Title

The effects of habitat composition, quality, and breaks on home ranges of exploited nearshore reef fishes

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Project summary:

No-take marine reserves have become a popular tool in fisheries management worldwide; however, many aspects of their design, including optimal size and location, are still debated. This is due, in part to a lack of critical knowledge on behavior of many exploited marine organisms. Because a primary application of no-take marine reserves is to protect adult reproductive stock, which may serve to supply larvae and juveniles to adjacent unprotected areas, reserves must be large enough at minimum to encompass the daily movement patterns of adult fishes. Previous studies on home range sizes and site fidelity of kelp bass and sheephead in California marine reserves have suggested that habitat composition may influence the size and shape of home ranges, and that breaks in habitat may serve as natural barriers, restricting the home ranges of some fishes. Surprisingly, little is known about how habitat composition, quality and gradients may influence home range sizes and site fidelity of nearshore kelp bed fishes. Knowing fish-habitat relationships and how habitat edges affect fish movement will allow managers to site reserves knowledgeably with goals of optimizing “leaky” boundaries that allow for spillover into the fishery or “tight” boundaries that minimize movements of fish across the boundary.

The ***primary hypothesis*** of this project is that high-resolution maps that include spatial layers of benthic substratum, landscape slope, macroalgae coverage, conspecific density, and temperature can be used to predict home range sizes and shapes of California sheephead (*Semicossyphus pulcher*), kelp bass (*Paralabrax clathratus*), barred sand bass (*Paralabrax nebulifer*), and ocean whitefish (*Caulolatilus princeps*). The ***secondary hypothesis*** is that the daily area use of each species will be related to habitat composition and that strong habitat edges will restrict movements of kelp bass and sheephead.

In order to achieve the overall project goals, several specific objectives will be accomplished. Although we have already established some relationships between movements and habitat use for kelp bass and sheephead, we are missing critical information on home range and habitat use of barred sand bass and ocean whitefish, and long term site fidelity of kelp bass. All of this research took place in the Catalina Island Marine Science Center Marine Life Refuge (CLMR), a 0.13 km^2 no-take marine protected area since 1988.

Specific objective #1: Determine home range sizes and shapes for adult ocean whitefish and barred sand bass in the CMLR using acoustic telemetry active tracking. (*Year 1*).

Specific objective #2: Determine longer-term site fidelity to home ranges (> 1 year) and the willingness of fish to cross habitat edges by translocating transmitter tagged individuals with established home ranges to locations of continuous or discontinuous habitat adjoining the reserve. Through such studies we will be able to assess the effects of habitat characteristics and composition on home range size, shape, and site fidelity across several fish species. (*middle of Year 1*).

Specific objective #3: Define habitat "quality" based on characteristics of habitat through analysis of usage patterns using GIS and high resolution geo-referenced maps of CMLR including layers of benthic substratum, landscape slope, macroalgae coverage, conspecific density, amount of habitat edge, distance from habitat edge, and water temperature. (*Year 2*).

Information gained through this study will provide resource managers with a powerful model for designing more effective MPAs by addressing two essential goals of the state MLPA, 1) determine home ranges of economically important species and 2) determining essential fish habitat and habitat components that may define "quality" based on usage patterns. By being able to predict home range size and shape of economically important nearshore gamefishes using benthic habitat maps, MPAs can be designed to allow for export or retention of adult stock.

RESULTS

Objectives 1: ***Home range sizes and shapes of Ocean whitefish and Barred sand bass***

Ocean whitefish:

Short-term (1-2 months), fine-scale movement and activity patterns of ocean whitefish and barred sand bass were determined using active tracking techniques. Adult ocean whitefish were caught within the CMLR using hook and line. Standard surgical techniques were used (Summerfelt and Smith 1990; Eristhee et al. 1999; Zeller 1999; Jepsen et al. 2002; and Bridger and Booth 2003; Lowe et al. 2003; Topping et al. 2005) to implant a small (Vemco Model V8SC-1L), continuous pulse acoustic transmitters in the peritoneal cavity of 17 adult ocean whitefish. These transmitters were programmed to a specific frequency within a 65-80 kHz range, with a continuous pulse interval of 1000, 1250, 1500, 1750, or 2000 msec. Following the tagging, the total length (TL) was measured and each individual was fitted with an external plastic dart tag (Hallprint Ltd.) inserted through the dorsal musculature to allow easy identification of tagged fish by divers (Lowe et al. 2003; Topping et al. 2005, 2006; Bellquist and Lowe in press). Each fish was then released at the site of capture at which time active acoustic tracking commenced. Fish were tracked from a 4 m skiff with a Vemco Model V10 directional hydrophone and Model VR60 acoustic receiver (e.g. Holland et al. 1993; Lowe et al. 2003; Topping et al. 2005). The 31-61 d battery life of the transmitters allowed multiple 24 hr tracks for each fish, allowing fine-scale movement measurements. To assess the effects of catch, handling, and surgery on behavior, additional control fish were fed acoustic transmitters hidden in squid by divers (Winger et al., 2002). However, these control fish were only tracked for one 24 hr period each because transmitters were usually passed after 1-2 days.

Short-term movements and habitat use were analyzed using a Geographic Information System (GIS) with Arcview 3.2 and the Animal Movements Analyst Extension (Hooge and Eichenlaub 2000). Activity spaces were calculated using two methods: the 95% kernel utilization distribution (KUD), the area in which an individual has a 95% chance of being found during the tracking period (Lowe et al. 2003; Topping et al. 2005); and the Minimum Convex

Polygon (MCP), a polygon created using all the outermost position fixes. Position fixes for each track were separated by day and night, defined as the periods between times of sunrise and sunset, and both the KUD and MCP were determined over each period. Once activity spaces were determined for each track, relocation positions from all tracks for each fish were pooled to create overall KUD and MCP home range estimates. Total distance traveled was calculated as the sum of the distances between successive position fixes over each 24 hr period. A linearity ratio, the ratio between the distance from the first to last recorded position and the total distance traveled during the tracking period (Zeller 1997), was calculated to measure the degree to which individuals exhibited home ranging behavior. Small linearity ratios indicate back-and-forth movements (home ranging), whereas large ratios indicate unidirectional movements (nomadic). Aspect ratios for each MCP were calculated by dividing the maximum distance across the MCP (length) and the maximum distance perpendicular to the maximum length (width). This described the shape of the MCP, with values close to 1 indicating circular activity spaces, and values close to 0 indicating more elliptical activity spaces. Linear regressions were used to measure the relationships between fish total length and various movement parameters (e.g. activity space size and aspect ratio, mean linearity ratio, and mean distance traveled).

Because effects of catch and handling-induced stress could affect post-release behavior and survivorship in fishes (Jarvis and Lowe in press), short-term survivorship was measured by assessing fine-scale movements of each fish during each track immediately following release. To test for behavioral effects of stress due to catching and surgical procedures, two-sample t-tests were used to compare daily activity space (using both the 95% KUD and MCP estimates), distance traveled, and mean linearity ratio for the first 24 hrs following release between fish surgically fitted with transmitters and control fish that were fed transmitters via SCUBA. Fish surgically fitted with transmitters were usually tracked multiple times over a 1-2 month period.

