

# Long-Term Movement Patterns and Habitat Use Of Nearshore Groundfish: Tag-Recapture in Central and Southern California Waters

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**Abstract:** We conducted a mark-recapture tagging study evaluating long-term movement patterns and broad-scale habitat use by groundfish off southern and central California. Thirty-two species (32,366 fish) were tagged in nearshore and offshore island areas from Point Estero, California to the U.S. – Mexico border during 253 chartered fishing trips over 4 years. There were 1,569 (4.9%) tag recoveries with recorded days at liberty (DAL) ranging 0 – 2,603 days (mean 288 d). Observed capture and handling mortality was 1,532 fish (4.52%). Median recovery straight-line distance was 5 km from original tagging site for all recaptured fish; 64% of all recaptures were greater than 100 DAL. Recovery distances of 50 km or more were observed for 51 fish among nine species. Longest minimum distances recorded were 510 km (342 DAL) by a mature olive rockfish (*Sebastes serranoides*) and 488 km (1,222 DAL) for an immature copper rockfish (*S. caurinus*). The two greatest DAL were for a brown rockfish (*S. auriculatus*) recaptured at 2,603 DAL and 3 km from tag/release site and a California scorpionfish (*Scorpaena guttata*) recaptured at 2,126 DAL and 0.3 km from tag/release site. Tag recoveries, though obtained primarily in recreational fishing locations, were not spatially restricted indicating the importance of rocky reef habitat and may reflect the extent of fishable, quality habitat in southern California waters. Large sample size and tag recoveries indicate use of multiple groundfish habitats and greater movement than previously suspected.

**Keywords:** Channel Islands, California Bight, MPA, rockfish, mark-recapture.

## INTRODUCTION

The objective of this work was to develop an understanding of long-term movement patterns and broad-scale habitat use of groundfish comprising nearshore rocky reef assemblages off central California and the southern California Bight. In collaboration with California Department of Fish and Game (CDFG) and Pacific States Marine Fisheries Commission (PSMFC) we conducted a tag and recapture program over an eight-year period using volunteer anglers aboard West Coast For Hire Sector vessels (WCFHS).

Groundfish of the family Scorpaenidae [1] including the California scorpionfish (*Scorpaena guttata*), and rockfish of the species-diverse genus *Sebastes* [2], along with several other groundfish species (*e.g.*, lingcod, *Ophiodon elongatus*), which dominate nearshore and shallow shelf demersal (<100 m) rocky reef fish assemblages of the California coastal ecosystem [3-5]. Groundfish species are important to recreational and commercial fisheries including the California live-fish fishery [4, 6, 7]. Seven rockfish species (canary, *Sebastes pinniger*; darkblotched, *S. crameri*; widow, *S. entomelas*; yelloweye rockfish, *S. ruberrimus*; bocaccio, *S. paucispinis*; cowcod, *S. levis*; and Pacific Ocean perch, *S. alutus*) off the west coast of the United States are currently designated as overfished [8, 9].

To promote groundfish stock rebuilding and ensure fisheries yield, management measures have been implemented, as well as, additional protective measures (*e.g.*, time and area closures, bag and size limits) [10]. Spatially based management including Essential Groundfish Habitat and Marine Protected Areas (MPA) with ecosystem based fisheries management, is being implemented and evaluated for conservation of fish and other marine populations off California and the U.S. west coast [11-14].

Implicit to the effectiveness of spatial management techniques, are the underlying habitat use and rates of movement for the protected species [15]. Mark and recapture (tagging) studies provide a means of examining broad fish movement patterns, potentially over long time periods [16]. Lowe [17] summarized the relative advantages and disadvantages of techniques used to assess fish movement and noted that tag and recapture methods are dependent upon (and may be biased by) fisheries distribution and fishing effort. In addition, capture and handling of many scorpaeniid species possessing swim bladders is complicated by physiological stress (barotrauma) that occurs as they are brought from depth to the surface [6, 18]. Methods for deflating the swim bladder, as well as, innovative *in situ* techniques applied to tagging of deeper water species [15, 19] are helping to lessen these problems.

Traditional tag and recapture techniques cannot provide fine-scale temporal and spatial data as acoustic tagging can provide when examining site fidelity and home range patterns [*e.g.* 20- 22]. At this individual level, fine scale studies

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**Fig. (1).** Cross hatching for areas of tagging effort in central and southern California.

may represent movement of the whole population [17] but large scale tag and recapture studies may be useful for developing insight into long-term movement patterns and areas of use for the overall population or stock.

## MATERIALS AND METHODOLOGY

We chartered WCFHS on which we captured and tagged groundfish along the mainland of Central California and throughout the Southern California Bight (Fig. 1). Volunteer anglers (skillful sport fishermen, chosen by WCFHS skippers) used hook and line to catch groundfish for tagging. They used a variety of fishing technics and gear configurations to catch the fish. Fishing was limited to about five anglers per fishing stop (tagging site) to control rate of fish captured and minimize fish time out of water. Anglers reeled fish to the surface slowly in an attempt to minimize barotrauma. Hyper-inflated swim bladders were deflated with 18 gauge, hypodermic needles that had been cleaned with chlorine solution [23, 24] and soaked in oxytetracycline. Each fish was measured to fork length in centimeters [25]. Fish were externally tagged using Floy Mark II tagging guns (Floy Tag & Manufacturing, Inc., Seattle, WA) with FD-94 Floy T-bar anchor tags (6 cm long). Tags were embedded in the dorsal musculature between pterygiophores with the free end of the tag slanting tail-ward. High retention rates have been demonstrated for use of the FD-94 tag among three freshwater fish species [26-28].

Data collection and tagging were conducted by scientific and technical staff.

