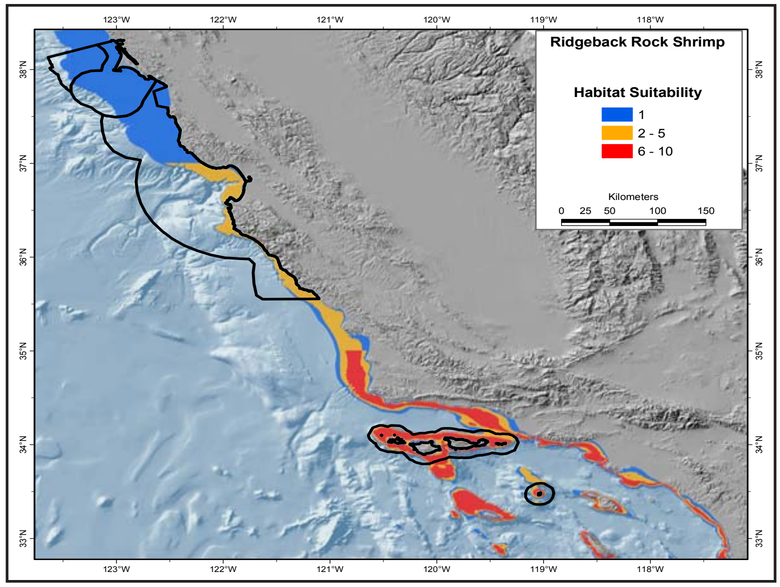

Figure 3.1.27. Ridgeback rock shrimp habitat suitability off central and southern California.

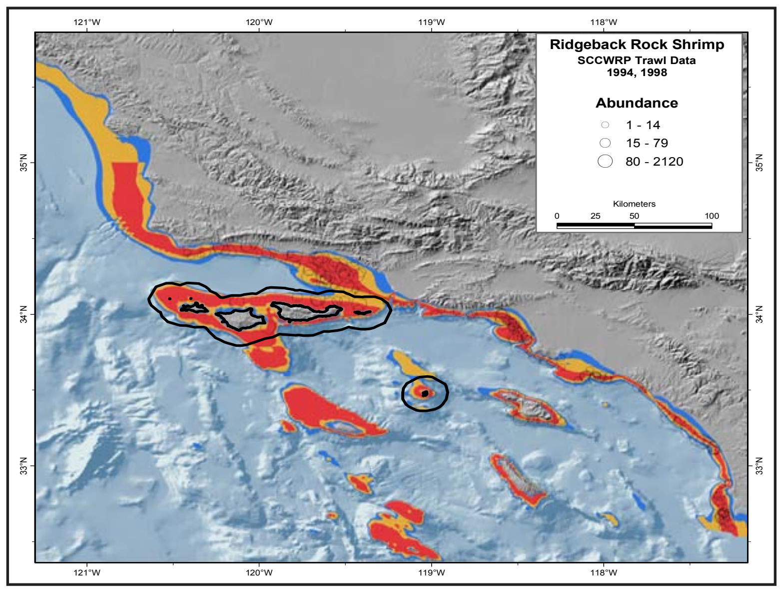

Figure 3.1.28. Location of SCCWRP trawls (1994, 1998) and ridgeback rock shrimp mean abundance superimposed over predicted habitat suitability.

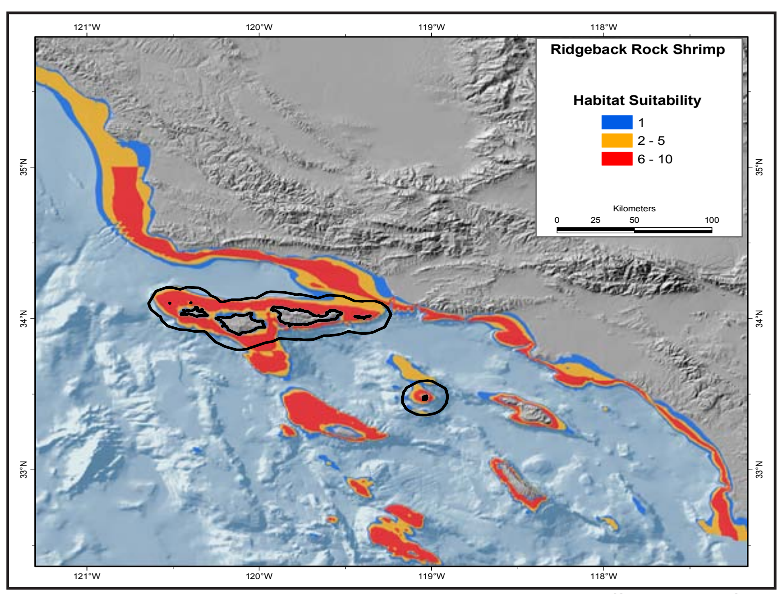

Figure 3.1.29. Ridgeback rock shrimp habitat suitability off southern California.

ridgeback rock shrimp. Areas of suitable habitat increased with increasing concept size (Figure 3.1.30) but exhibited a relative decline in terms of the proportion of total area contained. Highly suitable habitat increased slightly within Concepts 4 and 5, while substantial gains were observed within the remaining concepts. The Study Area, which is not considered as a boundary concept, provided the highest OAI (Table 3.1.9) and Concept 2 produced the highest OAI value for the concepts under consideration.

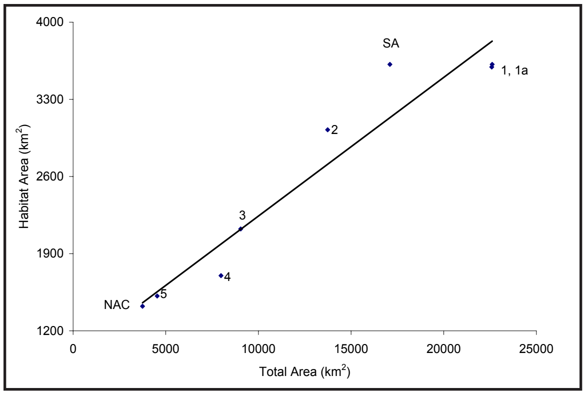

Figure 3.1.30. Regression of highly suitable habitat area for ridgeback rock shrimp and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Summary

• Highly suitable habitat for ridgeback rock shrimp was considered to occur over hard and soft substrates at depths between 40-160 m and below 35°N.

• The commercial fishery has declined in recent years but landings have been highest in southern California.

• Of the five boundary concepts being considered, Concept 2 provided the optimal proportional change of highly suitable habitat for ridgeback rock shrimp/total concept area relative to the NAC.

Table 3.1.9. Analysis of ridgeback rock shrimp habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	1423	-	-	-
5	4538	**1516**	21.12	6.54	0.31
4	7981	**1701**	113.11	19.54	0.17
3	9044	**2124**	141.50	49.26	0.35
2	13736	**3024**	266.78	112.51	0.42
1	22613	**3617**	503.82	145.18	0.31
1a	22591	**3593**	503.23	152.49	0.30
SA	*17093*	***3617***	*356.42*	*145.18*	*0.43*

California spiny lobster *(Panulirus interruptus)*

California spiny lobster inhabit intertidal and subtidal hard substrates (to 80 m) from Monterey Bay to central Mexico, with most of the population occurring south of Point Conception (Morris *et al*., 1980; Leet *et al*., 2001). Juveniles (under 2 years) utilize shallow (5 m) vegetated reefs, especially surfgrass beds, as nursery habitats (Engle, 1979). Adults inhabit crevices in rocky areas, from which they emerge at night to forage on a wide variety of invertebrates, including worms, molluscs, and sea urchins. Spiny lobsters may live 30 years or more (Leet *et al*., 2001).

Spiny lobsters have been commercially harvested using traps in California for over 100 years. Most of the fishery occurs in water less than 30 m deep, although the fishery has expanded to include deeper habitats. A sport fishery (hand capture) is popular among scuba divers in southern California. Other sources of mortality include predation by octopus and fishes. California spiny lobster populations have not been well studied; however, population levels appear to be fairly stable. Lobster populations are likely maintained by recruitment from Baja California facilitated by warm-water patterns over the past two decades. Landings declined from 1950 to 1975, then increased coincident with the establishment of escape ports for sub-legal sized lobsters in traps and development of the long-term warming trend (Leet *et al*., 2001).

Broad-scale Patterns

Highly suitable habitat for California spiny lobster was considered to occur over hard and soft substrates at depths between 0-30 m. Suitability was defined as moderate between 30-60 m, and low between 60-80 m. Leet *et al*., (2001), report that lobsters are rare north of Point Conception; therefore, suitability was considered moderate around Point Conception from approximately 34.5° N to 35°N and low above 35°N (Figure 3.1.31) to Monterey Bay. As such, highly suitable habitat is distributed primarily along the nearshore of the mainland and around the Channel Islands and offshore banks.

Catch per unit effort (CPUE) data were available from CDFG's commercial lobster fishery during 1998-2002 (Figure 3.1.32). These data were insufficient to compare statistically; however, visual observation shows that most landings grids occurred over habitats that were predicted to have high or moderate suitability; while, some grids with high CPUE occurred over habitats with low suitability. Examination of mean CPUE and maximum HSM value for each grid cell shows increasing CPUE with increasing habitat suitability.

Analysis of Boundary Concepts

Approximately 9% (341 km^2) of the current CINMS area (NAC) was considered highly suitable for spiny lobster (Figure 3.1.33). No additional gains of highly suitable habitat were observed within Concepts 4 and 5. A relative increase of 12% was observed within Concept 3, 55% within Concept 2, and 172% for the larger concepts (Figure 3.1.34). The Study Area provided the greatest proportional increase in suitable habitat/total area gained compared to the NAC; however, this boundary is not being considered as a concept. Of the six concepts under consideration, Concepts 1 and 1a yielded the highest OAI value (Table 3.1.10).

Summary

• Highly suitable habitat for California spiny lobster occurs from Point Conception southward over hard and soft substrates at depths of 0-30 m.

• CPUE data were not consistent with HSM results.

• Of the six boundary concepts being considered, Concepts 1 and 1a provide the optimal proportional gains in highly suitable habitat for California spiny lobster/total area relative to the NAC.

California sea cucumber *(Parastichopus californicus)*

California sea cucumbers inhabit low intertidal and subtidal waters to depths of 120 m from Alaska to central Baja California and occur mainly on soft-bottom habitats (Morris *et al*., 1980; Leet *et al.,* 2001). Although relatively sedentary, they may move up to 4 m per day (Lambert, 1997). The diet of California sea cucumbers consist of detritus and small organisms, which they ingest with bottom sediments. This species may live up to12 years. (Morris *et al*.,1980; Leet *et al.,* 2001).