Short-term survivorship for the actively tracked individuals was high (94%), with only one mortality out of 17 actively tracked fish, despite frequent signs of barotrauma (e.g., over-inflated swim bladders). Post-release survival of tagged ocean whitefish was determined based on rate, timing, and directionality of movement. There were no significant differences in activity space size using either the 95% KUD (t = -1.22, p = 0.24) or MCP (t = -0.58, p = 0.57) between ocean white fish fed or surgically fitted with acoustic transmitters. There were also no significant differences in either the mean distance traveled (two sample t-test: t = 1.40, p = 0.18) or mean linearity ratio (t = -0.95, p = 0.36) between individuals fed or surgically fitted with acoustic transmitters. Individuals surgically fitted with transmitters were tracked for up to three 24 hr periods per fish. The initial track was conducted immediately following release, and the second track of the same fish was conducted at least 10 d after release to allow recovery from potential stress associated with catching and surgery. There were no differences in 95% KUD sizes (F = 2.46, p = 0.13), MCP sizes (F = 0.38, p = 0.70), rates of movement (F = 1.80, p = 0.21), or linearity ratios (F = 2.42, p = 0.13) between the initial and subsequent tracks for surgically fitted fish. To further test for an initial stressed period, only the first tracks of fed and surgically fitted fish were compared. There were no significant differences in mean linearity ratio (t = -1.51, df = 14, p = 0.15) or 24 hr activity spaces (t = 0.078, df = 14, p = 0.939). However, distance traveled during the first track of surgically fitted fish was significantly less than for the first track of fed fish (t = 2.69, df = 14, p = 0.02).

Seventeen ocean whitefish (size range: 36-60 cm TL) were tagged (11 surgical implants and 6 fed) within the Catalina Marine Science Center Marine Life Refuge (CMLR) and actively tracked over one to three 24 hr periods (Table 1). Ocean whitefish exhibited diurnal activity patterns, with repeated use of daytime and nighttime areas. Because limited movement at night resulted in a high concentration of points in a very small area, nighttime positions were omitted from the 95% KUD to avoid bias in the activity space estimate. Mean daytime activity space size using a 95% kernel utilization distribution (KUD) was 20,439 ± 28,492 m^2 (± SD), and using a minimum convex polygon (MCP) was 35,474 ± 50,554 m^2 (Table 1, Fig. 1a-f). Data for only sixteen fish are included in activity space analyses due to one assumed predation event that occurred during the initial track of fish ID #16 (Table 1). Ten of the 16 individuals had 95% KUDs that extended beyond the reserve boundary, including 2 fish that were tracked approximately 1 km beyond the edge of the reserve. Mean distance traveled was 3,781 ± 1,215 $m\ day^{-1}$ (± SD), and linearity ratios averaged 0.032 ± 0.022 (Table 1).

There was no significant relationship between activity space size and fish total length (TL) using either the MCP ($F = 0.01$, $r^2 = 0.10$, $p = 0.93$) or 95% KUD ($F = 0.00$, $r^2 = 0.00$, $p = 0.97$) estimates. There was also no significant relationship between fish TL and either mean distance traveled per day ($F = 0.78$, $r^2 = 0.05$, $p = 0.39$) or mean linearity ratio ($F = 0.34$, $r^2 = 0.02$, $p = 0.57$). However, MCP aspect ratios were significantly lower for fish tracked along the narrow rocky reef wall than for those tracked inside the cove ($t = 5.46$, $p < 0.001$).

Table 1. Active tracking summary information for 17 ocean whitefish tagged within the CMLR. Mean values are reported (± SD), although individuals that were only tracked once do not have measures of dispersion. A probable predation event during the first track for fish #16 precluded adequate data collection. Hence, values are represented by asterisks (*).

Fish ID	Number of Tracks	Total Length (cm)	Implant Method	95% KUD (m^2)	MCP (m^2)	Mean Distance Traveled Day^{-1} (m) ± SD	MCP Aspect Ratio	Mean Linearity Ratio ± SD
1	1	60	Fed	7,018	14,183	3,818	0.761	0.014
2	1	60	Fed	29,935	36,654	3,639	0.662	0.057
3	1	60	Fed	15,921	29,396	5,572	0.672	0.022
4	2	39	Surgical	41,186	147,346	4,882 ± 2,180	0.138	0.060 ± 0.051
5	2	39	Surgical	1,927	4,688	1,928 ± 1,273	0.578	0.018 ± 0.006
6	3	36	Surgical	117,335	177,207	6,211 ± 2,693	0.531	0.053 ± 0.024
7	3	37	Surgical	8,899	17,026	2,662 ± 603	0.382	0.006 ± 0.001
8	3	42	Surgical	10,262	21,752	2,493 ± 331	0.452	0.049 ± 0.050
9	2	41	Surgical	20,510	13,911	2,634 ± 115	0.151	0.062 ± 0.066
10	3	42	Surgical	3,874	4,987	3,846 ± 882	0.638	0.011 ± 0.009
11	1	45	Fed	2,174	17,396	3,738	0.834	0.013
12	3	42	Surgical	10,880	17,565	3,558 ± 743	0.485	0.011 ± 0.006
13	1	48	Fed	5,754	10,806	5,566	0.590	0.013
14	1	40	Fed	2,722	6,808	3,551	0.639	0.028
15	3	45	Surgical	28,102	27,466	2,920 ± 898	0.192	0.032 ± 0.042
16	*	40	Surgical	*	*	*	*	*
17	3	36	Surgical	10,526	20,392	3,486 ± 830	0.283	0.071 ± 0.048