Handling time (out of water to release) was approximately 5 minutes or less per fish and decreased during the project. Fish condition was assessed upon capture; subsequent to tagging; and upon release. Condition was recorded using a standardized, coded index based on categories of injuries, e.g. hook wound, tissue damage, bleeding, and fin

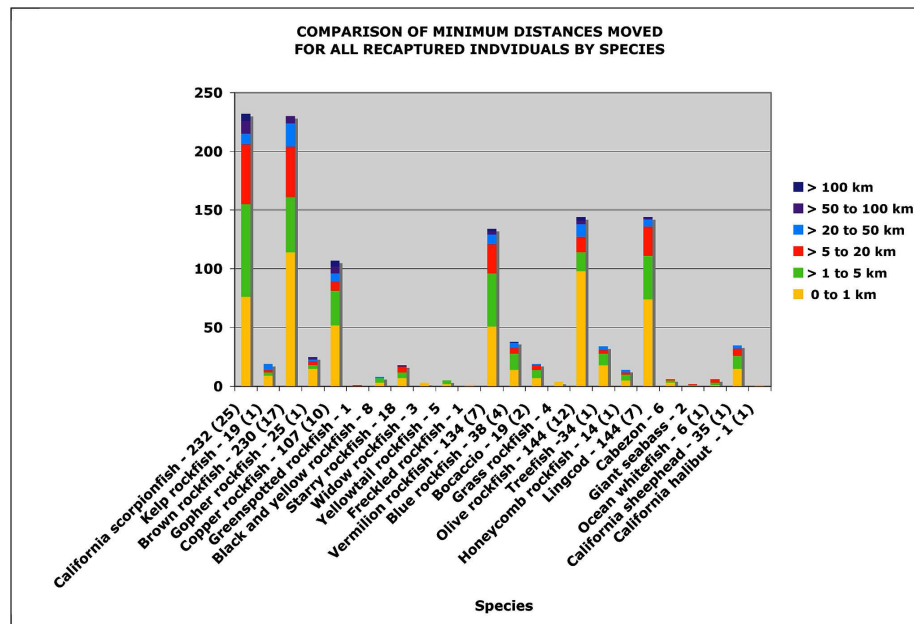
damage [29]. Condition was broadly categorized as good - no eye damage, stomach and anus intact; moderate - evidence of eye distention but no crystallization; slight stomach distention; or poor - both eyes damaged with evidence of crystallization, bleeding, stomach or anus distention. Fish in poor condition were placed in holding tanks for up to 15 minutes for observation, recovery, and release. If the fish was not suitable for release (decided by tagging technician) they were sacrificed; if tagged and tag salvageable, tags were reused.

Observed mortality (determined by tagging technician as a fish that appeared lifeless and unresponsive to touch) was assessed and occurrence pre-tagging or post-tagging was recorded. Post-tagging mortality does not account for any mortality that occurred after fish were released and unobservable by technician or crew.

An informational flyer offering a reward for tagged fish was periodically distributed at landing sites and docking facilities to alert recreational and commercial fishermen regarding the study. Tags were individually numbered and marked "CDFG REWARD 562-342-7100." Reward was a letter describing tagging location, date, and fish length when tagged, along with a "Nearshore Groundfish Tagging Project" t-shirt displaying fish illustrations and logos of the participating agencies on the back.

For these analyses, we used recovery information received from November 2002 to August 2010 but recovery data are continuing to be received (i.e., 5 March 2011, vermillion rockfish (*S. miniatus*) recaptured at 111 km; 2,104 DAL). Recoveries were reported to D. A. Hanan and E. W. Roberts or other CDFG personnel which allowed verification when reporting fishermen; tags were also returned by mail.

We estimated total observed mortality by species as the sum of all fish that died (pre- and post- tagging mortality). Tag recovery rates were computed as number recovered di-



**Fig. (2).** Minimum distance moved with increments according to legend on right. Total recoveries follow common name; those with no distance estimate in parentheses.

vided by number tagged. Average length of tagged fish was calculated by species. Approximate maturity was estimated based on published results of maturity ogives and, when possible, using ogives specific to California waters. Straight-line recapture distance was calculated to nearest nautical mile and then converted to kilometers. We summarized distances within increments of  $\leq 1$  km,  $>1$  to  $\leq 5$  km,  $>5$  to  $\leq 20$  km,  $>20$  to  $\leq 50$  km,  $>50$  to  $\leq 100$  km, and  $> 100$  km (Fig. 2).

DAL and distance from tagging site were plotted and linear regression of distance on DAL were computed for species with recapture distances  $> 50$  km and sample size 25 recoveries or greater. We accept that displacement resulting from capture and release may have affected movement of some tagged fish.

## RESULTS

Scorpionfish, rockfish of the family Scorpaenidae, and six other fish species were tagged during the tagging study period, 21 November 2002 to 24 July 2006. A total of 253 trips with the WCFHS were chartered for tagging in near-shore areas (including seven State Recreational Groundfish Management Areas [10], several State Marine Reserves along the mainland, and the Channel Islands Marine Protected Areas [30]) from Point Estero, California to waters off Imperial Beach, California near the U.S. – Mexico border (Fig. 1). Among fishing locations, there were a total of 1,873 tagging sites (vessel stops) with corresponding latitude and longitude coordinates and water depths ranging from 4 to 116 m (mean 29 m). We coordinated with WCFHS skippers to choose locations where groundfish were likely to be caught and in areas with water depth tended to be less than 100 ft (30.5 m).

A total of 33,882 fish were caught, representing 32 species (scorpionfish, 25 rockfish species, and nearshore species: lingcod, cabezon (*Scorpaenichthys marmoratus*), giant seabass (*Stereolepis gigas*), ocean whitefish (*Caulolatilus princeps*), California sheephead (*Semicossyphus pulcher*),

California halibut (*Paralichthys californicus*), (Table 1). A total of 32,366 fish were tagged and released. There were 1,569 (4.9%) reports of tagged fish recaptured or observed. Of these, 1,321 reports had recapture information sufficient for analysis. Recapture and then re-release on the same day as tagged was considered zero (0) DAL. On the day of tagging, 193 fish were recaptured (0 DAL) and re-released. These 193 fish were of 11 species, predominately California scorpionfish ( $n=95$ ) and lingcod ( $n=69$ ). Twelve of the 193 fish were recaptured a third time at a later date (23-607 DAL). The two greatest DAL were for a brown rockfish (*S. auriculatus*; 2,603 DAL) recaptured 3 km from tag/release site and a California scorpionfish (2,126 DAL) recaptured 0.3 km from tag/release site.

The majority of tag recoveries were made by recreational fishermen (private vessels and WCFHS) but a few recoveries ( $< 100$ ) were from commercial vessels, kayakers, and divers (including underwater visual tag observations and video by divers). Recovery location was based on exact coordinates if available but occasionally by CDFG fisheries statistical catch areas (Fish and Game reporting blocks). Some tagged fish were recaptured; then re-released with the tag intact and recovery information reported by the fishermen. Data on disposition of fish subsequent to first recapture and re-release are inconsistent; therefore, the total number of tagged fish recaptured and retained and total number of tagged fish re-released are not known with certainty. A total of 53 fish were confirmed to have been recaptured at least two times after day of tagging, and four of these were recaptured a third time (Table 2). One treefish (*S. serriceps*) was recaptured four times (the four DAL periods in chronological order were: 70, 16, 175, and 537; total DAL to last capture = 798).