No sport fishery for this species exists. A commercial fishery for California sea cucumbers started in California in 1978 (Leet *et al.,* 2001). In 1982, the center of the fishery shifted to southern California where they are harvested from the Santa Barbara channel by trawling. Other sources of mortality include predation by sea stars, fishes, and crabs.

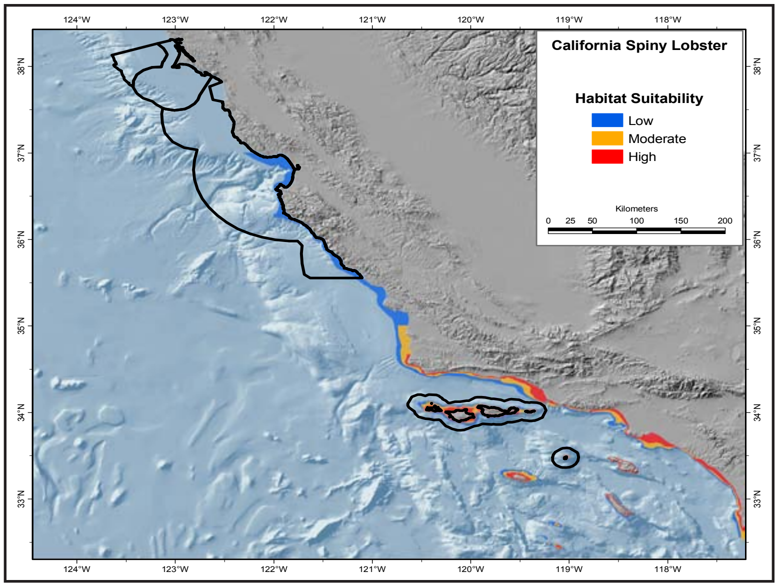

Figure 3.1.31. California spiny lobster habitat suitablity off central and southern California.

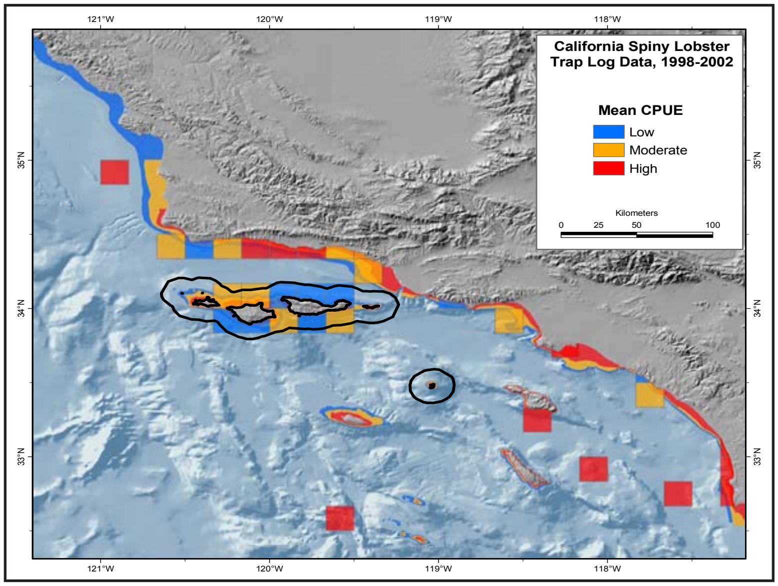

Figure 3.1.32. California spiny lobster commercial landings data from CDFG Commercial Logs, 1998-2002, superimposed over predicted habitat suitability.

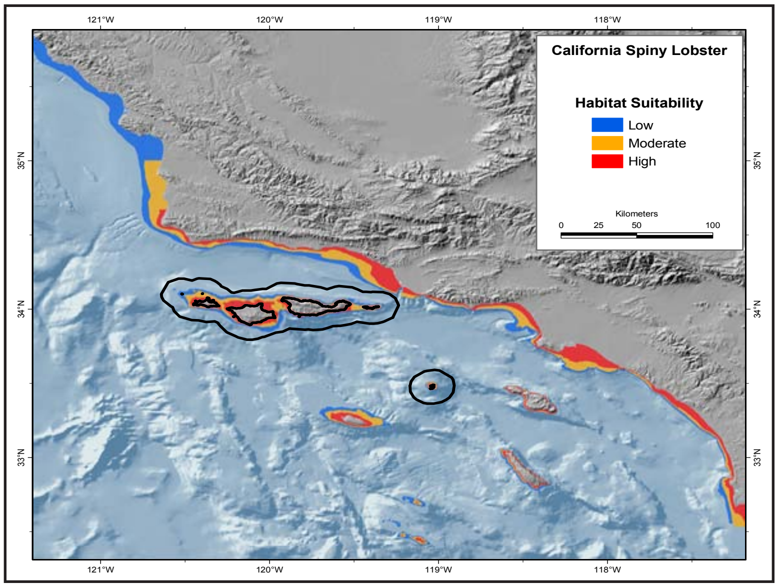

Figure 3.1.33. California spiny lobster habitat suitability off southern California.

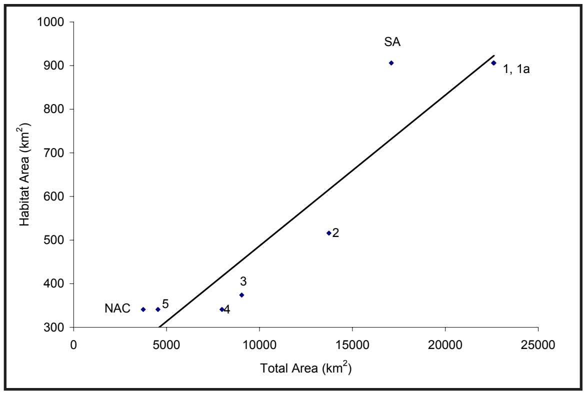

Figure 3.1.34. Regression of highly suitable habitat area for California spiny lobster and total area for the current and proposed boundary alternatives. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.10. Analysis of California spiny lobster habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area(%)	OAI (absolute)
NAC	3475	341	-	-	-
5	4538	341	21.12	0.00	0.00
4	7981	341	113.11	0.00	0.00
3	9044	**374**	141.50	9.68	0.07
2	13736	**516**	266.78	51.32	0.19
1	22613	**906**	503.82	165.69	0.33
1a	22591	**906**	503.23	165.69	0.33
SA	*17093*	***906***	*356.42*	*165.69*	*0.46*

Broad-scale Patterns

Highly suitable habitat was considered to occur over hard and soft habitats between 40-90 m; moderate suitability extends from the intertidal zone to 40 m and between 90-110 m. Low suitability was determined to occur between 110-120 m. As such, highly suitable habitat is extensive comprising vast areas of the continental shelf throughout offshore California waters, including all national marine sanctuaries, and the southern islands (Figure 3.1.35).

Trawl data from SCCWRP surveys (1994 and 1998) were used to test model performance. Catches appeared to occur primarily close to the mainland of southern California (Figure 3.1.36) and around Santa Catalina Island. Chi-square results indicated a statistically significant relationship (X^2<0.0001, r^2=0.09), with mean abundance increasing as habitat suitability increased.

Analysis of Boundary Concepts

Highly suitable habitat comprises approximately 40% of the current CINMS boundary (Figure 3.1.37). Slight gains were observed within Concepts 3, 4, and 5, while significant gains of highly suitable habitat were observed within Concepts 1, 1a, 2, and the Study Area (Figure 3.1.38). Maximum benefit, in terms of the OAI, was observed for Concept 2, which yielded the best proportional change of highly suitable habitat/total area relative to the NAC (Table 3.1.11). The Study Area had the highest OAI value, but this concept is not under consideration.

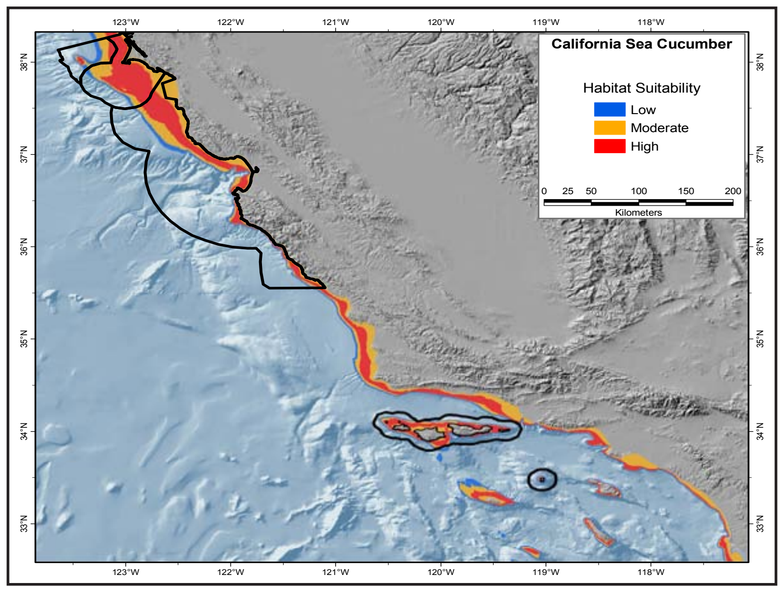

Figure 3.1.35. California sea cucumber habitat suitability off central and southern California.

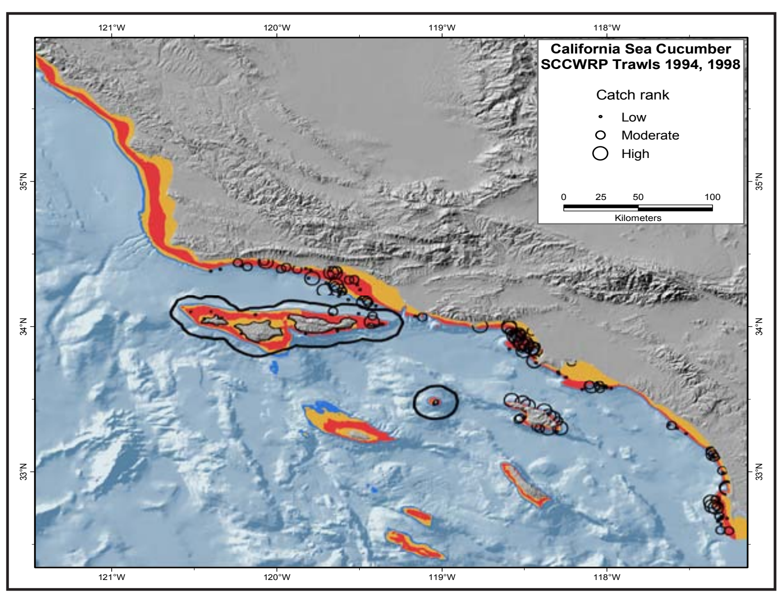

Figure 3.1.36. Location of SCCWRP trawls (1994, 1998) and California sea cucumber mean abundance superimposed over predicted habitat suitability.