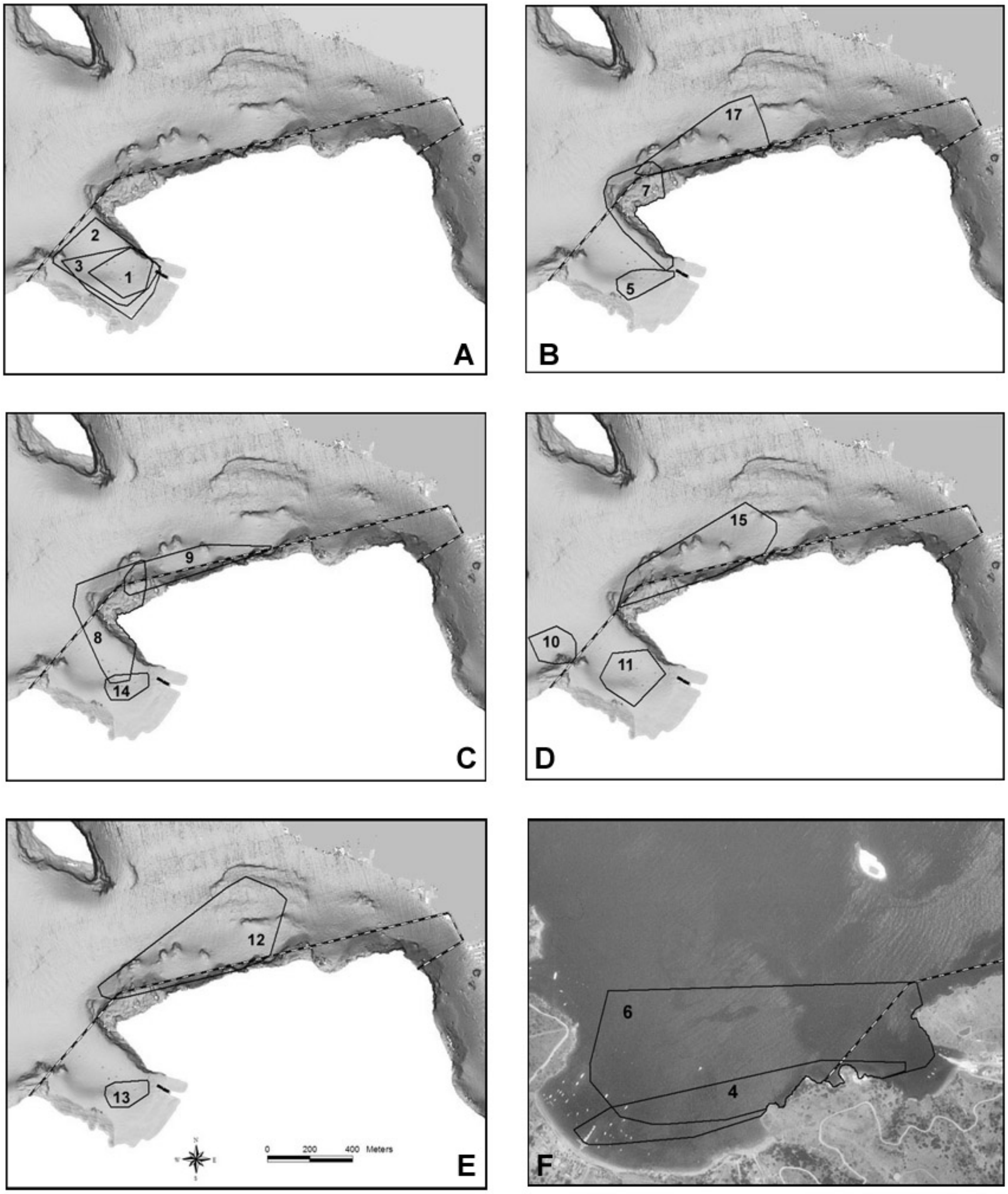

Fig. 1a-f. High resolution shaded relief maps showing benthic topography with diel home range estimates of ocean whitefish using MCPs for a) fish #s 1, 2, 3 b) 5, 7, 17 c) 8, 9, 14 d) 10, 11, 15 e) 12, 13 and f) aerial photo map for fish #s 4 and 6.

Barred sand bass:

The same methods were used for active tracking of barred sand bass in the CLMR. Unfortunately, barred sand bass are not very abundance at Catalina Island, so it was extremely difficult to catch fish to tag and track. Over the two year study period we spent over 1200 fisher/hrs trying to capture more barred sand bass. Despite using a variety of techniques including hook & line, trapping, surround nets, and underwater fishing, we only managed to capture a total of eleven barred sand bass in the CLMR and neighboring area.

Six barred sand bass (33-52 cm) were actively tracked to measure home range and habitat use in the CMLR (Table 2). Individuals were tracked from 65 to 72 hrs each resulting in a total of 427 tracking hours and 2,562 relocations. The average time period between tracks was 8 days, with no significant difference found in daily activity space size (95%KUD) between the first track (immediately following surgery) and successive tracks ($p = 0.9$) (Fig.2).

Table 2. Summary for barred sand bass actively tracked in the CLMR. Minimum convex polygon (MCP) and 95% Kernel Utilization Distribution (KUD) home range sizes for barred sand bass actively tracked inside of the CMLR.

Fish ID	Number of Tracks	TL (cm)	Implant Method	95% KUD (m^2)	MCP (m^2)
1	3	42	Surgical	10,707	52,903
2	3	52	Surgical	4,927	46,513
3	3	45	Surgical	7,429	39,517
4	3	45	Surgical	15,593	42,909
5	3	33	Surgical	15,623	26,820
6	3	47	Surgical	5,737	12,057

Home range sizes (95% KUD) varied among individuals and averaged 10,003 m^2 ± 4,773 m^2 (mean ± SD) (Table 2). Differences in fish length did not explain the variation in home range size, as there was no significant relationship between the size of an individual and its home range using either MCP (linear regression, $R^2 = 0.007$, $p = 0.88$) or 95% KUD (linear regression, $R^2 = 0.60$, $p = 0.07$). Barred sand bass had significantly larger daytime activity spaces (mean ± SE; 32,665 ± 4,902 m^2) than nighttime activity spaces (9,043 ± 2,344 m^2) (paired *t*-test: $t = 4.20$, $p =$ 008). All six actively tracked fish were caught inside the CMLR (Fig. 2) and spent some time outside of the CMLR during daylight hours. However, none of the six fish left the CMLR during the night. Barred sand bass were detected outside the CLMR only 10% of the time.

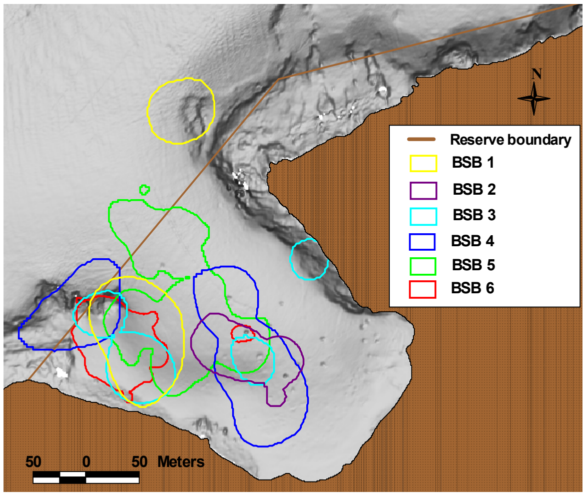

Fig. 2. High resolution shaded relief maps showing benthic topography with diel home range estimates using 95% KUD for the six actively tracked barred sand bass. BSB represents barred sand bass.

The 95% KUD home ranges of barred sand bass (10,003 m^2 ± 4,773 m^2) were on average three times larger than kelp bass home ranges (3,249 m^2 ± 3,328 m^2) (Lowe et al. 2003), and smaller than both sheephead (15,134 m^2 ± 26,007 m^2) (Topping et al.2005) and ocean whitefish (20,439 m^2 ± 28,492 m^2) (Bellquist and Lowe in press).

Objectives 2: ***Long-term site fidelity to home ranges and translocation response of kelp bass, sheephead, ocean whitefish, and barred sand bass***

Long-term (1 yr) movement patterns and site fidelity of kelp bass, sheephead, ocean whitefish, and barred sand bass were determined using passive acoustic telemetry. All fish were caught within the CMLR using hook and line during the summer months of 2005 and 2006, were surgically fitted with coded acoustic transmitters, and released at their site of capture. We used random pulse coded transmitters (Vemco Model V8SC-2L-R256), which emitted a pulse series containing a specific code unique to each tag at a 69 kHz frequency at random intervals between 50-150 sec. This yielded a battery life of approximately 1 year. The presence (time and date) of tagged fish were recorded by stationary automated underwater acoustic receivers (VEMCO Ltd. Model VR1) strategically placed at 11 locations inside and outside the CMLR (Fig. 3).