Sex of most fish tagged was not known with certainty; although, average fork length of tagged fish (Table 1) exceeded length at sexual maturity for California scorpionfish, greenspotted rockfish, black and yellow rockfish, bocaccio,

**Table 1. Summary of All Species Tagged in Nearshore Central and Southern California Waters and Offshore Island Areas Between November 2002 and July 2006, and Recovery Data Through August 2010**

Species	Number Tagged	Number Recoveries	Percent Recovered	Fork Length at Tagging (Average cm)	Fork Length (Range cm)	Average Days at Liberty (SD)	Days at Liberty (Range)
California scorpionfish	2751	257	9.3%	27.5 (n=2743)	12.9 - 43.5	408.8 (431.6)	2 - 2126
Kelp rockfish	1746	20	1.2%	30.0 (n=1731)	18.0 - 45.6	157.5 (142.7)	14 - 415
Brown rockfish	1453	247	17.0%	27.3 (n=1448)	13.7 - 47.5	204.7 (278.0)	1 - 2603
Gopher rockfish	2709	26	1.0%	25.7 (n=2685)	11.6 - 51.3	352.6 (388.9)	14 - 1650
Copper rockfish	2828	117	4.1%	32.2 (n=2821)	13.4 - 61.0	441.5 (396.6)	11 - 2052
Greenspotted rockfish	56	1	1.8%	28.3 (n=55)	20.4 - 34.2	560	560
Black and yellow rockfish	115	8	7.0%	25.5 (n=114)	11.0 - 34.2	322.9 (311.3)	38 - 824
Starry rockfish	478	18	3.8%	28.1 (n=470)	13.5 - 49.4	457.0 (315.2)	30 - 1263
Calico rockfish	82	0	0.0%	14.4 (82)	10.9 - 21.0	-	-
Widow rockfish	128	3	2.3%	29.7 (n=128)	11.4 - 43.4	203	203
Yellowtail rockfish	71	5	7.0%	26.2 (n=71)	13.3 - 35.0	233.2 (79.7)	159 - 354
Squarespot rockfish	76	0	0.0%	20.0 (n=76)	13.7 - 30.2	-	-
Freckled rockfish	6	1	17.0%	22.7 (n=6)	21.2 - 25.5	52	52
Black Rockfish	15	0	0.0%	28.3 (n=15)	20.5 - 26.4	-	-
Vermilion rockfish	3161	141	4.5%	34.5 (n=3149)	12.6 - 85.1	455.5 (415.86)	3 - 1963
Blue rockfish	5221	42	0.8%	28.1 (n=5189)	11.3 - 63.2	339.7 (295.0)	42 - 1460
China rockfish	7	0	0.0%	29.1 (n=7)	25.1 - 34.0	-	-
Bocaccio	454	21	4.6%	43.7 (n=449)	11.5 - 63.0	529.5 (424.1)	51 - 1558
Canary rockfish	13	0	0.0%	30.0 (n=13)	25.7 - 34.1	-	-
Grass rockfish	26	4	15.4%	31.4 (n=26)	22.0 - 43.9	34.8 (43.8)	16 - 99
Rosy rockfish	131	0	0.0%	19.9 (n=29)	14.4 - 29.6	-	-
Flag rockfish	22	0	0.0%	25.9 (n=21)	16.2-34.1	-	-
Olive rockfish	3278	156	4.8%	29.9 (n=3255)	12.4 - 57.8	129.6 (128.9)	1 - 866
Treefish	945	35	3.7%	28.2 (n=940)	13.5 - 39.9	436.9 (395.8)	4 - 1780
Honeycomb rockfish	610	15	2.5%	19.4 (n=607)	11.6 - 30.2	540.8 (462.1)	67 - 1849
Kelp greenling	38	0	0.0%	32.8 (n=37)	25.5-46.6	-	-
Lingcod	3865	151	3.9%	56.0 (n=3853)	21.3 - 94.5	287.3 (323.6)	1 - 1791
Cabazon	300	6	2.0%	39.2 (n=300)	18.4 - 59.4	112 (108.2)	3 - 304
Giant seabass	14	2	14.3%	65.4 (n=14)	41.7 - 102.2	742.5 (703.6)	245 - 1240
Ocean whitefish	210	7	3.4%	38.6 (n=208)	25.7 - 65.0	536.3 (699.0)	84 - 2085
California sheephead	1485	36	2.4%	38.2 (n=1476)	19.5 - 75.6	402.5 (440.3)	7 - 1721
California halibut	72	2	2.8%	60.2 (n=68)	31.1 - 113.5	194.5 (75.7)	141 - 248

**Table 2. Fish Tagged, Recaptured, and Re-Released by Fishermen with Tag in Place**

Species	Number Fish Second Recapture	Days at Liberty (Range Capture 1 and 2)	Number Fish Third Recapture	Days at Liberty (Range Capture3)	Number Fish Fourth Recapture	Days at Liberty (Range Capture 4)
California scorpionfish	10	11-1486	0	-	0	-
Brown rockfish	18	8-1228	2	67-95	0	-
Gopher rockfish	2	24-196	0	-	0	-
Vermilion rockfish	4	95-528	1	118	0	-
Blue rockfish	2	504-909	0	-	0	-
Olive rockfish	8	15-228	3	104-138	0	-
Treefish	2	16-196	1	261	1	537
Lingcod	5	48-389	0	-	0	-
California sheephead	2	99-487	0	-	0	-

**Table 3. Observed Mortality for Fish by Species Caught in this Tagging Study**

Species	Total Number Caught	Total Observed Mortality	Pre-Tagging Mortality	Post-Tagging Mortality	Pre-Tagging Mortality (%)	Post-Tagging Mortality (%)	Total Percent Observed Mortality
California scorpionfish	2,752	1	0	1	0.00	0.04	0.04%
Kelp rockfish	1,796	50	30	50	1.67	1.11	2.78%
Brown rockfish	1,470	17	16	1	1.09	0.07	1.16%
Gopher rockfish	2,936	227	171	56	5.52	1.91	7.73%
Copper rockfish	2,971	143	89	54	2.99	1.82	4.81%
Greenspotted rockfish	70	14	4	10	5.71	14.29	20.0%
Black and yellow rockfish	118	3	3	0	2.54	0.00	2.54%
Starry rockfish	513	35	24	11	4.68	2.14	6.82%
Calico rockfish	94	12	11	1	11.7	1.06	12.76%
Widow rockfish	134	6	0	6	0.00	4.48	4.48%
Yellowtail rockfish	72	1	0	1	0.00	1.39	1.39%
Squarespot rockfish	88	12	12	0	12	0.00	13.64%
Freckled rockfish	7	1	1	0	14.29	0.00	14.29%
Black Rockfish	15	0	0	0	0.00	0.00	0.00%
Vermilion rockfish	3,655	494	203	291	5.55	7.96	13.51%
Blue rockfish	5,348	127	103	24	1.92	0.45	2.37%
China rockfish	7	0	0	0	0.00	0.00	0.00%
Bocaccio	506	52	36	16	7.11	3.16	10.27%
Canary rockfish	13	0	0	0	0.00	0.00	0.00%
Grass rockfish	26	0	0	0	0.00	0.00	0.00%
Rosy rockfish	192	61	31	30	16.15	15.62	31.77%

Table 3. cont....