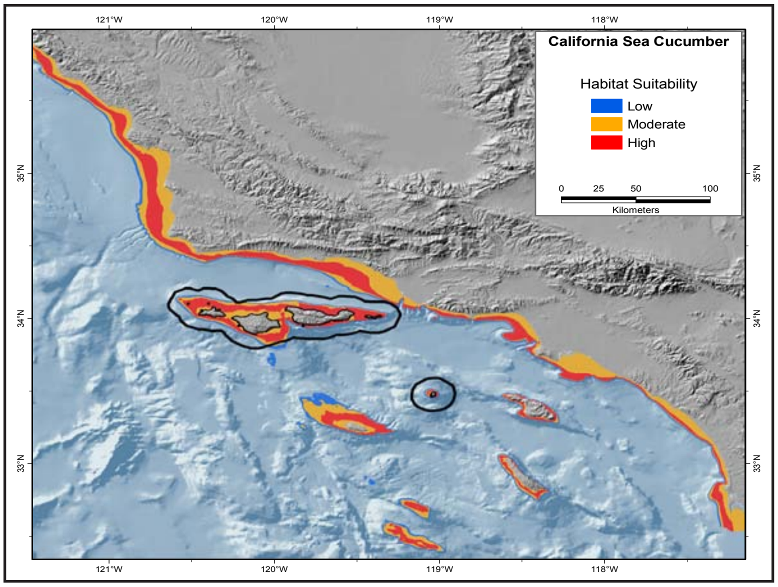

Figure 3.1.37. California sea cucumber habitat suitability off southern California.

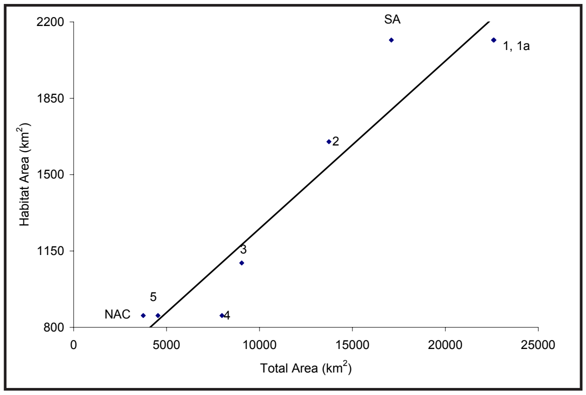

Figure 3.1.38. Regression of highly suitable habitat area for California sea cucumber and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Summary

• Highly suitable habitat for California sea cucumbers occurs over all substrates between 40-90 m.

• A significant commercial fishery has recently developed in southern California.

• Of the five boundary concepts being considered, Concept 2 provided the best proportional change of highly suitable habitat for California sea cucumbers/total area relative to the NAC.

Table 3.1.11. Analysis of California sea cucumber habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area (%)	OAI (absolute)
NAC	3475	854	-	-	-
5	4538	854	21.12	0.00	0.00
4	7981	854	113.11	0.00	0.00
3	9044	**1095**	141.50	28.22	0.20
2	13736	**1651**	266.78	93.33	0.35
1	22613	**2117**	503.82	147.89	0.29
1a	22591	**2117**	503.23	147.89	0.29
SA	*17093*	*2117*	*356.42*	*147.89*	*0.41*

Warty sea cucumber *(Parastichopus parvimensis)*
Warty sea cucumbers habitat overlaps slightly with California sea cucumbers. Warty sea cucumbers occur predominantly in low intertidal waters to depths of 27 m from Monterey Bay to central Baja California and may range to 40 m (Morris *et al*.,1980; Leet *et al*., 2001). These warmer-water sea cucumbers are common on both soft substrates and rocky reefs. Warty sea cucumbers are common in the study area, though natural populations are poorly studied (Gotshall and Laurent, 1979; Morris *et al*., 1980). This slow-moving sea cucumber feeds on detritus and small organisms, which it ingests with bottom sediments. It may live about 12 years (Morris *et al*.1980; Leet *et al.,* 2001).

No sport fishery for this species exists. A commercial fishery by hookah divers using rakes started in California in 1978 (Leet *et al*., 1992). Other sources of mortality include predation by sea stars, fishes, crabs, sea otters, and bacterial diseases which may significantly reduce population sizes (Engle, 1994; Eckert *et al.,* 2000).

Broad-scale Patterns

Highly suitable habitat for warty sea cucumbers was considered to occur over hard and soft substrates between the intertidal zone and 20 m. Moderately suitable habitats extended from 20-30 m, while habitats between 30 -40 m were considered low suitability. Warty cucumbers are less abundant north of Point Conception (Leet *et al*., 2001), thus habitat suitability is moderate from the intertidal to 60 m north of 34.5°N to Monterey Bay (Figure 3.1.39). Highly suitable habitat is located nearshore from Point Conception through southern California to San Diego. Also, highly suitable habitat encompasses most of the Channel Islands.

No data were available for testing model performance.

Analysis of Boundary Concepts

Less than 10% of the area (341 km^2) within the current CINMS boundary was considered highly suitable for warty sea cucumbers (Figure 3.1.40). No additional gains of highly suitable habitat were contained within Concepts 4 and 5. Considerable gains of suitable habitat occurred within concepts that included area along the mainland (Figure 3.1.41). The OAI was used to assess the relative abundance of highly suitable habitat within boundary concepts compared to the NAC (Table 3.1.12). Although the Study Area ranked highest for the OAI, it is not a concept under consideration. Therefore, Concepts 1 and 1a are the most preferable for warty sea cucumber.

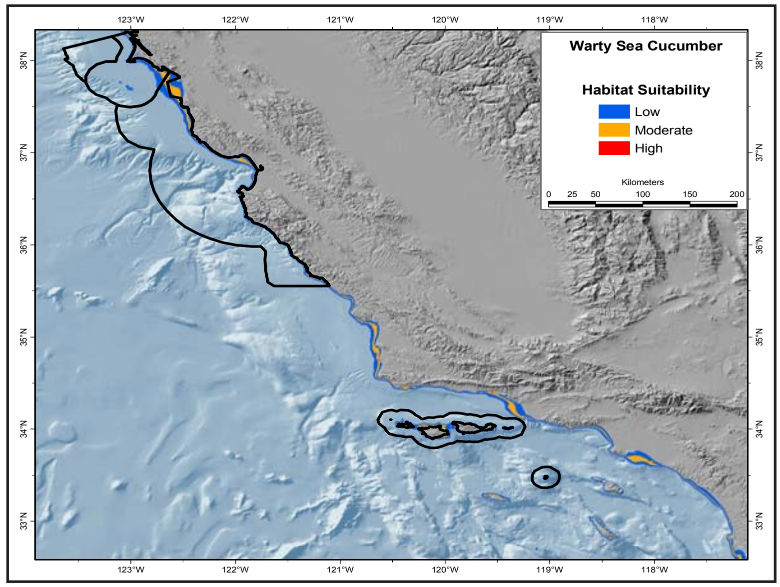

Figure 3.1.39. Warty sea cucumber habitat suitability off central and southern California.

Summary

• Suitable habitat for warty sea cucumbers consists of hard and soft substrates between 0-30 m south of 35°N.

• Of the six boundary concepts being considered, Concept 1a provided the best proportional change of highly suitable habitat for warty sea cucumbers/total concept area relative to the NAC.

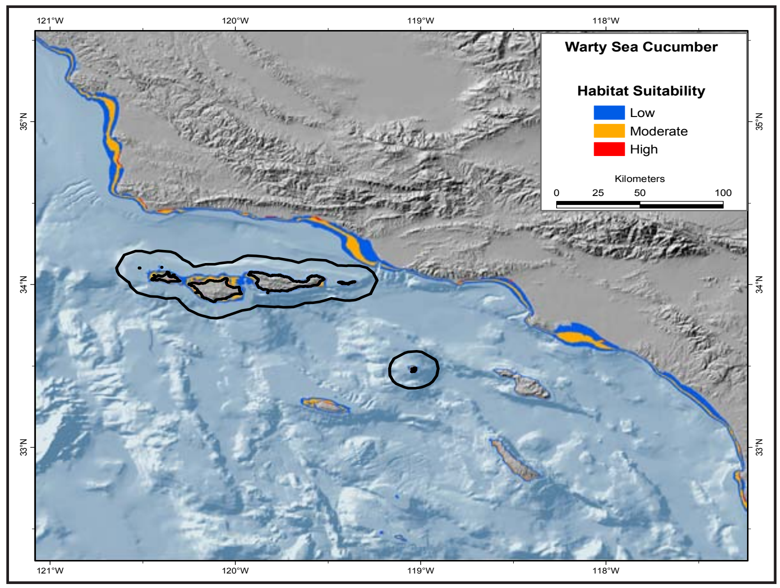

Figure 3.1.40. Warty sea cucumber habitat suitability off southern California.

Red sea urchin *(Strongylocentrotus franciscanus)*

Red urchins inhabit intertidal and subtidal rocky substrates to depths of 130 m from Alaska to central Baja California, but are most abundant from 10-30 m (Bernard and Miller, 1973; Russo, 1979; Durhan *et al*., 1980; Barr and Barr, 1983). Red urchins are identified by their red, maroon, or black color and large size (Morris *et al*., 1980; Leet *et al.,* 2001). When food is abundant, red urchins are relatively sedentary. However, when food is scarce, red urchin motility increases (to 1 m/day) (Harrold and Reed, 1985). Red urchin spines are refuges for a variety of small invertebrates (including juvenile red urchins) and fishes (Tegner and Dayton, 1977). The diet of red urchins consists of a variety of red and brown algae, but the kelp M*acrocystis* is preferred. Red urchins compete with abalone for food and space. This species may live 20 years or more. (Morris *et al*.,1980).