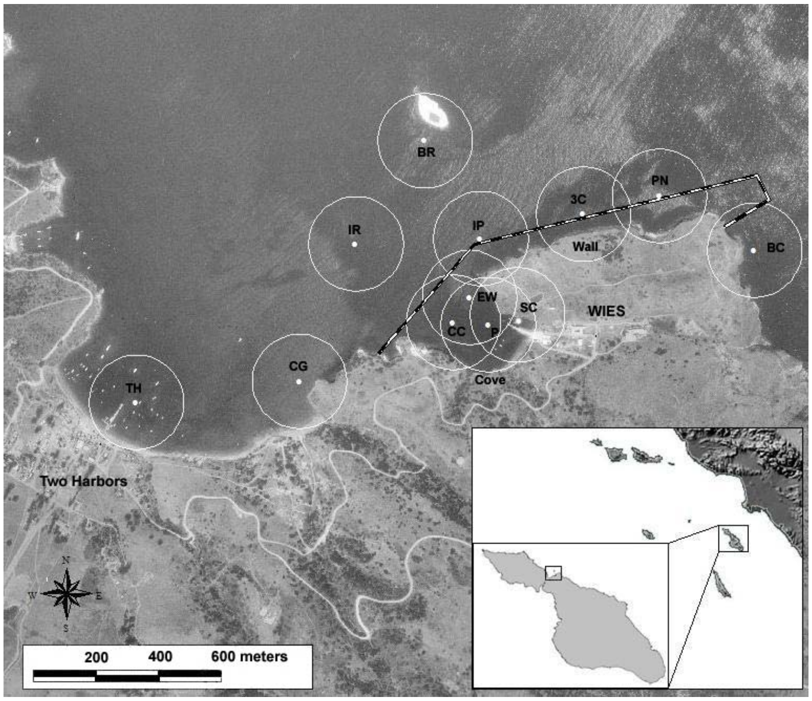

Fig. 3. Aerial photograph of the Catalina Island Marine Science Center Marine Life Refuge (CMLR) (33°26′N, 118°29′W) and town of Two Harbors. The inset shows the location of the site at Santa Catalina Island in relation to the southern California coast. White dots represent the location of twelve VR1 acoustic receivers (TH—Two Harbors, CG—Campground, IR—Isthmus Reef, BR—Bird Rock, CC—Chalk Cliffs, P—Pier, SC—Shark Cove, EW—East Wall, IP—Intake Pipes, 3C—Three Caves, PN—Pumpernickel, and BC—Blue Caverns), and white rings indicate 150 m acoustic detection radii of each receiver. The black and white hatched line represents the reserve boundary.

Twenty four individuals of kelp bass, CA sheephead, ocean whitefish, and 10 barred sand bass were monitored for longer-term site fidelity over a one year period (Table 3). Four of the actively tracked barred sand bass were also implanted with these long-term tags, which allowed these individuals to be both actively and passively tracked. Originally, we planned to recapture 10 tagged individuals of each species and then translocate 5 individuals per species to an area of continuous rock habitat and the other 5 individuals to an area of discontinuous rock habitat outside the CLMR in order to determine if habitat breaks (expanses of sand) acted as barriers to movements. Unfortunately, after over 1500 hrs of fishing using multiple techniques we were only able to recapture 4 individuals (1 of each species) for translocation. To provide some information on translocation movements we caught, tagged, and translocated 11 additional fish. In total (4 previously tagged and recaptured plus 11 additional fish), nine fish were translocated to discontinuous rock habitat and six fish were translocated to continuous habitats (Table 3). Individual fish were translocated different distances depending upon capture location and translocation destination. An area known as “Blue Caverns” (BC), which is located about 1 km from Big Fisherman’s Cove (BFC), was the site of all continuous reef translocations. Individuals moved to discontinuous reefs were taken to one of two locations, the High Spot or Bird Rock. The High Spot is surrounded by soft-sediment habitat and is approximately a 1 km away from BFC. Bird Rock offers comparable habitat to that of the CMLR but is separated from the reserve boundary by ~300 m of deep soft-sediment habitat (depth ~30-40 m) (Fig. 4 and Fig. 11).

Table 3. Summary of four species of nearshore gamefish passively tracked using acoustic telemetry in the CLMR to monitor longer-term site fidelity (1 year) and homing after translocation across continuous and discontinuous rock habitat. TL represents the total length of the fish tagged. Average (± SD) percentage of days tagged fish of each species and sex were detected within the acoustic array.

Species	N	TL (cm) (Avg. ± SD)	# of fish translocated per habitat	% days detected (Avg. ± SD)
Barred sand bass	10	45 ± 6	1 - Discontinuous	86 ± 24
Sheephead (F)	10	29 ± 2	1 - Discontinuous 1 - Continuous	58 ± 47
Sheephead (M)	8	44 ± 8	1 - Discontinuous 1 - Continuous	66 ± 40
Sheephead (T)	6	37 ± 3	none	95 ± 10
Kelp bass	24	40 ± 6	3 - Discontinuous 2 - Continuous	87 ± 23
Ocean whitefish	24	39 ± 6	3 - Discontinuous 2 - Continuous	88 ± 23

The site fidelity of each tagged fish to the study site was quantified as the percentage of days detected within the VR1 receiver array over a 1-year period. Movement of translocated fish back to the CMLR was quantified as the percentage of fish for each species that returned from continuous reef habitat and discontinuous habitat. The percentage of fish that returned and the time it took individuals to return was used as a metric for measuring which habitats may restrict or facilitate movement for each species.

Long-term site fidelity - Eight of the 10 barred sand bass, 19 of the 24 kelp bass, 18 of the 24 sheephead, and 19 of the 24 ocean whitefish were passively tracked and detected within the

CMLR acoustic receiver array for a one year period to quantify site fidelity to the study area (Fig. 5-8). The number of days individuals were detected in the study site ranged from 4 - 356 across all species. Ocean whitefish and kelp bass had the highest site fidelity (both detected 87% of the days in the study area) followed by barred sand bass (86%) and sheephead (73%) (Fig. 5-8). Three sheephead tagged in the CMLR were detected in the study site for total of only 17 days; however, none of the other species had individuals that exhibited this behavior and were detected in the study site for at least 52 days.

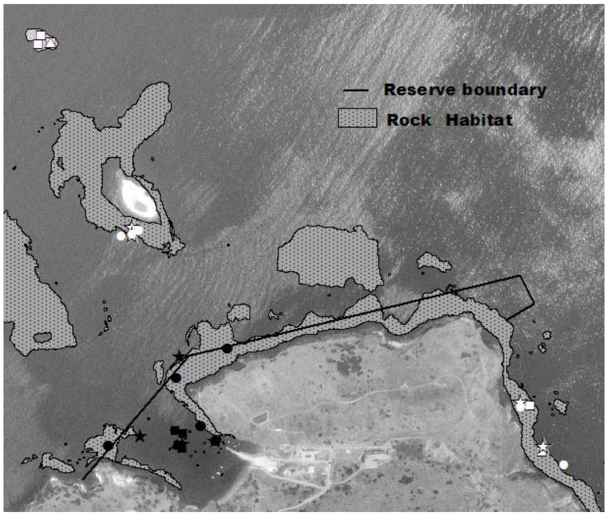

Fig. 4. Map of the locations where four species of nearshore gamefishes were translocated after being caught in the CLMR and fitted with coded acoustic transmitters. The hashed polygons represent the rock habitat. Black symbols represent capture locations and white symbols represent release locations. Triangles = barred sand bass, circles = kelp bass, stars = sheephead, and squares = ocean whitefish.

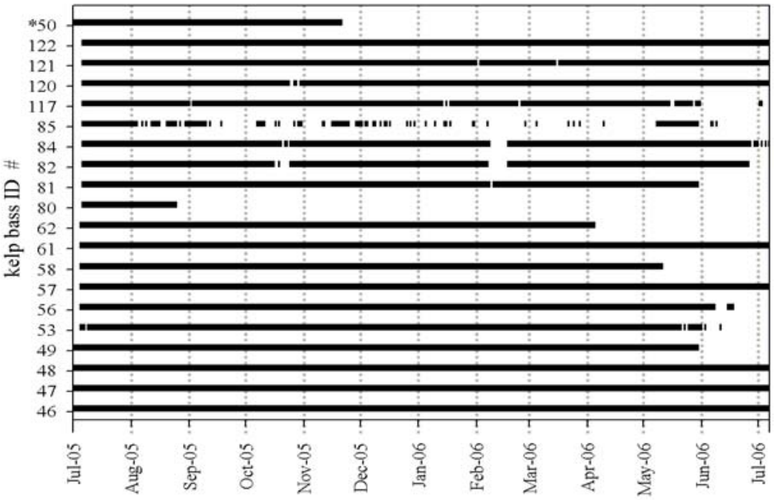

Fig. 5. Detection plot for kelp bass tagged within the CLMR and detected by the acoustic receiver array. Each black line represents a detection for that individual on a given day. Gaps in black lines represent periods when individuals were not detected by any receiver within the array. *50

represents a kelp bass recaptured and then translocated to Bird Rock and never returned to the receiver array.