Species	Total Number Caught	Total Observed Mortality	Pre-Tagging Mortality	Post-Tagging Mortality	Pre-Tagging Mortality (%)	Post-Tagging Mortality (%)	Total Percent Observed Mortality
Flag rockfish	26	4	3	1	11.54	3.84	15.38%
Olive rockfish	3,412	134	89	45	2.61	1.32	3.93%
Treefish	981	36	28	8	2.85	0.82	3.67%
Honeycomb rockfish	689	79	38	41	4.68	2.14	11.47%
Kelp greenling	39	1	0	1	0.00	2.56	2.56%
Lingcod	3,871	6	6	0	6.00	0.00	0.15%
Cabezon	300	0	0	0	0.00	0.00	0.00%
Giant seabass	14	0	0	0	0.00	0.00	0.00%
Ocean whitefish	210	0	0	0	0.00	0.00	0.00%
California sheephead	1,485	16	8	8	0.54	0.54	1.08%
California halibut	72	0	0	0	0.00	0.00	0.00%
OVERALL TOTAL	33,882	1,532	906	656	2.7	1.9	4.5%

Table 4. Details of Nine Fish Species with Estimated Distances from Tagging/Release Site to Recapture Site of 50 km or Greater. Abbreviations: A-Neither Eye Distended, C-Both Eyes Distended, D-One Eye Crystallized, E-Both Eyes Crystallized, F-Stomach Extended into Mouth, H-Hook Wound Minor, I-Hook Wound Severe, L-Bleeding, R-Active, X-Abdomen Swollen, West Coast For Hire Sector (WCFHS)

Species	Tag	Capture Habitat and Depth (m)	Length at Tagging (cm)	Estimated Maturity	Fish Condition at Release	Days at Liberty	Distance Moved (km)	Rate of Movement (km/Day)	Re-Capture Vessel
California scorpionfish	01820	rocky; 15	30.1	M	good	224	197	0.88	Commercial trawl
	02533	rocky; 16	30.4	M	good	92	200	2.17	Commercial trawl
	02546	rocky; 16	25.8	M	good	197	200	1.02	Commercial trawl
	04619	artificial reef; 22	19.6	M	good, A, R	1788	53	0.03	Recreational - WCFHS
	05173	artificial reef; 22	23.5	M	good, A	515	94	0.18	Recreational - WCFHS
	11561	rocky, kelp; 26	31.5	M	good, A	810	171	0.21	Recreational - WCFHS
	11981	rocky; 26	24.4	M	good	187	53	0.28	Commercial trawl
	16571	rocky; 29	30.4	M	good	511	173		Recreational - WCFHS
	17155	NA; 29	29.1	M	good	442	80	0.18	Recreational - WCFHS
	17199	NA; 29	26.0	M	good	555	70	0.13	Recreational - WCFHS
	17204	NA; 29	29.0	M	good	68	70	1.03	Recreational - WCFHS
	27543	artificial reef; 43	28.0	M	good, H, R	1022	68	0.07	Not known

Table 4. cont....

Species	Tag	Capture Habitat and Depth (m)	Length at Tagging (cm)	Estimated Maturity	Fish Condition at Release	Days at Liberty	Distance Moved (km)	Rate of Movement (km/Day)	Re-Capture Vessel
	27638	artificial reef; 44	31.6	M	good, H, R	287	85	0.30	Recreational - WCFHS
	27655	artificial reef; 44	28.2	M	good, H, R	320	75	0.23	Recreational - WCFHS
	27661	artificial reef; 44	37.7	M	good, H, R	549	84	0.15	Recreational - WCFHS
	30111	large rock; 49	29.8	M	good, H, R	424	129	.30	Recreational - WCFHS
	32595	rocky; 46	27.6	M	good	86	91	1.06	Recreational - WCFHS
Brown rockfish	03900	rocky; 18	28.6	PM	good	95	76	0.80	Recreational - WCFHS
	09165	rocky; 22	26.4	PM	good, A	793	52	0.07	Recreational - WCFHS
	25343	rocky reef, kelp; 37	26.4	PM	good, A	334	89	0.27	Not known
	32523	rocky, kelp; 45	20.2	IM	good, A	323	50	0.15	Recreational - WCFHS
	34151	rocky, kelp; 79	29.2	PM	good, A	45	59	1.31	Recreational - WCFHS
	34293	rocky, kelp; 79	36.4	PM	good, A	45	59	1.31	Recreational - WCFHS
Gopher rockfish	01659	rocky; 15	39.0	M	good	583	109	0.19	Recreational - WCFHS
	20764*	rocky; 31	27.5	M	poor, C, E, F, X	196	50	0.26	Recreational - WCFHS
Copper rockfish	08123	rocky; 24	32.5	M	good, A	622	74	0.12	Recreational - WCFHS
	08194	rocky; 24	32.9	M	good, A	718	66	0.09	Recreational - WCFHS
	08203	rocky; 24	33.0	M	good, A	698	134	0.19	Recreational - WCFHS
	08212	rocky; 24	32.2	M	good, A	718	66	0.09	Recreational - WCFHS
	13952	rocky; 31	33.6	M	good, A	1053	220	0.21	Recreational - WCFHS
	17934	rocky; 30	35.1	M	good, A	857	71	0.08	Recreational - WCFHS
	23249	rocky; 34	28.2	IM	good, A	1085	153	0.14	Recreational - WCFHS
	23396	rocky; 34	30.2	IM	poor, C, E, F, X	1222	488	0.40	Recreational - private
	25173	rocky; 33	34.8	M	poor, C, D, F, X	67	164	2.45	Recreational - WCFHS
	28751	rocky; 39	25.1	IM	poor, C, D, F, X	280	84	0.30	Recreational - WCFHS
	33859	rocky, 66	26.6	IM	poor, I, J, K, L	476	51	0.12	Recreational - WCFHS
Starry rockfish	11147	rocky; 24	30.5	M	good, A	740	102	0.14	Recreational - WCFHS

Table 4. cont.....