A significant commercial fishery for red urchin began during the 1970s in the study area (Leet *et al.,* 1992). Commercial hookah divers harvest red urchins using rakes at depths of up to 33 m. Landings of red urchins increased from the beginning of the fishery until 1989, after which the statewide fishery declined steadily through 1996. Landings from the Channel Islands began to decline in the late 1970s. The relative abundance of red urchins in southern California has also declined (Carroll *et al*., 2000). Other sources of mortality include predation by sea stars, fishes, lobsters, and sea otters (Tegner and Dayton, 1981; Tegner and Levin, 1983; Rogers-Bennett, 1998; Leet *et al*., 2001).

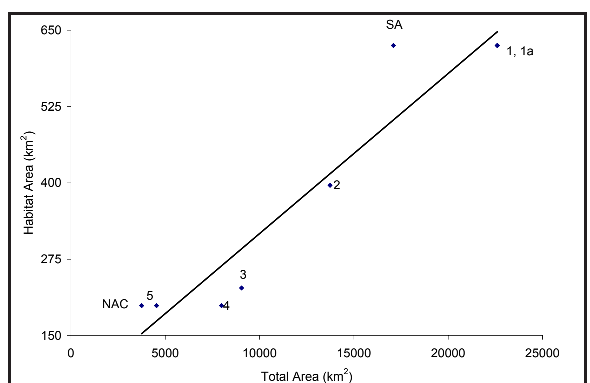

Figure 3.1.41. Regression of highly suitable habitat area for warty sea cucumber and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Broad-scale Patterns

Highly suitable habitat for red sea urchins was considered to occur over hard and soft substrates between the depths of 10-30 m. Moderate suitability was assigned to depths from the intertidal zone to 10 m and 30-90 m. Habitat suitability was considered low at depths between 90-130 m. As such, highly suitable habitat extends narrowly off the California mainland with broader areas located in southern California. Small bands of highly suitable habitat are also observed around the Channel Islands (Figure 3.1.42).

No commercial data were available for testing model performance.

Analysis of Boundary Concepts

Approximately 7% (257 km^2) of the total area within the current CINMS boundary is considered high suitability habitat for red sea urchins (Figure 3.1.43). These areas are located close to shore along the Channel Islands, with the greatest areas located on the northern shores of San Miguel and Santa Rosa Islands. No additional highly suitable habitat was gained with the increases of boundary size for Concepts 4 and 5. Suitable habitat increased by 33% within Concept 3, which included areas near Point Conception. Highly suitable habitat was significantly greater within Concepts 1, 1a, 2 and the Study Area (Figure 3.1.44), which can be attributed to increases in habitat near Point Conception and other nearshore areas along the mainland. Although the Study Area ranked highest for the OAI (Table 3.1.13), Concepts 1 and 1a yielded the highest OAI ranking among the six concepts under consideration.

Summary

• Highly suitable habitat for red sea urchins was determined to occur between 10-30 m on hard and soft substrates.

• The commercial fishery for red sea urchins occurs primarily in southern California.

• Of the six boundary concepts being considered, Concepts 1 and 1a displayed the highest OAI ranking.

Table 3.1.12. Analysis of warty sea cucumber habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area (%)	OAI (absolute)
NAC	3475	199	-	-	-
5	4538	199	21.12	0.00	0.00
4	7981	199	113.11	0.00	0.00
3	9044	**228**	141.50	14.57	0.10
2	13736	**396**	266.78	98.99	0.37
1	22613	**625**	503.82	214.07	0.42
1a	22591	**625**	503.23	214.07	0.43
SA	*17093*	**625**	*356.42*	*214.07*	*0.60*

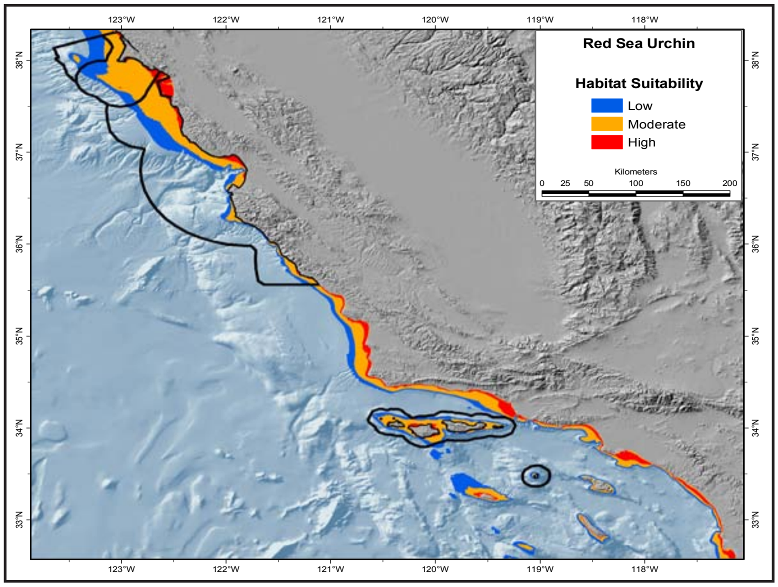

Figure 3.1.42. Red sea urchin habitat suitability off central and southern California.

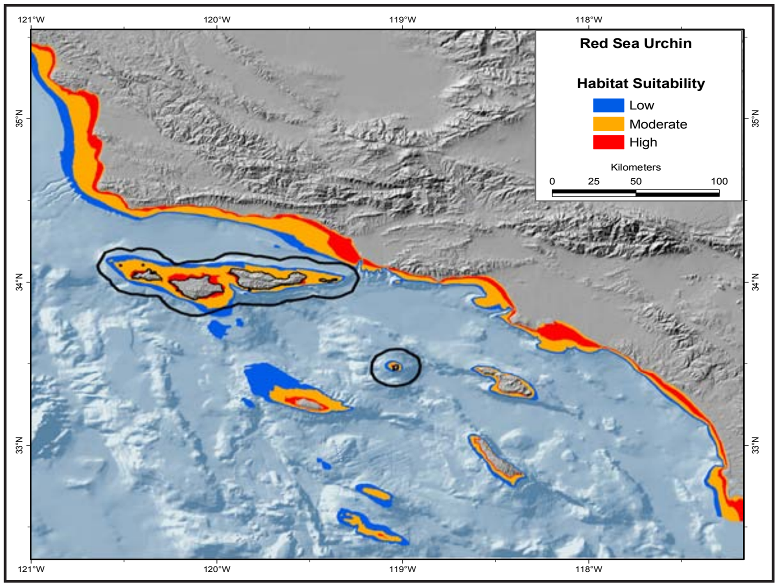

Figure 3.1.43. Red sea urchin habitat suitability off southern California.

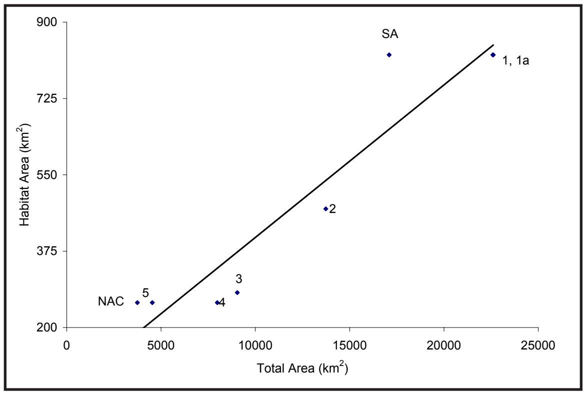

Figure 3.1.44. Regression of highly suitable habitat area for redsea urchin and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

Table 3.1.13. Analysis of red sea urchin habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km²)	High Suitability Area (km²)	Δ Area (%)	Δ High Suitability Area (%)	OAI (absolute)
NAC	3475	257	-	-	-
5	4538	257	21.12	0.00	0.00
4	7981	257	113.11	0.00	0.00
3	9044	**280**	141.50	8.95	0.06
2	13736	**472**	266.78	83.66	0.31
1	22613	**825**	503.82	221.01	0.44
1a	22591	**825**	503.23	221.01	0.44
SA	*17093*	*825*	*356.42*	*221.01*	*0.62*

Purple sea urchin (*Strongylocentrotus purpuratus)*
Purple urchins inhabit low intertidal and subtidal depths (to 160 m) from southern British Columbia (Canada) to central Baja California. They prefer intertidal and subtidal (to 30 m) rocky habitats with moderate to strong wave action, where they normally inhabit crevices or depressions (Kalvass, 1992). Purple urchins are identified by their purple color and relatively small size. The diet of purple urchins consists of a variety of red and brown algae, but the kelp *Macrocystis* is preferred. They are relatively sedentary when food is abundant, with motility increasing as food availability decreases (to 1 m/day) (Harrold and Reed, 1985). This species may live up to 30 years (Morris *et al*., 1980).

A minor fishery for purple urchins exists, but the small size and variable development of roe has precluded expansion of the fishery at this time. Other sources of mortality include predation by sea stars, fishes, lobsters, and sea otters (Tegner and Dayton, 1981; Tegner and Levin, 1983; Leet *et al*., 2001). Coincident with the decline of competing red urchins described above, purple urchin populations have increased markedly at many island sites, creating vast areas denuded of macroalgae (Harold and Reed, 1985; Ambrose *et al*., 1993; Engle, 1994; Richards *et al*., 1997; Carroll *et al*., 2000; Lafferty and Kushner, 2000).

Broad-scale Patterns
Highly suitable habitat for purple sea urchin overlaps that defined for red sea urchins (0-30 m) while moderate suitability extends to deeper waters (30-90 m). Suitability was considered low at depths between 90-160 m (Figure 3.1.45). As such, greater amounts of highly suitable habitat are available for purple sea urchins than for red urchins and the same pattern of distribution is observed with the exception of highly suitable habitat extending up to the intertidal zone for purple sea urchins.

No commercial data were available for testing model performance.