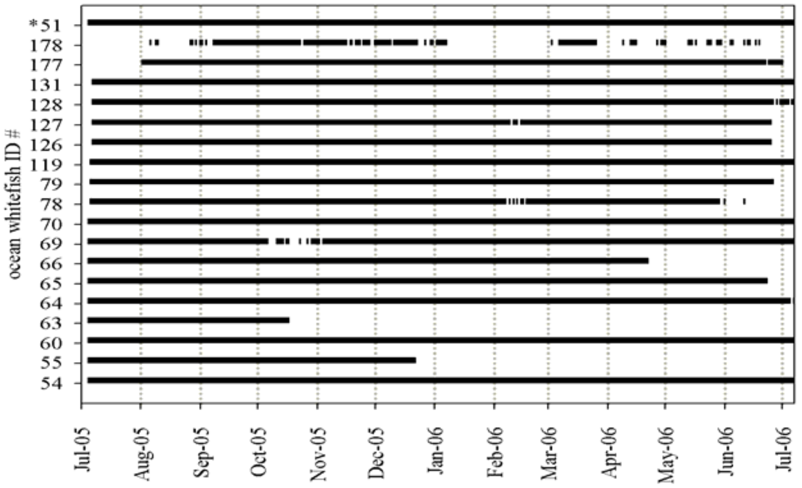

Fig. 6. Detection plot for ocean whitefish tagged within the CLMR and detected by the acoustic receiver array. Each black line represents a detection for that individual on a given day. Gaps in black lines represent periods when individuals were not detected by any receiver within the array. *51 represents an ocean whitefish recaptured and then translocated to High Spot and returned to the CLMR within 9 hrs.

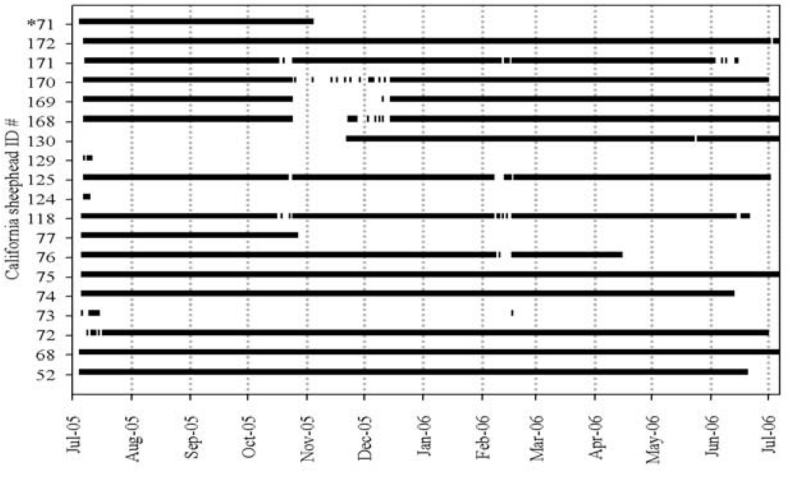

Fig. 7. Detection plot for sheephead tagged within the CLMR and detected by the acoustic receiver array. Each black line represents a detection for that individual on a given day. Gaps in black lines represent periods when individuals were not detected by any receiver within the array. *71 represents a sheephead recaptured and then translocated to Bird Rock and never returned to the CLMR.

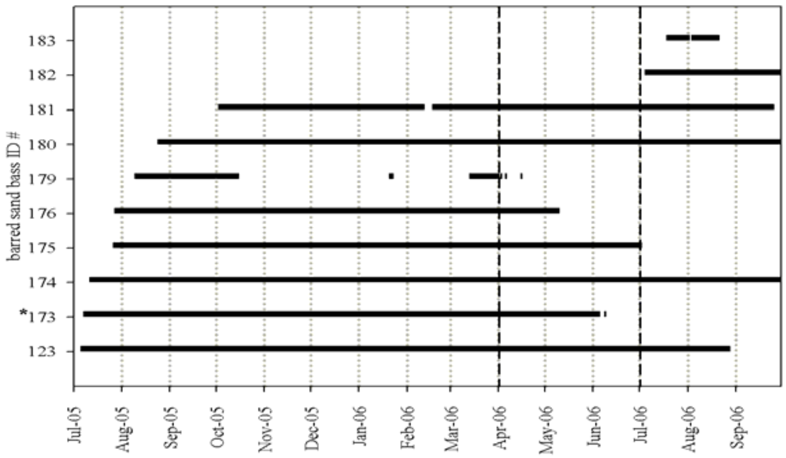

Fig. 8. Detection plot for barred sand bass tagged within the CLMR and detected by the acoustic receiver array. Each black line represents a detection for that individual on a given day. Gaps in black lines represent periods when individuals were not detected by any receiver within the array. *173 represents a barred sand bass recaptured and then translocated to High Spot and returned to the CLMR within 19 hrs. The area between the dashed lines represents the spawning season for barred sand bass in southern California.

Translocation - A total of fifteen individuals were translocated from inside the CMLR to discontinuous rock reefs and continuous reefs adjacent to the CMLR (Fig. 4). Ocean whitefish and barred sand bass were translocated to a discontinuous reef ~1 km away from the CMLR, while kelp bass and sheephead were translocated and adjacent reef ~0.5 km away the CMLR. Only five of the nine fish (55%) (1 barred sand bass, 1 sheephead, 2 kelp bass, and 1 ocean whitefish) translocated to discontinuous adjacent reefs returned (Table 4).

Table 4. Summary of four species of nearshore gamefish translocated from the CLMR to either continuous rock habitat (C. Habitat) or discontinuous rock habitat (D.C. Habitat). Return time represents the amount of time it took tagged fish to return to the CLMR after translocation based on their detection within the acoustic receiver array.

	No. of fish translocated		No. of returning fish		Return time (hr)		Translocation distance (km)	
Species	C. Habitat	D.C. Habitat	C. Habitat	D.C. Habitat	C. Habitat	D.C. Habitat	C. Habitat	D.C. Habitat
Barred sand bass	–	1	–	1	–	9	–	1
Sheephead	2	2	2	1	27, 32	262	1.1	0.5
Kelp bass	2	3	2	2	8, 15	149, 166	1.1	0.5
Ocean whitefish	2	3	2	1	9, 11	19	1.1	1

Of the fish that returned to the CLMR from discontinuous adjacent reefs, the barred sand bass returned in 9 hrs and the ocean whitefish returned in 19 hrs following translocation, which was faster than kelp bass (6 d and 7 d following translocation) and sheephead (11 d following translocation) (Table 4). All six fish (100%) (two of each species except for barred sand bass) translocated to continuous reef habitat returned to the CMLR (Table 4). It took individuals less time to return to the CMLR from contiguous reef with ocean whitefish taking 9 and 11 hrs and kelp bass taking just 8 and 15hrs. Sheephead took 27 and 32 hrs to return to the CLMR after translocation to continuous reefs (Table 4).