Species	Tag	Capture Habitat and Depth (m)	Length at Tagging (cm)	Estimated Maturity	Fish Condition at Release	Days at Liberty	Distance Moved (km)	Rate of Movement (km/Day)	Re-Capture Vessel
Vermilion rockfish	04077	rocky; 18	32.0	IM	deflated	353	116	0.33	Recreational - WCFHS
	04286	rocky; 18	38.7	IM	deflated	419	114	0.27	Recreational - WCFHS
	04289	rocky; 18	33.3	IM	deflated	384	96	0.25	Recreational - WCFHS
	30192	rocky, pipeline; 49	30.7	IM	poor, C, D, F, H, X	347	54	0.14	Recreational - WCFHS
	30609	rocky, pipeline; na	21.9	IM	moderate, A, F, H, S	624	59	0.09	Recreational - WCFHS
Blue rockfish	23493	rocky; 36	28.4	IM	moderate, F, X	544	92	0.17	Recreational - WCFHS
Olive rockfish	10516	rocky; 26	41.9	M	good, A	625	308		Recreational - WCFHS
	19405	rocky, kelp; 31	35.5	M	good, A	342	510	1.49	Recreational - WCFHS
	22075	rocky, kelp; 34	32.9	IM	good, A	653	359	0.55	Recreational - WCFHS
	28767	rocky; 38	24.7	IM	moderate, F, X	254	94	0.37	Recreational - WCFHS
	32516	rocky, kelp; 45	20.4	IM	moderate, H, L	233	50	0.21	Recreational - WCFHS
	32520	rocky, kelp; 45	24.3	IM	good, A	233	50	0.21	Recreational - WCFHS
	34276	rocky; 68	31.8	IM	good, A	81	62	0.77	Recreational - WCFHS
Lingcod	15512	rocky; 27	46.0	M	good, A	81	67	0.83	Recreational - private
	32594	rocky; 46	40.8 (Male)	IM	good	475	153	0.32	Recreational - WCFHS

grass rockfish, honeycomb rockfish, and kelp greenling (*Hexagrammos decagrammus*) [4, 31-35].

Total observed mortality was 1,532 fish, 4.5% of fish caught. Pre-tagging mortality was higher at 906 fish (2.7%) than post-tagging mortality 656 fish (1.9%). Observed mortality was highest for rosy rockfish (*Sebastes rosaceus*; 31.8%), high for green-spotted rockfish (*S. chlorostictus*; 20%), and lowest for California scorpionfish (0.04%). Mortality was not observed for: black (*S. melanops*), china (*S. nebulosus*), nor canary rockfish; not observed for lingcod, cabezon, giant seabass, ocean whitefish, nor California halibut. Pre-tagging mortality was relatively high for rosy rockfish (16.5%) and freckled rockfish (*S. lentiginosus*, 14.3 %). Post-tagging mortality was relatively high for rosy (15.6%) and greenspotted (14.3%) rockfish (Table 3).

For all recaptured fish about 50% were recovered at distances greater than 5 km from the original tag/release sites; the number of fishes recaptured diminished with increasing distance from tagging/release site (Fig. 2). Long distance movements of 50 km or more were observed among 9 spe-

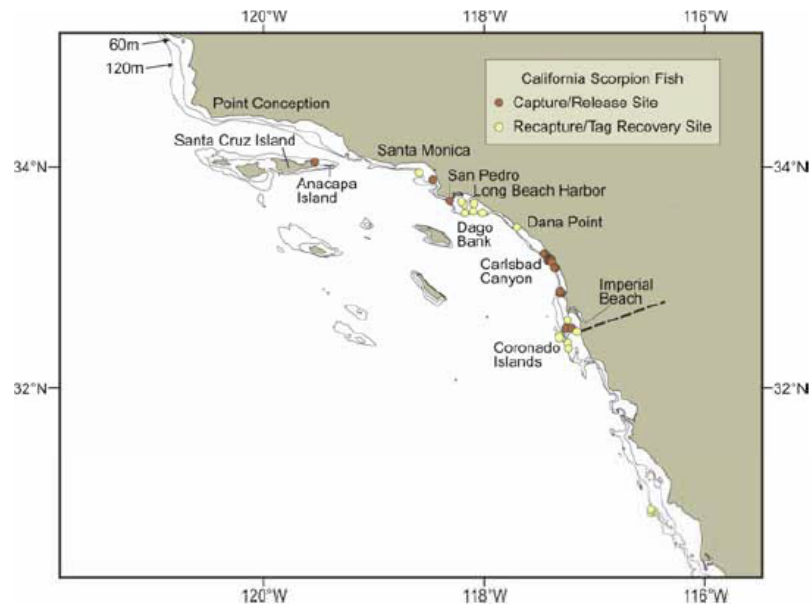
cies (Table 4). The longest straight line distances estimated were 488 km for copper (*Sebastes caurinus*) and 510 km for a mature olive rockfish (*S. serranoides*).

Linear regression analysis revealed no significant correlation between DAL and distance from tagging site for 8 species tested (brown, gopher; copper, vermilion, blue, olive rockfish, California scorpionfish, and lingcod).

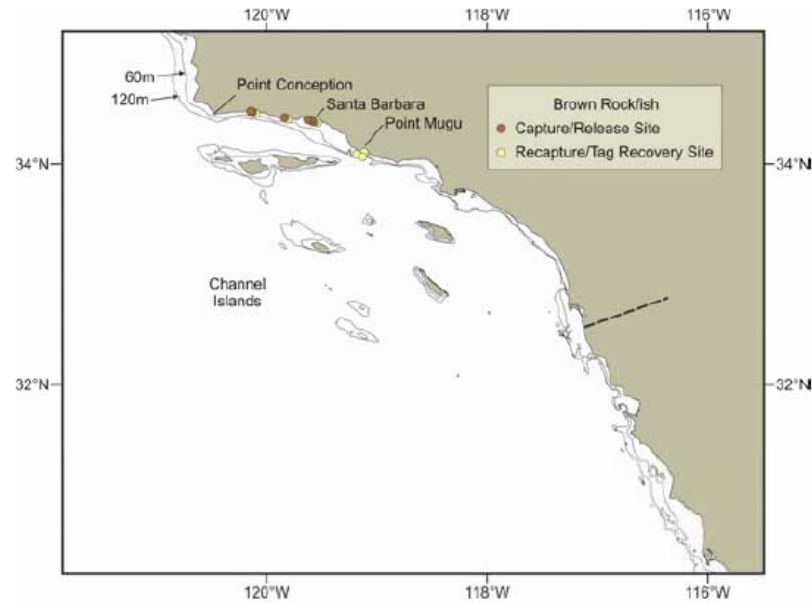
Individuals from 9 species moved 50 km or more. Fish of 7 species (California scorpionfish, n=4; gopher rockfish, n=1; copper rockfish, n=4; starry rockfish, n=1; vermilion rockfish, n=4, blue, n=1, and olive rockfish, n=4) tagged in nearshore areas were recaptured offshore or at offshore islands as described below.