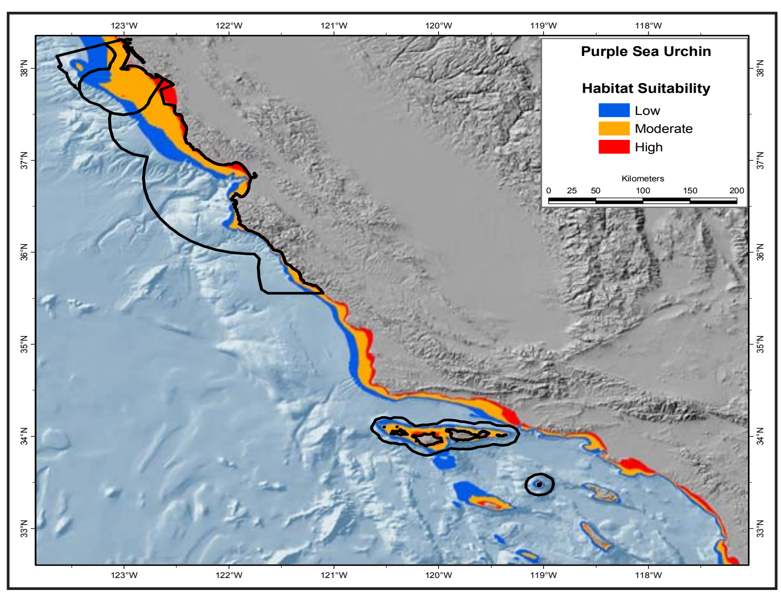

Figure 3.1.45. Purple sea urchin habitat suitability off central and southern California.

Analysis of Boundary Concepts
Approximately 341 km² of suitable habitat was determined to occur within the current CINMS boundary (Figure 3.1.46). No additional gains of highly suitable habitat were observed within Concepts 4 and 5. Highly suitable habitat increased by 12% within Concept 3, while considerably larger gains were observed within the larger concepts (Figure 3.1.47). These gains were attributed to the inclusion of nearshore habitat along the mainland. Although the Study Area ranked

highest for the OAI, Concepts 1 and 1a provided the most beneficial proportional change of suitable habitat/total concept area gained relative to the NAC (Table 3.1.14).

Summary

• Highly suitable habitat for purple urchins consists of hard and soft substrates within 0-30 m.

• Of the six boundary concepts being considered, Concepts 1 and 1a provided the optimal proportional change of suitable habitat/total concept area relative to the NAC.

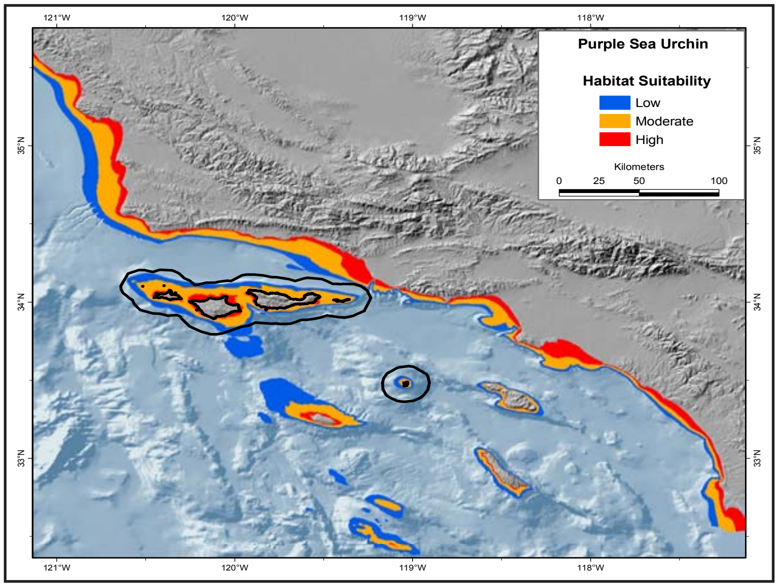

Figure 3.1.46. Purple sea urchin habitat suitability off southern California.

Table 3.1.14. Analysis of purple sea urchin habitat suitability within boundary concepts. Numbers in bold indicate an increase in the estimate when compared to the No Action Concept (NAC). OAI estimates shaded in gray represent maximum observed benefit. Delta (Δ) indicates a rate of change calculation, and is always expressed as a percent change from the NAC.

Concept	Area (km^2)	High Suitability Area (km^2)	Δ Area (%)	Δ High Suitability Area (%)	OAI (absolute)
NAC	3475	341	-	-	-
5	4538	341	21.12	0.00	0.00
4	7981	341	113.11	0.00	0.00
3	9044	**374**	141.50	9.68	0.07
2	13736	**626**	266.78	83.58	0.31
1	22613	**1052**	503.82	208.50	0.41
1a	22591	**1052**	503.23	208.50	0.41
SA	*17093*	*1052*	*356.42*	*208.50*	*0.58*

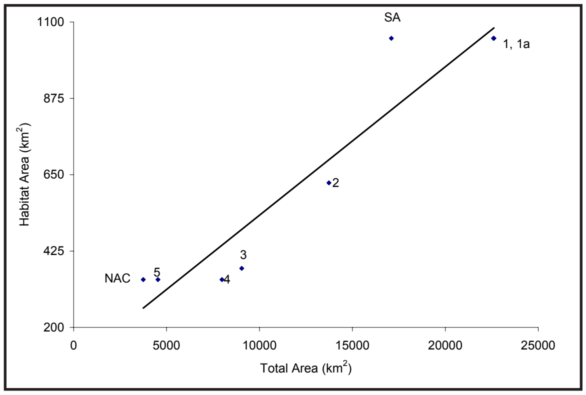

Figure 3.1.47. Regression of highly suitable habitat area for purple sea urchin and total area for the current and proposed boundary concepts. Numbers indicate concepts and NAC=No Action Concept, SA=Study Area.

3.2 MACROINVERTEBRATE ASSEMBLAGE STRUCTURE

The primary objective of this chapter is to define biogeographic patterns of invertebrates and to provide an understanding of invertebrate multi-species community structure in a spatial context. Community metrics and multivariate statistics were used to analyze marine invertebrate species assemblages off southern California. Analyses were completed using data provided by the Southern California Coastal Water Research Project (SCCWRP) for 41 species of demersal invertebrates. Five objectives were defined to:

• Calculate Shannon index of diversity for all invertebrates identified to species level in all trawls;
• Determine which species tend to co-occur (i.e., species assemblages);
• Map locations that contained similar catches (i.e., site groups);
• Resolve where species assemblages were being caught by combining results from objectives 1 and 2; and,
• Investigate boundary concepts using objectives listed above.

Data and Methods

Southern California Bight Regional Survey data obtained from SCCWRP consisted of 426 fisheries-independent trawl samples collected June to September in 1994 and 1998. Samples were collected with a 7.6 m headrope semiballoon otter trawl with 1.25 cm codend mesh towed for 5 minutes (in bays) to 10 minutes (on coast) along isobaths at each station, ranging in depth from from 2-215 m (Allen *et al.,* 1998, 2002). In 1994, the survey targeted the mainland shelf at 10-200 m, whereas the 1998 survey added trawls near islands and within bay and harbor areas, sampling from 2-200 m (Allen *et al.,* 1998, 2002). The data set contained information for 288 invertebrate species in 426 trawls, but removal of rare species (see below) resulted in 41 species in 401 trawls analyzed for assemblage structure.

Invertebrate diversity (H') was calculated with the Shannon index of diversity (Shannon and Weaver, 1949):

$$H' = -\Sigma[(n_i/N)\ \ln(n_i/N)]$$

where n_i is the number of individuals belonging to the i^{th} species (s) in the sample, and N is the total number of individuals in the sample. Individual results are presented to show the distribution of effort and site diversity. Spatially summarized results also are provided to determine if larger spatial patterns were present that may have been masked by the high variability present in the individual trawl results. Using ArcGIS, 5 x 5 minute grids were created and mean diversity was calculated for each grid cell containing data. Results were sorted by diversity and divided into quintiles (i.e., each quintile contains 20% of the sites) for display.

It is important to analyze not just the diversity of species present, but to also investigate which species are commonly found together. Clustering is "a technique for optimal grouping of entities according to the resemblance of their attributes as expressed by given criteria" (Boesch, 1977), or in short, a method that puts variables (sites, species, etc) into groups. Cluster analyses began with either a site by species, or species by site matrix of invertebrate abundances which resulted in species assemblages or site groups depending on which matrix was utilized. Invertebrates that were not present in at least 5% of the trawls were removed from this analysis. Rare species were removed because their occurrence is often due to chance, and can therefore negatively impact results (Boesch, 1977; Gauch, 1982). The 5% cutoff was implemented because it reduced the number of zeros present in the matrices, while keeping an adequate number of species for analysis. Abundance estimates were transformed because the raw data did not conform to assumptions of a normal distribution and homogeneity of variances. A fourth root transformation was utilized as it is invariant to scale changes (Field *et al*., 1982). Data were standardized by species abundances (i.e., the abundances for each species were adjusted such that the mean is zero and the standard deviation is one). This places all species on the same scale regardless of overall abundance, and ensures that abundant species did not overly influence the results. A series of exploratory analyses were performed on a variety of clustering methods to determine which consistently provided interpretable results without excessive chaining. When chaining occurs, entities fuse to a few nuclear groups one at a time rather than forming new groups, and make it impossible to divide the data into meaningful smaller groups (Boesch, 1977). Two dissimilarity methods, Bray-Curtis and Jaccard (both paired with average means clustering) met these criteria. As such, the Bray-Curtis technique was chosen to allow for comparisons with previous analyses of the SCCWRP data (Allen *et al*., 1998, 2002). The Bray-Curtis dissimilarity coefficient (b_{jk}) is calculated as:

$$b_{jk} = \frac{\sum_{i=1}^{n} | X_{ij} - X_{ik} |}{\sum_{i=1}^{n} (X_{ij} + X_{ik})}$$

where X_{ij} is the ith attribute (column) measured on the j^{th} object (row), and X_{ik} is the ith attribute on the k^{th} object (Romesburg, 1984). The Bray-Curtis dissimilarity metric often produces meaningful results with species abundance data, and is therefore one of the most widely used clustering methods in ecology (Boesch, 1977). Scree plots were used to determine where breaks in the similarity level occurred (McGarigal *et al*., 2000). Subsequently, group composition was analyzed to determine the best ecological groupings (*i.e*., if smaller or larger groups would provide a better ecological explanation; Boesch, 1977).

To resolve where the invertebrate assemblages were being caught (i.e., interaction between species assemblages and site groups), the average frequency of occurrence for each species was calculated for each site group. This analysis is a modified nodal analysis (Boesch, 1977). By analyzing average frequencies for species by site groups, it was possible to determine which species assemblages were influential in forming the site groups. Spatial distribution was visualized by mapping the site groups in a GIS. A step-wise discriminant analysis was performed to determine if parameters such as depth, latitude, or effort were significantly different between site groups.