Objectives 3: ***Habitat use of kelp bass, sheephead, ocean whitefish, and barred sand bass***

Barred sand bass (n = 6), sheephead (n = 12), ocean whitefish (n = 16), and kelp bass (n = 5) habitat use was analyzed by plotting relocations over the detailed geological habitat map habitat map layer in a GIS. Tracking location data for sheephead (Topping et al. 2005) and kelp bass (Lowe et al. 2003) came from previous studies, but were re-analyzed to standardize habitat use metrics. Ocean white fish habitat preference was analyzed separately from the other species. For ocean whitefish, the ratio of the proportion of each habitat used to the proportion of the habitat available yielded individual habitat selection (Manly, 2002). Available habitat was defined using Arcview GIS as the proportion of area of each habitat type within the MCP for each individual tracked. With this method, a value greater than 1 would indicate habitat selection. A Chi-square Goodness of Fit test was used to measure significance of habitat selection (Manly, 2002). For the other three species we used Euclidean distance based analysis (DA) (Conner and Plowman 2001) to quantify rock, sand, and mud habitat use within each individual's home range for each species (MCP). Random points (uniform distribution) were generated in each of the home ranges and the Euclidean distance to each habitat type was calculated for both the random and observed location data. The mean distance from each habitat for each individual was divided by the mean random distance for each of the habitats to generate a distance ratio. Values less than 1 indicated that the individuals were closer than expected to a habitat type and values greater than 1 further than expected. The spatial extent to which each of these species used rock and soft-sediment habitats was examined by creating histograms of the frequency of relocations at different distances from the edge of these habitats.

Because of the tremendous amount of time spent fishing for barred sand bass and trying to recapture previously tagged fish for translocation, we were not able to make diver based maps of macroalgae for habitat analysis or measure conspecific densities of all species. However, we were able to measure conspecific densities for ocean whitefish early in the project. Visual surveys of ocean whitefish density were conducted by divers at areas where individuals were actively tracked inside the CMLR. Because the ocean whitefish is generally a demersal species, all transects were conducted solely along the bottom. The CMLR was divided into four areas (Cove, Intakes, Three Caves, and Pumpernickel; Fig. 3), each stratified by depth (15 m, 20 m, and 30 m), thus creating 12 sampling zones. Transects were 4 m wide (2 m on each side of the diver), 4 m tall, and 30 m in length. All transects were surveyed by a single experienced diver to maintain consistency in abundance estimations and transect dimensions. Density surveys were conducted periodically throughout the year, although to ensure adequate visibility transects were not conducted during low light hours. The effect of conspecific densities on activity space size of ocean whitefish was measured to test for density-dependent effects on fish movements. It was hypothesized that increased conspecific densities would yield larger home ranges, possibly due to increased intraspecific competition. Mean ocean whitefish densities were assigned to each of the 12 depth zones by pooling all transects conducted in each zone. Position fixes for each active track were then layered over the zones in a GIS, and the proportion of fixes in each zone during each track was used to calculate the mean proportion of time spent by a fish in each zone. A conspecific fish density value was then assigned to each fish by using the mean density in each zone weighted by the proportion of time spent in each zone. These values were then paired with the corresponding 95% KUD and MCP values for each actively tracked individual. However, sampling zones were stratified by depth, which was likely to be a covariate affecting densities. Therefore, weighted mean depths were also calculated using the same method described for conspecific density. Linear regressions were used to measure the effect of conspecific density and depth on size of activity space.

For ocean whitefish, the habitat selection analysis indicated significant day-night differences in habitat selection (Fig. 9). During the day, ocean whitefish exhibited significant selection for sand habitat ($X^2 = 141.01$, df = 15, $p < 0.001$), and no significant selection against any other habitat type. During nighttime periods, ocean whitefish exhibited significant selection for high relief bedrock slope over all other habitat types ($X^2 = 243.36$, df = 8, $p < 0.001$), and were seldom found to use steep volcanic bedrock habitat ($X^2 = 7.70$, df = 2, $p = 0.021$). Bottom depth utilization showed clear day-night differences with ocean whitefish at a mean depth of 21 ± 8 m (SD) during the day, and moving shallower at night to a mean depth of 15 ± 7 m (Fig. 10). Overall, ocean whitefish generally followed the rock-sand ecotone, using a variety of habitats during the day but primarily selecting for sand. At night, individuals also used a range of habitats, but selected for high relief bedrock slope, and used shallower depths than during the day.

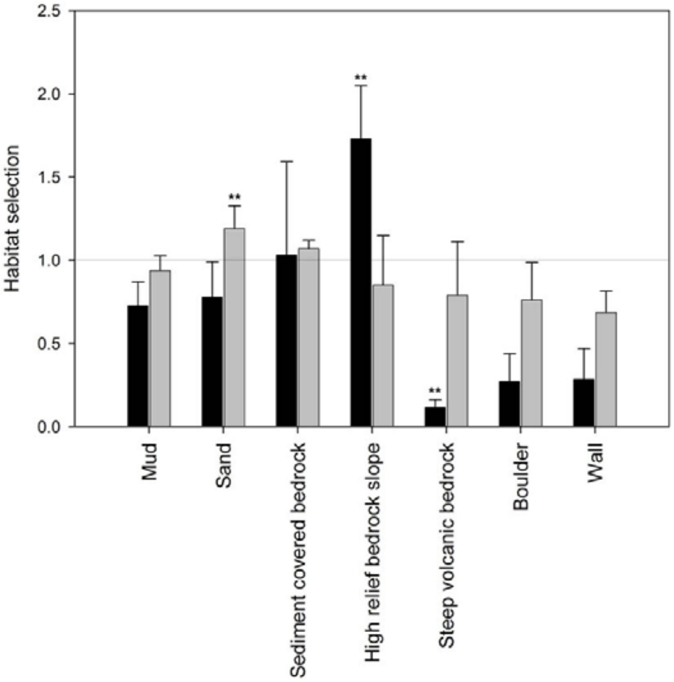

Fig. 9. Mean habitat selection index (+ SD) between night (black bars) and day (grey bars) periods. The grey horizontal line indicates the neutral reference value of 1. Values greater than 1 indicate preference for that habitat type. The ** symbols represent significance at $p < 0.01$.

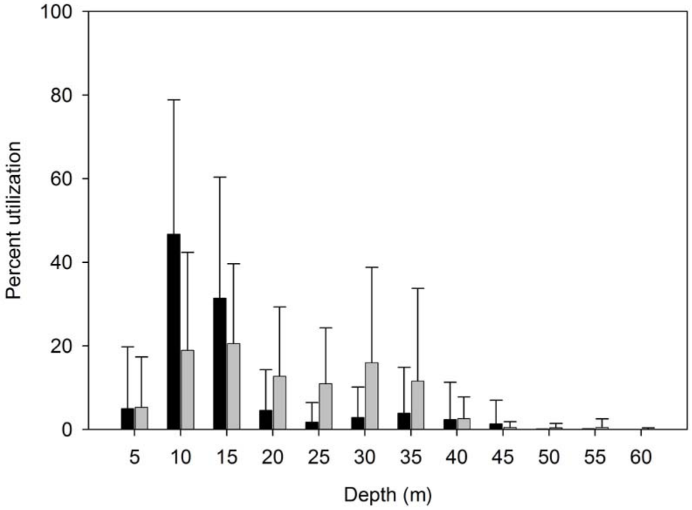

Fig. 10. Mean percent depth utilization (+ SE) between night (black bars) and day (grey bars). Depth values represent mean depth of the bottom at each position fix, rather than the actual depth of the fish.