Of 257 California scorpionfish recaptures, 155 (67%) were within 5 km of their original tag/release site (2 - 2,126 DAL) and 76 (33%) of these were within 1 km of the tagging site. California scorpionfish were caught primarily in areas nearshore between Pt. Mugu and San Diego, and near the Channel Islands, which includes possible important Southern California spawning grounds (Santa Monica Bay, Dago





**Fig. (3).** Tag and recovery sites for 17 tagged mature California scorpionfish (*Sebastes guttata*) with movement of at least 50 km off southern Calif. and Baja Calif., Mexico.



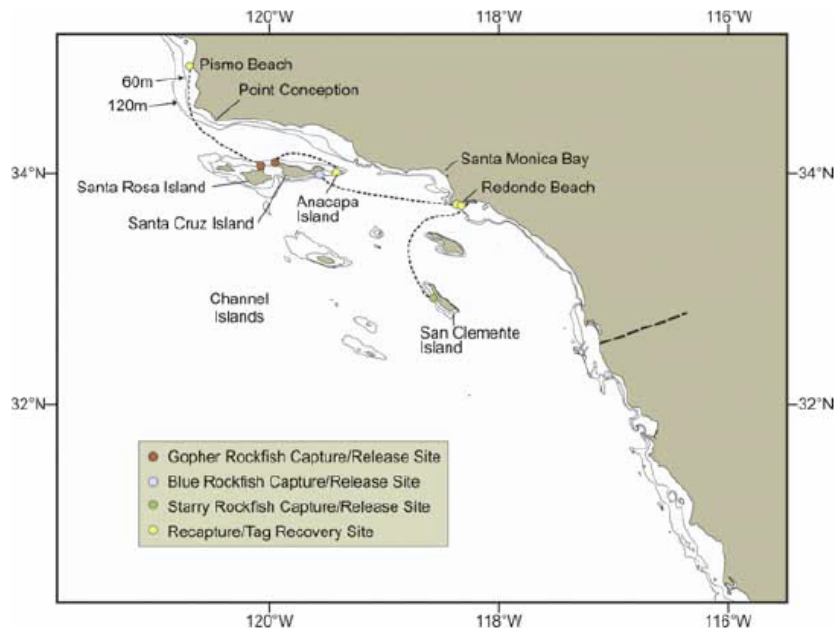
**Fig. (4).** Tag and recovery sites for 6 brown rockfish (*Sebastes auriculatus*) with movements of at least 50 km.

Bank near Long Beach Harbor, Anacapa Island, and the Coronado Islands [31]). Seventeen mature [31] California scorpionfish were recaptured at distances of 50 km or more (68 - 1,788 DAL) and 7 of these fish were recaptured at Dago Bank off Long Beach Harbor during May to December. Movements of fish among spawning grounds were observed. A scorpionfish tagged in April between Santa Cruz and Anacapa Islands was recaptured the following June off Long Beach (129 km, 424 DAL). Seven scorpionfish had recapture distances up to 200 km along coastal areas between Carlsbad and Baja California. Recoveries include 1 fish tagged in February off San Pedro, approximately 16 km from Dago Bank, which was recaptured off the Coronado Islands, Baja California (just south of the U.S.-Mexico border) in July (511 DAL; Fig. 3, Table 4). The most rapid movement rates from tagging/release sites to recapture sites were ob-

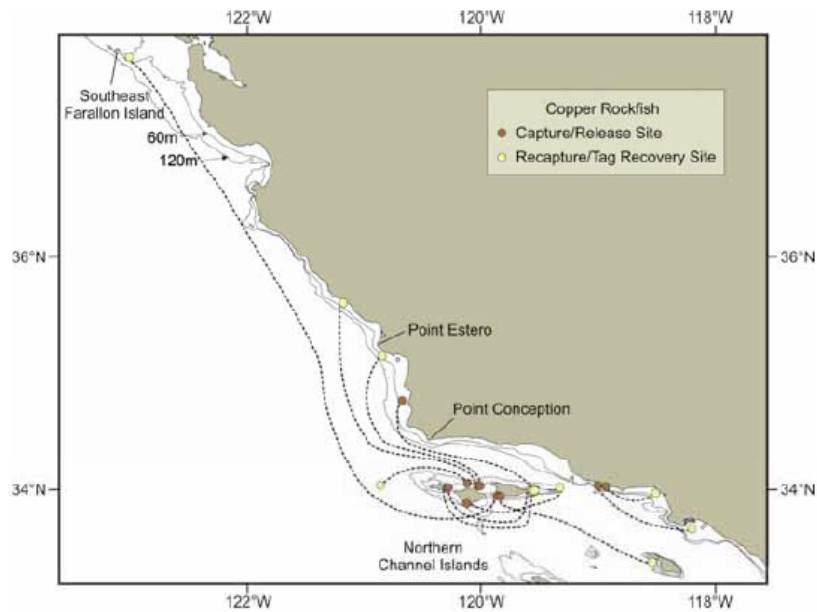
served for 3 mature California scorpionfish averaging speeds of 1.0, 1.1, and 2.2 km/day (Table 4).

The majority (n=161; 70%) of recaptured brown rockfish were within 5 km of the tag/release site and 50% were within 1 km (2 - 2,603 DAL). Long distance movements (>50 km) were observed for 6 brown rockfish and included movements along shore of up to 89 km (45 - 793 DAL) between points north of Santa Barbara to off Pt. Mugu (Fig. 4, Table 4). Movement rates >1 km/day were observed for two brown rockfish.

Fifteen (60%) of the recaptured gopher rockfish (*S. carnatus*) were within 1 km of the tag/release sites (19 - 636 DAL). One mature [33] gopher rockfish moved 109 km from east of Santa Rosa Island to nearshore south of Pismo Beach in Central California (583 DAL, Fig. 5, Table 4).



**Fig. (5).** Tag and recovery sites of a mature gopher (*Sebastes carnatus*; 109 km), a mature starry (*S. constellatus*; 102 km), and a mature blue rockfish (*S. mystinus*; 92 km).



**Fig. (6).** Tag and recovery sites of eleven copper rockfish (*Sebastes caurinus*; 7 at size of maturity, 4 immature) with movements at least 50 km.

Fourteen (37%) of the recaptured blue rockfish (*S. mystinus*) were within 1 km of their tag/release site (74% within 5 km of tag/release sites; 42 - 688 DAL). Long distance movement was observed for an immature [4, 33] blue rockfish tagged between Santa Cruz and Anacapa Islands and recaptured in nearshore waters off Santa Monica (92 km, 544 DAL, Fig. 5, Table 4).