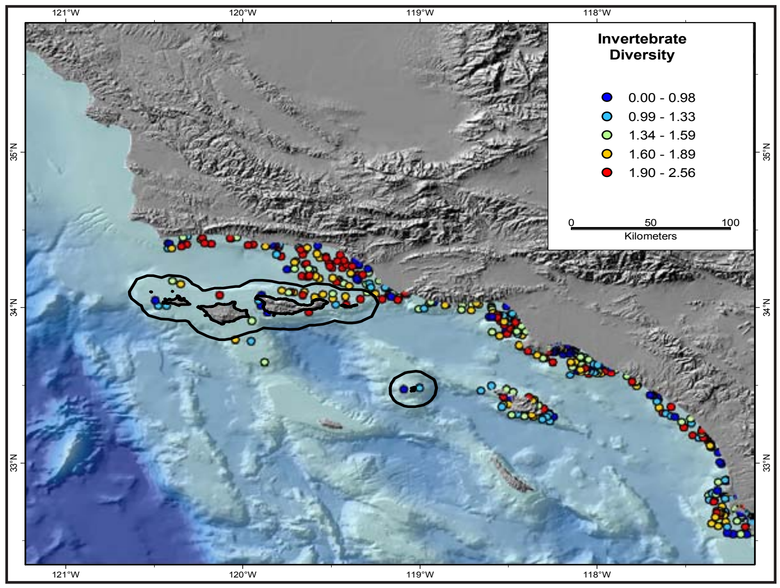

Figure 3.2.1. Invertebrate diversity for individual SCCWRP trawls during 1994 and 1998.

Broad-scale Patterns

The SCCWRP trawls were concentrated in the Southern California Bight, and provided information on benthic species found in water less than 215 m depth. Invertebrate diversity ranged from 0-2.38 with a mean of 1.0 ± 0.6, and a median of 0.95. Patches of high diversity exist northwest of San Miguel and Santa Cruz Islands, and southeast of Point Conception (Figure 3.2.1). Low diversity patches can be found on the southeast corner of Santa Catalina Island and within the Santa Barbara Channel near Carpinteria. There were no statistically significant relationships between diversity and any of the following: latitude (r^2=0.0, P=0.36), longitude (r^2=0.0, P=0.24), depth (r^2=0.01, P=0.11), or effort (r^2=0.0, P=0.47).

Clustering resulted in 41 invertebrate species being combined into eight species assemblages (Table 3.2.1), and sites classified into eight distinct groups (Figure 3.2.2; Table 3.2.2). There was a clear relationship between species assemblages and depth. This relationship can be visualized in Table 3.2.2, where site groups have been ordered from shallow to deep. The tuberculate pear crab assemblage consists of shallow species, the California sand star assemblage mid-shelf species, and the fragile sea urchin assemblage deeper, offshore species. Three assemblages contain species that were not collected around the islands: tuberculate pear crab assemblage, short-spined sea star assemblage, and sandflat elbow

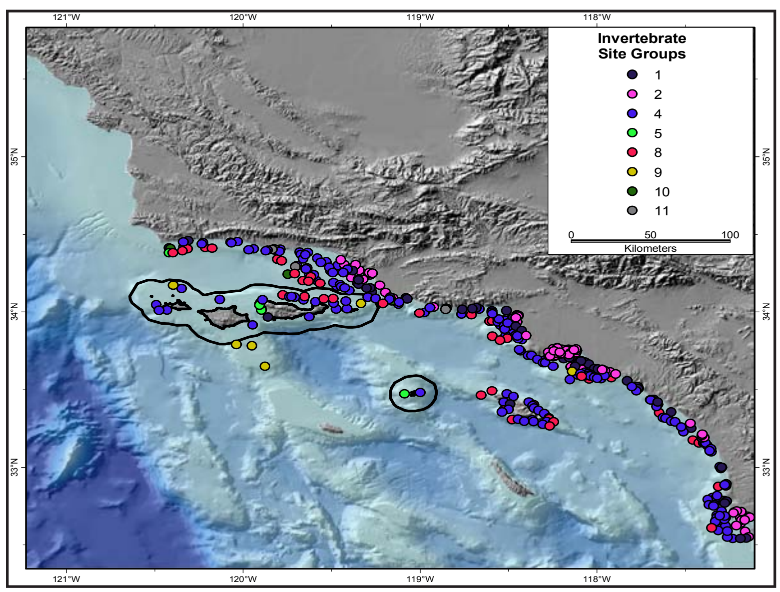

Figure 3.2.2. Location of site groups for SCCWRP survey data (1994, 1998).

crab. Site groups also form clear bands along a depth gradient off the coast (Figure 3.2.2). Site Groups 1 and 2 tend to be shallow and coastal, while Groups 4 and 8 are deeper and common around the islands. Groups 5, 9, 10, and 11 only contain a few sites each. The reasons these sites were isolated and grouped separately are not clear. Because the numbers of stations involved were so few, clustering could be a result of random conditions. Therefore, the clustering results for these groups are provided, but no discussion of these site groups was included. After using discriminate analysis (N=398) there were significant differences observed between site groups in all three parameters investigated: depth (r^2=0.79; F=213; P<0.0001), effort (r^2=0.23; F=16; P<0.0001), and latitude (r^2=0.03; F=2; P<0.06). Changes in areas targeted for trawling and large-scale weather/temperature patterns may have affected observed species assemblages. In 1994, the survey targeted the mainland shelf at 10-200 m, whereas the 1998 survey added trawls near islands and within bay and harbor areas sampling from 2-200 m. In addition, 1998 was a strong El Niño year, with water temperatures much warmer than normal. The cluster results presented here, while based on both years (1994 and 1998), align closely with previous results from 1998 alone (Allen *et al*., 1998, 2002).

Table 3.2.1. Species assemblage results for SCCWRP survey data (1994, 1998) using the Bray-Curtis dissimilarity metric with average means clustering. Assemblages are named for the most influential species in each group.

Group	Common Name	Scientific name
tuberculate pear crab assemblage	tuberculate pear crab spiny sand star blackspotted bay shrimp navanax sea slug yellowleg shrimp	*Pyromaia tuberculata* *Astropecten armatus* *Crangon nigromaculata* *Navanax inermis* *Penaeus californiensis*
shortspined sea star assemblage	shortspined sea star spotwrist hermit	*Pisaster brevispinus* *Pagurus spilocarpus*
sandflat elbow crab assemblage	sandflat elbow crab	*Heterocrypta occidentalis*
California sand star assemblage	California sand star trailtip sea pen California blade barnacle mosaic sand star fringed sand star gray sand star white sea urchin red octopus Pacific spiny brittlestar brokenspine brittlestar California sea cucumber New Zealand paperbubble California sea slug ridgeback rock shrimp slender sea pen yellow sea twig California market squid eastern Pacific bobtail	*Astropecten verrilli* *Acanthoptilum* spp. *Hamatoscalpellum californicum* *Luidia armata* *Luidia asthenosoma* *Luidia foliolata* *Lytechinus pictus* *Octopus rubescens* *Ophiothrix spiculata* *Ophiura luetkenii* *Parastichopus californicus* *Philine auriformis* *Pleurobranchaea californica* *Sicyonia ingentis* *Stylatula elongata* *Thesea* spp. *Loligo opalescens* *Rossia pacifica*
tower snail assemblage	tower snail Alaska bay shrimp thinbeak neck crab rosy tritonia	*Megasurcula carpenteriana* *Crangon alaskensis* *Podochela lobifrons* *Tritonia diomedea*
red sea star assemblage	red sea star orange sand star slenderclaw hermit crab	*Mediaster aequalis* *Astropecten ornatissimus* *Paguristes turgidus*
fragile sea urchin assemblage	fragile sea urchin northern heart urchin Pacific heart urchin flagnose bay shrimp moustache bay shrimp California heart urchin	*Allocentrotus fragilis* *Brisaster latifrons* *Brissopsis pacifica* *Neocrangon resima* *Neocrangon zacae* *Spatangus californicus*
sheep crab assemblage	sheep crab armed box crab	*Loxorhynchus grandis* *Platymera gaudichaudii*

The Channel Islands are divided into two main biogeographical provinces: the warm-temperate San Diegan and the cold-temperate Oregonian. San Miguel, Santa Rosa, and San Nicolas largely have Oregonian biota, while Santa Cruz (eastern part) Anacapa, Santa Barbara, Santa Catalina and San Clemente Islands contain San Diegan biota. Research on intertidal areas and kelp forests further separated the San Diegan province into two smaller groups (Murray *et al*., 1980; Murray and Littler, 1981; Littler *et al*., 1991; Pondella *et al*., 2005). All of these studies placed Santa Catalina and San Clemente into one group and Santa Barbara and Santa Cruz into a second group. It is important to note that most of these studies analyzed rocky intertidal flora and fauna, and are greatly influenced by local temperatures and conditions. The invertebrate site groups from this analysis do not segregate according to these provinces. However, because the SCCWRP trawls targeted benthic species up to 215 m, the species may be less influenced by surface currents and temperature and less likely to show the segregations detailed above.

Analysis of Boundary Concepts

Areas of high invertebrate diversity were observed within the NAC and near the mainland which would be included within Concepts 3, 2, 1, 1a, and the Study Area. However, quantitative comparison of the boundary concepts was not possible due to the distribuiton of survey effort. Few samples were conducted in the deeper portions of the Southern California Bight and no surveys were conducted north of Point Conception. Given the available data highest mean invertebrate diversity was observed within Concept 2 (Figure 3.2.3).

Table 3.2.2. Mean frequency of occurrence for each SCCWRP site group. N=trawl effort. Bold common names indicate principle species for each site group. Gray and blue shaded cells represent species presence in half or a quarter of the groups in that site, respectively.