For the other three species (kelp bass, sheephead, and barred sand bass), the geological habitat in the CMLR as determined by multibeam side-scan sonar was categorized as rock wall, steep rock, rock boulders (including mooring blocks), rock rubble, mud, and sand (Greene et al., 2001) (Fig. 11). For this study, all similar habitat types were consolidated and grouped as rock, sand, or mud habitat. Distance ratios suggest that kelp bass (0.53 ± 0.46) (mean ratio ± 95% CI), barred sand bass (0.74 ± 0.19), and sheephead (0.86 ± 0.52) were more closely associated to rock habitat than expected (Fig 12). Sand habitat use varied by species, with barred sand bass being more closely associated to sand habitat (0.53 ± 0.35) than both sheephead (2.32 ± 1.04) and kelp bass (1.23 ± 0.66), which were further than expected. However, sheephead were more closely associated to mud habitat (0.80 ± 0.38) than that of barred sand bass (1.26 ± 0.71) and kelp bass (1.33 ± 0.99).

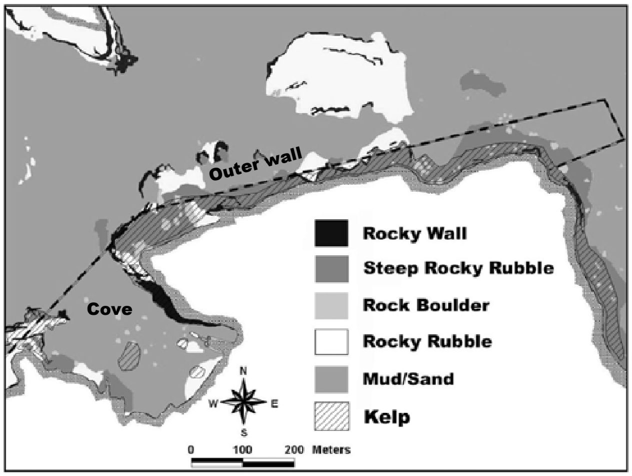

Fig. 11. Benthic habitat map for CLMR based on a multibeam sonar survey in 2000 (R. Kvitek and G. Greene). Kelp layer was based on estimates of canopy cover in 2002.

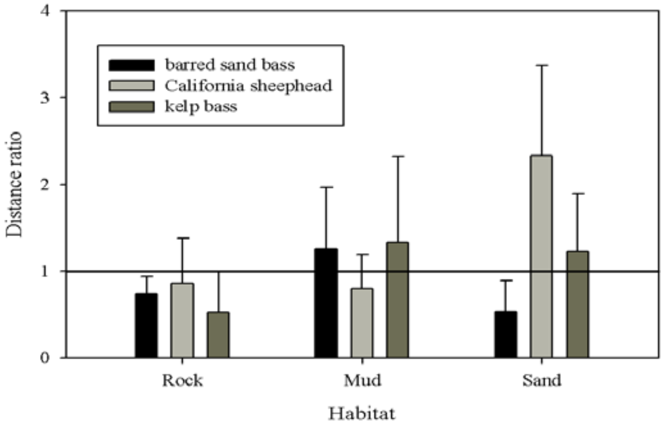

Fig. 12. Euclidean distance based habitat analysis for three nearshore gamefish for three types of benthic habitat. Mean distance ratios (± 95% CI) less than 1 indicate preference.

The spatial extent to which fish utilize the rock - soft-sediment ecotone during the day varied by species (Fig. 13). During the day, barred sand bass were close to the reef edge, predominantly on the soft-sediment side of the ecotone, while at night they moved further into the soft-sediment habitat (Fig. 14). Sheephead used both rock and soft-sediment habitats close to the habitat edges, while ocean whitefish predominantly used the soft-sediment habitat side of the reef edge (Fig 13). Kelp bass tracked along the outer wall used the interior of habitats particularly rock habitats, while those tracked in the cove used soft-sediment habitat more frequently (Fig. 15).

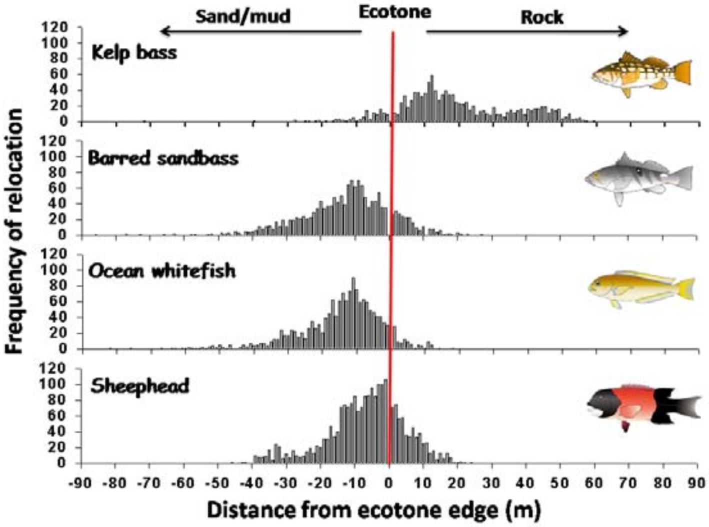

Fig. 13. Frequency of daytime relocations relative to distance from rock – sand/mud ecotone edge for four species of nearshore gamefish. Kelp bass data are only from fish tracked along the "outer wall" and ocean whitefish data are only from individuals tracked within the "cove." The red line indicates the location of the ecotone.

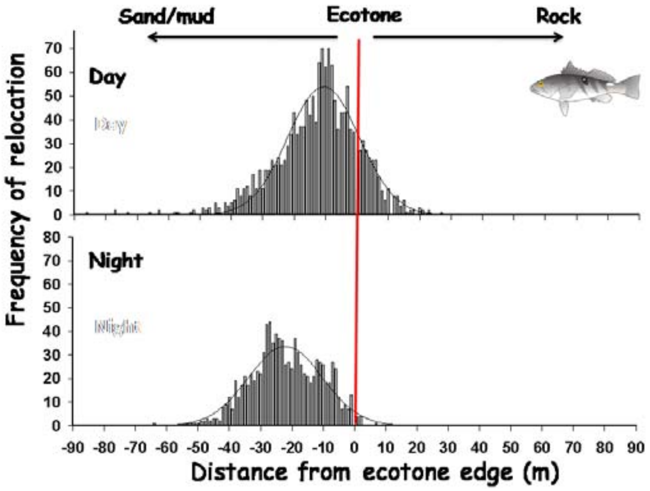

Fig. 14. Frequency of daytime and nighttime relocations relative to distance from rock – sand/mud ecotone edge for barred sand bass. The red line indicates the location of the ecotone.

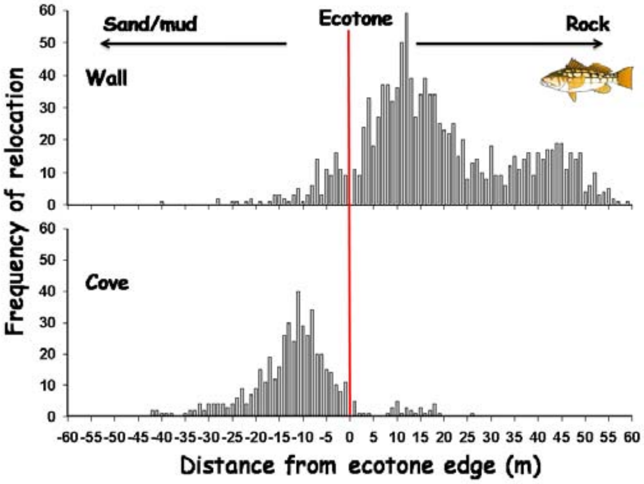

Fig. 15. Frequency of daytime relocations relative to distance from rock – sand/mud ecotone edge for kelp bass tracked along the "outer wall" or within the "cove." The red line indicates the location of the ecotone.