Seven (39%) of the recaptured starry rockfish (*S. constellatus*) were within 1 km of the tag/release site (67% within 5 km their tag/release sites; 30 - 1,263 DAL). Long distance movement was observed for a mature [33] starry rockfish tagged off San Clemente Island, recaptured nearshore off Redondo Beach (102 km, 740 DAL, Fig. 5, Table 4).

Long distance movements were observed for copper rockfish recaptured between coastal and offshore island areas, and among offshore islands (Fig. 6). Of 81 copper rockfish recaptured, 62 (76%) were recaptured within 5 km of the tag/release sites (49% within 1 km of the tag/release site; 11 - 1,513 DAL). Two mature [4, 33, 36] copper rockfish, tagged off Santa Cruz Island were recaptured northward off the central California coast at 164 km (67 DAL) and 220 km (1,053 DAL). Mature copper rockfish tagged between Santa Rosa and San Miguel Islands and off the central California coast were recaptured in the same State Marine Reserve off Santa Cruz Island. Of copper rockfish tagged off Gull Island on the west side of Santa Cruz Island, an immature [4, 33, 36] fish was recaptured southward 153 km (1,085 DAL) at

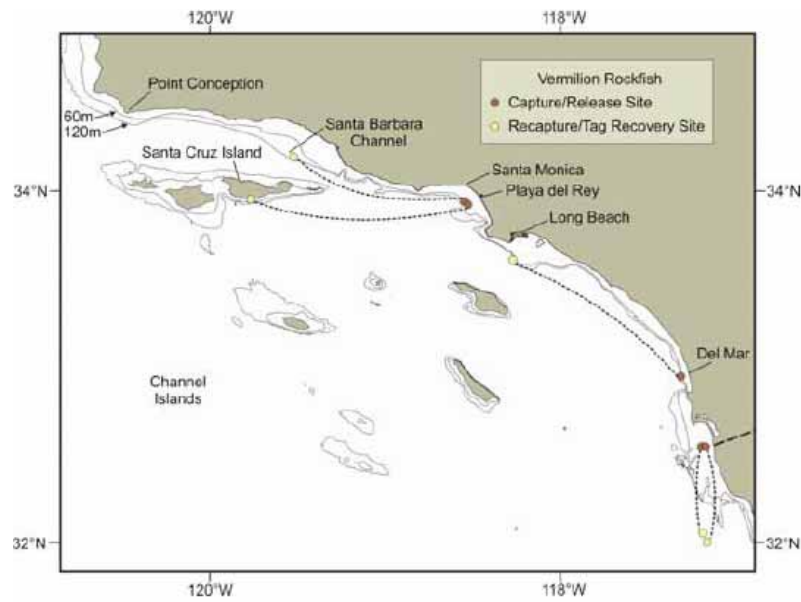


Fig. (7). Tag and recovery sites of 5 mature vermilion rockfish (*Sebastes miniatus*) that moved at least 50.

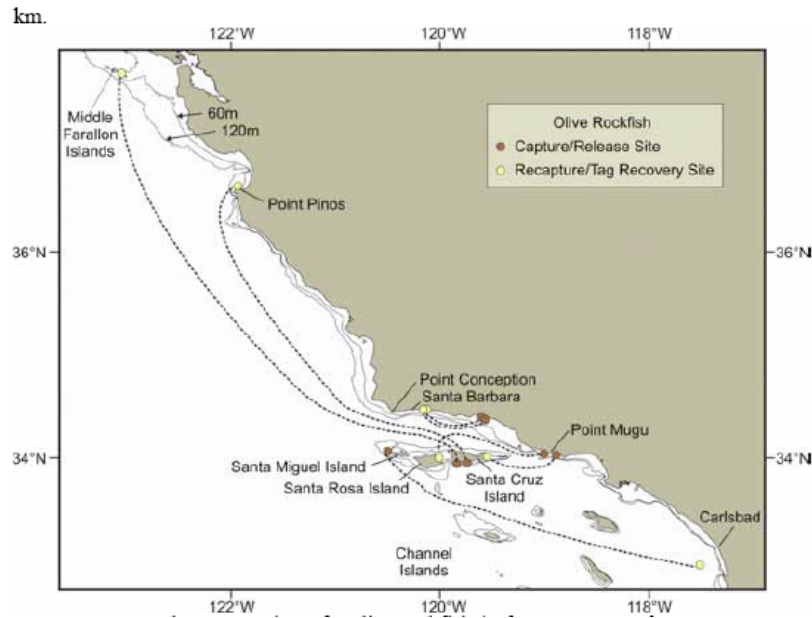


Fig. (8). Tag and recovery sites of 7 olive rockfish (*Sebastes serranoides*; 2 mature, 5 immature).

Santa Catalina Island and another immature was recaptured northward 488 km (1,222 DAL) at Southeast Farallon Island off San Francisco (Fig. 6, Table 4).

Of 51 recaptured vermilion rockfish, 38% were recaptured less than 1 km from their original tag/release sites (72% within 5 km; 3 - 1,694 DAL). Five mature [4, 32] vermilion were recaptured at long distances along coastal areas and at the offshore islands (Fig. 7). Two immature vermilion rockfish were tagged off Playa del Rey; one was recaptured off Santa Cruz Island (114 km, 419 DAL) and the other in the Santa Barbara Channel (96 km, 384 DAL, Fig. (7), Table 4).

Of 101 lingcod recaptured, 77% were within 5 km of the tag/release site (1 - 160 DAL); 51% of all lingcod recaptured were less than 1 km from tag/release site. An immature [37]

lingcod was tagged in nearshore waters north of Oceanside and recaptured 153 km (475 DAL) northward off Malibu (Table 4).

Of 98 recaptured olive rockfish, 68% were within 1 km of the original tag/release site (2 - 396 DAL); however, olive rockfish were also recaptured at long distances (50 - 510 km, Fig. 8). Movement was confirmed from the nearshore coastal waters to offshore islands, from offshore islands to nearshore areas, and among offshore islands. A mature [4, 38] olive, tagged north of San Miguel Island, was recaptured off Carlsbad (308 km, 625 DAL); an immature olive was tagged off Santa Cruz Island and recaptured off Point Pinos near Monterey, California (359 km, 653 DAL). A mature [4, 38] olive, tagged off Santa Cruz Island, was recaptured at Middle Farallon Island off San Francisco (510 km, 342 DAL).

This was longest recapture distance of any fish we tagged (Fig. 8, Table 4).