	Site Groups							
	2 N=87	1 N=73	5 N=4	11 N=4	4 N=182	10 N=3	9 N=7	8 N=41
tuberculate pear crab	57	34	0	0	7	0	0	0
spiny sand star	21	32	0	0	1	0	0	0
blackspotted bay shrimp	54	14	0	25	1	0	0	0
navanax sea slug	18	1	0	0	2	0	0	0
yellowleg shrimp	46	4	0	0	1	0	0	0
shortspined sea star	8	15	0	0	2	0	0	0
spotwrist hermit crab	6	10	0	0	5	0	14	0
sandflat elbow crab	3	29	0	0	6	0	0	0
California sand star	5	79	0	50	85	0	0	17
trailtip sea pen	1	1	0	0	39	0	14	22
California blade barnacle	0	7	0	0	25	0	0	10
California market squid	2	5	0	25	25	0	0	29
mosaic sand star	1	7	0	0	27	0	0	2
fringed sand star	0	3	0	0	12	0	0	0
gray sand star	1	10	0	0	46	0	14	61
white sea urchin	2	10	100	0	74	33	0	22
red octopus	0	3	25	100	29	0	0	17
Pacific spiny brittlestar	2	4	50	0	39	0	0	5
brokenspine brittlestar	0	0	0	0	20	0	14	0
California sea cucumber	5	3	0	0	63	33	0	41
New Zealand paperbubble	20	8	0	0	35	0	14	7
California sea slug	1	3	0	25	37	100	0	44
eastern Pacific bobtail	1	0	0	0	17	0	0	29
ridgeback rock shrimp	6	8	0	75	79	0	0	78
slender sea pen	3	7	0	0	20	0	0	5
yellow sea twig	0	0	0	0	28	0	43	5
tower snail	0	3	0	0	18	0	0	10
Alaska bay shrimp	1	0	0	0	12	33	0	0
thinbeak neck crab	0	1	0	0	9	33	0	5
rosy tritonia	0	1	0	0	10	0	0	7
red sea star	0	0	0	0	15	0	57	12
orange sand star	0	0	0	0	10	0	0	17
slenderclaw hermit crab	1	1	0	0	7	0	43	12
fragile sea urchin	0	0	0	0	14	0	29	95
northern heart urchin	0	0	0	0	4	0	0	59
Pacific heart urchin	0	0	0	0	1	0	0	44
flagnose bay shrimp	0	0	0	25	4	0	0	46
moustache bay shrimp	0	0	0	25	8	0	0	63
California heart urchin	0	0	0	0	9	0	0	34
sheep crab	10	1	0	0	4	0	0	2
armed box crab	0	1	0	0	9	0	0	2

Quantitative evaluation of species assemblages were not conducted but general trends can be described. Four site groups were located within the existing sanctuary boundary. Site groups 4 and 8 occurred most frequently within the current sanctuary boundary and were more numerous in the larger concepts that reached the mainland. The majority of the trawls were located east and south of the sanctuary and were not included in any of the concepts. Site groups 2, 10, and 11 were not present in the current sanctuary boundaries, however, they were included within the larger concepts. Site Group 2 occurred frequently along the mainland and was most prevalent south of

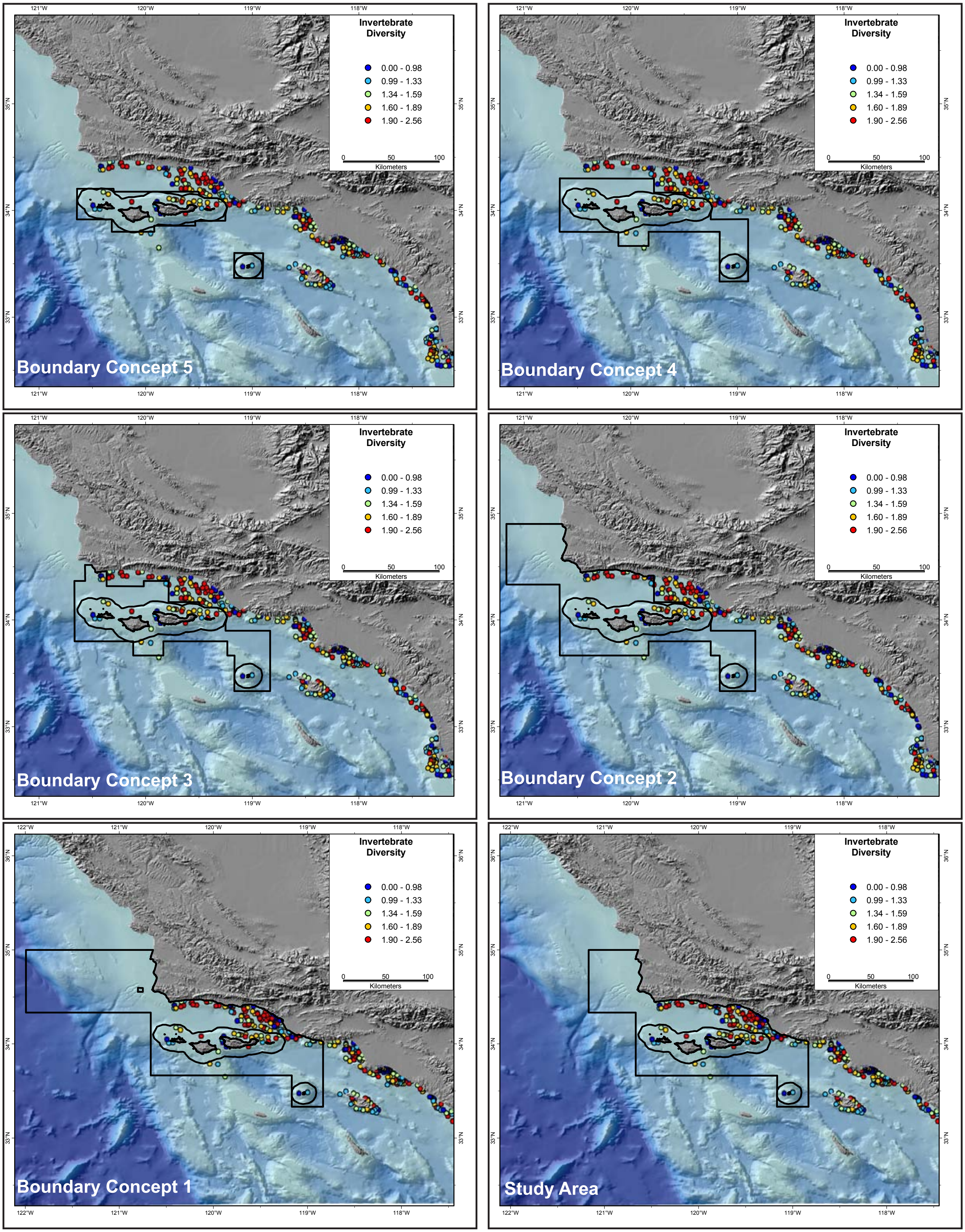

Figure 3.2.3. Overlay of invertebrate diversity and CINMS boundary concepts.

Palos Verdes Point. This group was defined by 87 shallow water trawls and these species may occur within the sanctuary, but shallow water trawls were limited within the sanctuary. It is recommended that additional surveys are needed to conduct an accurate spatial analysis for invertebrates.

Summary

• Invertebrate diversity ranged from 0 to 2.38, with a mean of 1.0. No spatial patterns within the diversity results were identified.

• Eight site groups and eight species assemblages were identified. There was a significant relationship between site groups and depth.

• In general, results indicate that invertebrate diversity and community structure may increase with the inclusion of coastal habitat that would be gained within the larger boundary concepts.

LITERATURE CITED

Allen, M.J., S.L. Moore, K.C. Schiff, S. B. Weisberg, D. Diener, J. K Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. 1998. Southern California Bight 1994 Pilot Project: V. Demersal fishes and megabethic invertebrates. Southern California Coastal Water Research Project. Westminster, CA. 365 pp.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S. A. Steinert, G. Deets, J. A. Noblet, S. Moore, D. Diehl, E. T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S. B. Weisberg, and T. Mikel. 2002. Southern California Bight 1998 Regional Monitoring Program: V. demersal fishes and megabenthic invertebrates. Southern California Coastal Water Research Project. Westminster, CA. 572 pp.

Altstatt, J.M., R.F. Ambrose, J.M. Engle, P.L. Haaker, K.D. Lafferty, and P.T. Raimondi. 1996. Recent declines of black abalone, *Haliotis cracherodii*, on the mainland coast of central California. Marine Ecology-Progress Series 142(1-3):185-192.

Ambrose, R.F., J.M. Engle, J.A. Coyer and B.V. Nelson. 1993. Changes in urchin and kelp densities at Anacapa Island. pp. 199-209. In: Third California Islands Symposium, F.G. Hochberg, (Ed.). Santa Barbara Museum of Natural History. Santa Barbara, CA.

Antonio, D.B., K.B. Andree, J.D. Moore, C.S. Friedman and R.P. Hedric. 2000. Detection of Rickettsiales-like prokaryotes by in-situ hybridization in black abalone, *Haliotis cracherodii*, with withering syndrome. Journal of Invertebrate Pathology 75(2):180-182.

Ault, J.S. 1985. Species Profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- Black, green, and red abalones. U.S. Fish and Wildlife Service Biological Report 82(11.32). 19 pp.

Barr, L. and N. Barr. 1983. Under Alaskan seas: The shallow water marine invertebrates. Alaska Northwest Publishing Co. Anchorage, AK. 208 pp.

Barsky, K. California Department of Fish and Game. Personal communication.

Bernard, F.R. and D.C. Miller. 1973. Preliminary investigation on the red sea urchin resources of British Columbia (*Strongylocentrrotus franciscanus*) (Agassiz). Fisheries Research Board of Canada. Technical Report 400. 37 pp.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. Special Scientific Report No. 77, EPA-600/3-77-033. Virginia Institute of Marine Science, Williamsburg, VA. 114 pp.

Bonnell, M.L. and M.D. Dailey. 1993. Marine mammals. pp: 604-681. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (Eds.), Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press. Berkeley/Los Angeles.

Brown, S.K., K.R. Buja, S.H. Jury, M.E. Monaco, and A. Banner. 2000. Habitat suitability index models for eight fish and invertebrate species in Casco and Sheepscot Bays, Maine. North American Journal of Fisheries Management 20:408-435.

Carlton, J.T., J.B. Geller, M.L. Reaka-Kudla and E.A. Norse. 1999. Historical extinctions in the sea. Annual Review of Ecology and Systematics 30:515-538.

Carroll, J.C. and R.N. Winn. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) – brown rock crab, red rock crab, and yellow crab. U.S. Fish Wildlife Service Biological Report 82 (11.117). U.S. Army Corps of Engineers, TR EL-82-4. 16 pp.

Carroll, J.C., J.M. Engle, J.A. Coyer and R.F. Ambrose. 2000. Long-term changes and species interactions in a sea urchin-dominated community at Anacapa Island, California. pp: 370-378. In: Proceedings of the Fifth California Islands Symposium.