There were significant differences in conspecific densities between sampling zones within the CMLR (*F* = 3.133, *p* = 0.001). Ocean whitefish densities were lower in the shallower depth zones (15 m: mostly rocky habitat), and increased significantly in the deeper zones (20 - 30 m: mostly sand habitat). There was no significant effect of ocean whitefish density or depth on either 95% KUD size (*p* = 0.289; Fig. 16) or MCP size (*p* = 0.440), although two outliers are driving this lack of a relationship. These individuals (fish # 1, 2, and 3) were fed transmitters by divers, and observational evidence suggests that these three fish could have actually been the same individual. Pooling these three individuals to calculate a single home range and density value yields a significant relationship between conspecific densities and home range size (F = 6.23, *p* = 0.034).

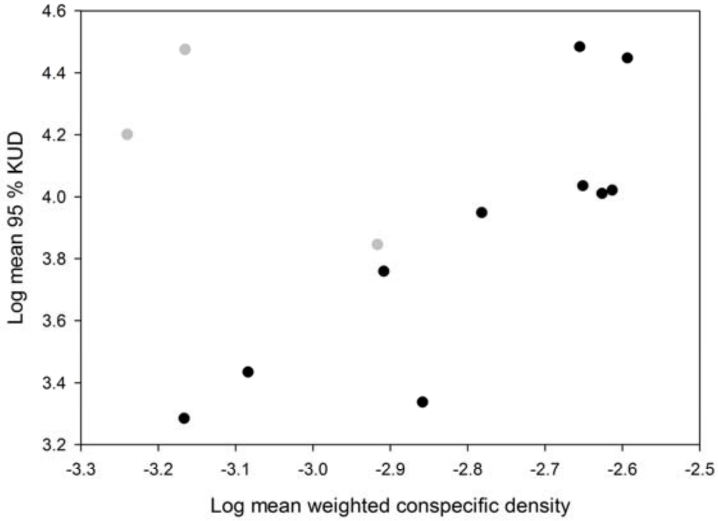

Fig. 16. Log 95% KUD (m^2) vs. log mean weighted conspecific density (no. of fish per m^3). Gray points represent Fish # 1-3 that were fed acoustic transmitters and could possibly be the same individual. Only 13 points are shown because 3 of the 16 fish left the surveyed area completely, and as a result, could not be correlated with a density value.

Summary:

We believe these findings will be of great benefit Calif. Dept. of Fish & Game and resource managers tasked with designing new MPAs in California and other locations. Our project provides one of the most detailed and comprehensive studies of movement patterns, habitat use, and site fidelity of four of the most popular sport fishes in southern California.

Kelp bass, barred sand bass, sheephead, and ocean whitefish all show distinct home ranging behavior and exhibit high site fidelity to their home ranges (period up to 1 year). Because kelp bass and barred sand bass are considered ambush predators, it is not surprising they have smaller home ranges than ocean whitefish and sheephead, which are considered benthic foragers. Based on analysis of habitat use and movement patterns, kelp bass and sheephead use the rock side of the ecotone, while ocean whitefish and barred sand bass use the sand/mud side of the ecotone. Kelp bass and sheephead are less likely to cross expanses of sand substratum to move between rock habitats, whereas ocean whitefish and barred sand bass are less restricted. Our analysis of ecotone edge use clearly indicates that “edge habitats” are important to all four species. These findings indicate that placing reserve boundaries at least 100 m away from the rock substratum will reduce capture rates of all four species.

Data generated from this study will provide ecological modelers with the first set of species specific movement and habitat use parameters needed to develop spatially explicit models for designing MPA of adequate size and habitat composition. We will be collaborating with ecological modelers at UC Davis to integrate our data into MPA design models. This is extremely important considering the impending MLPA mandate to establish a network of MPAs throughout southern California. Fishers and other shareholders will benefit from this information by knowing that empirical data now exist to better design MPAs to optimize function, either supplement fisheries via adult export (leaky boundaries) or maximize protection (via tight boundaries).

This research has greatly benefited graduate student Sea Grant Trainees (**Lyall Bellquist** and **Tom Mason**) and other CSULB graduate and undergraduate students that have participated on this project. These students have gained valuable field experience working on this project, as well as marketable skills in GIS management and spatial analysis. All participants have presented data collected from this project at local, national, and international scientific meetings, where California Sea Grant was acknowledged for funding support (see list of products below).

We are developing a webpage specifically to educate the general public, scientific community, and fishers about this research and its value for various shareholders (www.csulb.edu/web/labs/sharklab). At present, this work will result in four scientific manuscripts, one of which is published in Marine Ecology Progress Series and another is currently in press in Fisheries Research. In addition, two Masters Theses have resulted from this project (Lyall Bellquist and Tom Mason).

Project products to date:

Publications:

Bellquist, L.F., C.G. Lowe, and J.E. Caselle. in press. Fine-scale movement patterns, site fidelity, and habitat selection of ocean whitefish (*Caulolatilus princeps*). Fishery Research.

Topping, D.T., **C.G. Lowe**, and J.E. Caselle. 2006. Site fidelity and seasonal movement patterns of adult California sheephead, *Semicossyphus pulcher* (Labridae), ascertained via long-term acoustic monitoring. Marine Ecology Progress Series. 326:257-267.

Professional scientific presentations:

Lowe. C.G., T. Mason, L. Bellquist, D. Topping, B. Hight, and J. Caselle. (Nov. 2007). What do we know about movement patterns and habitat use of rocky reef associated gamefishes and why is it essential for MPA design? Presidents Symposium, Ann. Mtg. Western Society of Naturalists, Ventura, CA.

Lowe, C.G., K. Anthony, T. Mason, L. Bellquist, D. Topping, B. Hight, and J. Caselle. (Sep. 2007). Using acoustic telemetry to quantify movement patterns, habitat use and optimize MPA design for gamefishes. Ann. Mtg. American Fisheries Society, San Francisco, CA.

Mason, T.J., C.G. Lowe and J. Caselle. (Sep 2007). Barred sand bass (*Paralabrax nebulifer*) home range, habitat use, and site fidelity. Ann. Mtg. American Fisheries Society, San Francisco, CA.

Mason, T.J. C.G. Lowe and J. Caselle. (Nov. 2006). Barred sand bass (*Paralabrax nebulifer*) home range, habitat use, and site fidelity within a southern California marine reserve. Ann. Mtg. Western Society of Naturalists, Seattle, WA.

Lowe, C.G., K. Anthony, L. Bellquist, E. Jarvis, T. Mason, D. Topping, J. Vaudo, and J. Caselle. (Jul 2006). Effectiveness of VR receivers in monitoring movements of fishes in different marine habitats. International Congress on the Biology of Fish, St. John's, Newfoundland.

Bellquist, L.F., **C.G. Lowe**, and J.E. Caselle. (Nov. 2005). Movement patterns, home range, site fidelity, and habitat preference of ocean whitefish (Malacanthidae) in a Santa Catalina Island marine reserve. Ann. Mtg. Western Society of Naturalist. Monterey, CA.

Masters Degree Thesis:
Bellquist, L.F. 2006. Movement patterns and habitat selection of ocean whitefish, *Caulolatilus princeps*, in a southern California marine reserve. Masters Thesis. Department of Biological Sciences, California State University, Long Beach.

Mason, T.J. (graduate expected May 2008). The effects of habitat composition, quality, and breaks on home ranges and site fidelity of barred sand bass (*Paralabrax nebulifer*) compared with three other species of exploited nearshore reef fishes. Masters Thesis. Department of Biological Sciences, California State University, Long Beach.

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