## DISCUSSION

### Observed Mortality Rate and Effects of Handling

The low observed mortality rate in this study was consistent with those of Shaw *et al.* [30]. They used different tagging methodologies on rockfish off Vancouver Island, Canada and, similarly to this study, found higher pre-tagging mortality (5%) than post-tagging (1.9%). They had higher mortality rates of 21% pre-tagging and 12.9% post-tagging at Queen Charlotte Sound which were attributed to smaller sample sizes, but could have been associated with physiological or behavioral differences in species tagged.

Researchers have found species-specific responses to barotrauma [39-41]. Hannah and Matteson [40] used *in situ* video to examine the behavioral effects of barotrauma resulting from hook-and-line captures at 12-124 m depth for 9 rockfish species and found behavioral impairment to be depth related but variable among species. They documented high re-submergence success rates for black, yellowtail, and quillback rockfish (*S. maliger*) across all depths sampled, and concluded that catch and release of these species did not result in high rates of short-term mortality. Because of high catch and release mortality rates in blue rockfish, yelloweye, and canary rockfish, they did not expect these fish likely to survive discard (catch and release). Jarvis and Lowe [41] found short-term survival varied by species from 36-82% and that condition at capture was not the best predictor of short-term survival in rockfish. They concluded that short-term survival of rockfish increased with decreased surface holding time.

Post-release responses to capture and handling, including effects on recovery rates and potential mortality are unknown in this study, but we note that handling time was kept to a minimum. We acknowledge that displacement resulting from capture and release may have affected movement of some of our tagged fish.

### Site Fidelity

We found limited motility over time for most rocky reef species in nearshore and offshore island areas (5 km median recapture distance). We infer that most groundfish movement/motility or home range is confined to nearby rocky reef habitat [4, 25, 37, 42, 43] which is consistent with other groundfish studies [44-46]. However, we also observed long range movements not previously detected which indicates the need for this type of large scale research project to better understand groundfish behavior, movements, and habitat needs.

Various natural rocky reef [11, 12] and artificial areas (*e.g.*, pipeline, oil platforms) [47-51] provide important habitat and opportunity for residency to rockfish assemblages in temperate waters off California. Recently, Lowe *et al.*, [21] examined movement patterns and site fidelity for 15 groundfish species including both shallow and deep shelf rockfish, cabezon, and lingcod in relation to 3 Santa Barbara Channel oil platforms. Acoustic telemetry was used to monitor 100 fish over a study period of 655 - 714 DAL. After 6 days,

30% of tagged fish were not detectable, which was attributed primarily to post release mortality and emigration. The majority of fish tagged were vermilion (n=61) and, in this study, the most mobile. Although sample sizes of other species were small, and the authors noted the likelihood of individual variation in site fidelity, site fidelity was highest for flag rockfish (*S. rubrivinctus*) treefish, widow rockfish, and lingcod which exhibited the highest site fidelity in the study - 71% [20]. Lowe *et al.*, [21] found that site fidelity near oil platforms was moderate for cabezon, rosy rockfish, and brown rockfish, and was lowest for bocaccio and for blue, greenspotted, starry, vermilion, and copper rockfish.

### Long Distance Movements/Motility

We report copper rockfish of mature size that moved as far as 220 km, in contrast to previous tagging studies that have indicated very limited movement (2.8 km or less) [36, 37]. We also report new maximum movement/motility distances from two mature olive rockfish (308 and 510 km). Love *et al.* [4] and Love [24] reported a maximum recovery distance of 20 miles (33 km) for olive rockfish. Long distance (>50 km) movement/motility is likely to have implications for definition of stock discreteness. While percentages of tagged fish recaptured at long distances in this study were relatively small, this movement/motility provides important insight into fish biology and habitat use which is important when considering Marine Protected Area size and spacing.

We observed inshore and offshore long distance movement/motility of mature scorpionfish, which may be seasonally related to reproduction. Love *et al.*, [31] and Hartmann [36] suggested that California scorpionfish migrate to traditional grounds for spawning and remain there for brief periods.

As observed in this study, traditional tagging has shown that lingcod remain very close to tag/release sites [20, 37, 43, 52], but are known to make extensive migratory movements related to spawning [41, 53]. Lea *et al.*, [43] reported one recaptured lingcod at 124 km from the tag/release site. This species has been tracked, using acoustic tagging, moving up to 239 miles (385 km) [53].

Long distance movement/motility (beyond home range) has been reported for shallow demersal and shallow shelf rockfish, as well as, deeper water semi-pelagic rockfish [54-56]. This movement/motility has generally been attributed to ontogenetic shift: brown [4, 42, 56], vermilion [20], yellowtail rockfish [54], and bocaccio [36, 51]. We assume some movement/motility that we detected could be attributed to ontogenetic shift as we focused on catching fish for tagging in shallow waters (mean depth = 29 m; range 4 to 116 m).

We observed long distance movement/motility of mature fish of six species of rockfish (brown, copper, gopher, olive, starry, and vermilion). While 50% of the brown rockfish tagged in the present study were recaptured within 1 km of their tag/release sites, six mature fish were recaptured at distances up to 90 km (see Table 4).

Long distance movement/motility of two mature gopher rockfish was observed with one recaptured among the Channel Islands (50 km) and one tagged/released offshore at Santa Rosa Island and recaptured off the central California

coast (110 km, see Table 5). Previously, only movements of less than 3 km have been documented for gopher rockfish [43, 57].

Movement/motility of starry rockfish was previously little known. We documented a mature starry rockfish recapture at a minimum of 100 km from offshore San Clemente Island to nearshore off the southern California coast.

## CONCLUSIONS

Using tag returns, this study confirms that large sample sizes are needed to reveal the wide range of fish movement patterns. Our initial captures and tag-recaptures indicate specific regions are preferred habitat for rockfish species. Such areas are: between San Miguel and Santa Rosa Islands, Santa Cruz and Anacapa Islands, and State Marine Reserves on the east and west sides of Santa Rosa and Santa Cruz Islands. This may also indicate that fish require use of more than one such prime habitat during a lifetime. Fish moved, some over long distances, to shared recapture sites, as seen in copper and olive rockfish. Movement between offshore and inshore habitat such as movement from the Channel Islands to nearshore central and southern California are indicative of specific importance of particular areas.

We observed that groundfish move among areas of varying ecological importance and that the use of multiple areas by individual fishes underscores the importance of fisheries and spatial management to protect and improve yield and to ensure conservation of rockfish and other groundfish species. Finally, we infer from tagging results that long distance movements may be more prevalent and probably important to groundfish species than previously assumed.

## CONFLICT OF INTEREST

None declared.

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