Clark, R.C., J.D. Christensen, M.E. Monaco, P.A. Caldwell, G.A. Matthews, and T.J. Minello. 2004. A habitat-use model to determine essential fish habitat for juvenile brown shrimp (*Farfantepenaeus aztecus*) in Galveston Bay, Texas. Fisheries Bulletin 102:264-277.

Davis, G.E., P.L. Haaker, and D.V. Richards. 1996. Status and trends of white abalone at the California Channel Islands. Transactions of the American Fisheries Society125(1):42-48.

Davis, G.E., P.L. Haaker, and D.V. Richards. 1998. The perilous condition of white abalone, *Haliotis sorenseni*, Bartsch, 1940. Journal of Shellfish Research 17:871-875.

Douros, W.J. 1987. Stacking behavior of an intertidal abalone: an adaptive response or a consequence of space limitation? Journal of Experimental Marine Biology and Ecology 108:1-14.

Durham, J.W., C.D. Wagner, and D.P. Abbott. 1980. Echinoidea: The sea urchins. pp: 160-176 In: R.H. Morris, D.P. Abbott, and E.C. Haderlie (Eds.), Intertidal invertebrates of California. Stanford University Press. Stanford, CA.

Eckert, G.L., J.M. Engle and D.J. Kushner. 2000. Sea star disease and population declines at the Channel Islands. pp: 390-394. In: Proceedings of the Fifth California Islands Symposium. U.S. Minerals Management Service.

Engle, J.M. 1979. Ecology and growth of juvenile California spiny lobster, *Panulirus interruptus* (Randall). Sea Grant Dissertation Series, USCSC-TD-03-79. 298 pp.

Engle, J.M. 1994. Perspectives on the structure and dynamics of nearshore marine assemblages of the California Channel Islands. pp: 13-26. In: W.L. Halvorson (Ed.), Fourth California Islands Symposium: Update on the status of Resources, Santa Barbara Museum of Natural History. Santa Barbara, CA.

Field, J. G., K. R. Clarke, and R. M. Warwick. 1982. A practical strategy for analysing multispecies distribution patterns. Marine Ecological Progress Series 8:37-52.

Friedman, C.S., M. Thomson, C, Chun, P.L. Haaker and R.P. Hedrick. 1997. Withering syndrome of the black abalone, *Haliotis cracherodii* (Leach): Water temperature, food availability, and parasites as possible causes. Journal of Shellfish Research 16(2):403-411.

Gardner, G.R., J.C. Harshbarger, J.L. Lake, T.K. Sawyer, K.L. Price, M.D. Stephenson, P.L. Haaker and H.A. Togstad. 1995. Association of prokaryotes with symptomatic appearance of withering syndrome in black abalone, *Haliotis cracherodii.* Journal of Invertebrate Pathology 66(2):111-120.

Garth, J. and D.P. Abbott. 1980. Brachyura: the true crabs. pp: 594-630. In: R.H Morris, D.P. Abbott, and E.C. Haderlie, (Eds.), Intertidal invertebrates of California. Stanford University Press, Stanford, Calif.

Gauch, H.G., Jr. 1982. Multivariate analysis in community ecology. Cambridge University Press, New York.

Gotshall, D. and L.L. Laurent. 1979. Pacific Coast Subtidal Marine Invertebrates: a Fishwatcher's Guide. Sea Challengers, 1979. Los Osos, CA. 107 pp.

Harrold, C. and D.C. Reed. 1985. Food availability, sea urchin grazing, and kelp forest community structure. Ecology 66(4):1160-1169.

Kalvass, P. 1992. Northern California Comercial Sea Urchin Fishery: A Case Study, Department of Fish and Game, March 1992.

Lambert, P. 1997. Sea Cucumbers of British Columbia, Southeast Alaska and Puget Sound. UBC Press, Vancouver, BC, Canada. 176 pp.

Lafferty, K.D. and A.M. Kuris. 1993. Mass mortality of abalone, *Haliotis cracherodii* on the California Channel Islands: Tests of epidemiological hypotheses. Marine Ecology Progress Series 96(3):239-248.

Lafferty, K.D., M.D. Behrens, G.E. Davis, P.L. Haaker, D.J. Kushner, D.V. Richards, I.K. Taniguchi, and M.J. Tegner. 2004. Habitat of endangered white abalone, *Haliotis sorenseni*. Biological Conservation 116(2004): 191-194.

Leet, W.S., C.M. Dewees, R. Klingbeil, and E.J. Larson (Eds.). 2001. California Living Marine Resources: A Status Report. California Department of Fish and Game. University of California Agriculture and Natural Resources Report SG01-11. 592 pp.

Leighton, D.L. 1968. A comparative study of food selection and nutrition in the abalone, Haliotis rufescens, and the sea urchin, *Strongylocentrotus purpuratus*. Ph.D. Dissertation. University of California, San Diego. 197 pp.

Littler, M.M, D.S. Littler, S.N. Murray, and R.R. Seapy. 1991.Southern California rocky intertidal ecosystems. pp: 273-296. In: A.C. Mathieson and P.H. Nienhuis (Eds.), Intertidal and littoral ecosystems. Elsevier, New York.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife and ecology research. Springer-Verlag, New York. 130 pp.

Miller, A.C. and S.E. Lawrence-Miller. 1993. Long-term trends in black abalone, *Haliotis cracherodii* Leach, 1814, populations along the Palos Verdes Peninsula, California. J.ournal of Shellfish Research 12(2):195-200.

Morris, R.H., D.P. Abbott and E.C. Haderlie. 1980. Intertidal Invertebrates of California. Stanford University Press, Stanford, California. 690 pp.

Murray, S.N. and M.M. Littler. 1981. Biogeographical analysis of intertidal macrophyte floras of southern California. Journal of Biogeography 89:339-351.

Murray, S. N., M. M. Littler, and I. A. Abbott. 1980. Biogeograpy of the California marine algae with emphasis on the southern California Islands. pp. 325-338. In: D.M. Power, (Ed.), The California Islands: Proceedings of a multi-disciplinary symposium. Santa Barbara Museum of Natural History. Santa Barbara, California.

North, W.J., M. Neushul , and K.A. Clendenning. 1965. Successive biological changes observed in a marine cover exposed to a large spillage of mineral oil. pp. 335-354. In: Proceedings of the International Committee for Scientific Exploration of the Mediterranean Sea. Merit Symposium on marine pollution caused by micro-organisms and mineral oils, Monaco.

O'Clair R.M and C.E. O'Clair. 1998. Southeast Alaska's Rocky Shores Animals. Plant Press, Auke Bay Press, Alaska. 564 pp.

Pacific Fishery Management Council (PFMC). 1998. The Coastal Pelagic Species Fishery Management Plan. Pacific Fishery Management Council, Portland, OR. 180 pp.

Perez-Farfante, I. 1985. The rock shrimp genus *Sicyonia* (Crustacea: Decapoda: Penaeoidea) in the eastern Pacific. Fisheries Bulletin 83(1):1-79.

Pondella, D. J., B. E. Gintert, J. R. Cobb, and L. G. Allen. 2005. Biogeography of the nearshore rocky-reef invertebrates at the southern and Baja California islands. Journal of Biogeography 32:187-201.

Richards, D.V. and G.E. Davis. 1993. Early warnings of modern population collapse in black abalone, *Haliotis cracherodii*, Leach, 1814, at the California Channel Islands. Journal of Shellfish Research 12(2):189-194.

Richards, D.V., C. Gramlich, C.E. Davis and M.N. McNulty. 1997. Kelp forest monitoring: 1982-1989 report. Channel Islands National Park, Ventura, CA. Technical Report CHIS-97-05.

Rogers-Bennett, L. 1998. Marine Protected Areas and the Red Urchin Fishery. pp: (1) 412-423. In: Magoon, O.R., H. Converse, B. Baird, M. Miller-Henson, (Eds.),Taking a Look at California's Ocean Resources: An Agenda for the Future. 1998. Reston, VA.

Roper, C.F.E., M.J. Sweeney and C.E. Nauen. 1984. FAO (Food and Agriculture Assocaiton of the U.N.) species catalogue. Vol. 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. FAO Fisheries Synopsis. No. 124, FAO/UNDP, Rome. 277 pp.

Rubec, P.J., J.C.W. Bexley, H. Norris, M.S. Coyne, M.E. Monaco, S.G. Smith, and J.S. Ault. 1999. Suitability modeling to delineate habitat essential to sustainable fisheries. American Fisheries Society Symposium 22:108-133.

Russo, A.R. 1979. Dispersion and food differences between two populations of the sea urchin *Strongylocentrotus franciscanus*. Journal of Biogeography 6:407-414.

Schmidt, W.L. 1921. Marine decapod crustacea of California. University of California Publications on Zoology 23:1-470.

Shannon, C.E., and W. Weaver. 1949. The mathematical theory of communication. University of Illinois Press, Urbana, Il. 125 pp.

Sunada, J.S. 1984. Spot prawn (*Pandalus platyceros*) and ridgeback prawn (*Sicyonia ingentis*) fisheries in the Santa Barbara Channel. California Coopertative Oceanic Fisheries Investigations Reports 25:100-104.

Taylor, P.R. and M.M. Littler. 1979. The effects of *Antholpleura elegantissima* and *Haliotis cracherodii* on rocky intertidal community structure. Bureau of Land Management, U.S. Department of the Interior, Report II, Section II-4.0.

Tegner, M.J. and P.K. Dayton. 1977. Sea urchin recruitment patterns and implications of commercial fishing. Science 196:324-326.

Tegner, M.J. and P.K. Dayton. 1981. Population structure, recruitment and mortality of two sea urchins (*Strongylocentrotus franciscanus* and *S. purpuratus* in a kelp forest. Marine Ecology-Progress Series 5:255-268.

Tegner, M.J. and L.A. Levin. 1983. Spiny lobsters and sea urchins: Analysis of a predator-prey interaction. Journal of Experimental Marine Biology and Ecology 73:125-150.

Van Blaricom, G.R., J.L. Ruediger, C.S. Friedman, D.D. Woodard, and R.P. Hedrick. 1993. The discovery of withering syndrome among black abalone, *Haliotis cracherodii* Leach, 1814, populations at San Nicloas Island, California. Journal of Shellfish Research 12(2):185-188.

Winn, R.N. 1985. Comparative ecology of three cancrid crab species (*Cancer anthonyi, C. antennarius* and *C.productus*) in marine subtidal habitats in southern California. Ph.D. Dissertation. University of Southern California, Los Angeles. 235 pp.