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Movements of Black Rockfish (Sebastes melanops) in Carmel Bay, California

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MOVEMENTS OF BLACK ROCKFISH (*Sebastes melanops*) in

CARMEL BAY, CALIFORNIA

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The Degree

Master of Science
In
Marine Science

by

Kristen Marie Green

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CERTIFICATION OF APPROVAL

I certify that I have read *Movements of Black Rockfish (Sebastes melanops) in Carmel Bay, CA* by Kristen Marie Green, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree: Master of Science in Marine Science at San Francisco State University.

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MOVEMENTS OF BLACK ROCKFISH (*Sebastes melanops*) in

CARMEL BAY, CALIFORNIA

Kristen Marie Green

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2010

Movements of 23 sub-adult and 10 juvenile black rockfish (*Sebastes melanops*) implanted with acoustic transmitters were monitored during 16 months in Carmel Bay, California. Most tagged sub-adult black rockfish (14 fish) were resident to the study area (>75% time). The remaining 9 sub-adult black rockfish had low residency (<35% time). All tagged juvenile black rockfish vacated the study area within 3 months of release. When tagged fish were in the study area, mean activity space was < 0.4 km^2. From October to May, sub-adult black rockfish during daytime moved to deeper waters offshore, returning at night. In the summer, diurnal movements of sub-adult black rockfish decreased, perhaps due to locally abundant food resources associated with seasonal upwelling. The black rockfish is currently managed with other nearshore, residential rockfishes, yet the complex movement patterns of black rockfish described in this study should be considered in a species-specific management plan.

I certify that the Abstract is a correct representation of the content of this thesis.

____________________________________ __________

Chair, Thesis Committee Date

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INTRODUCTION

In the United States, the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) of 1976 is the primary law governing federal fisheries management; it established a system of management councils and processes. In 1996, the MSFCMA was amended by the Sustainable Fisheries Act to increase conservation in U.S. fisheries. The Sustainable Fisheries Act mandates that the federal government prevent overfishing and rebuild already overexploited fish stocks. Various states have adopted similar legislation requiring sustainable fisheries management for fisheries in state waters (in California, less than 3 miles from the coastline). The California legislative effort resulted in the creation of the Marine Life Management Act (MLMA) in 1999. The goals of the MLMA are to prevent overfishing, protect and restore fish habitat, develop information for management decisions, and rebuild fish stocks in California waters (Weber and Heneman 2000).

The MLMA requires that the California Department of Fish & Game (CDF&G) develop fisheries management plans that incorporate the legislative goals set forth for the management and conservation of California's commercial and recreational fisheries (Weber and Heneman 2000). One of the major fisheries in California is the nearshore finfish fishery, which contains economically valuable species caught by commercial and recreational fishermen. Under MLMA legislation, the nearshore finfish fishery was indentified as a top priority for the development of a fishery management plan. In response, the CDF&G selected 19 commercially-important species in the nearshore finfish fishery for a fishery management plan. However, there are few data available to develop management plans for these species. Information about the life history, distribution, abundance, and movements is required to complete management plans for each of these 19 species.

Black rockfish (*Sebastes melanops*) are among the 19 species in the nearshore finfish fishery slated for an individual fishery management plan. Black rockfish consistently rank among the state's top ten landings by weight in the recreational finfish fishery (PMFC 1998, NMFS 2008). In 2003, the Pacific Fisheries Management Council implemented the Rockfish Conservation Area, a depth-related restriction zone in offshore waters, and in 2008, a statewide recreational salmon fishery closure. These closures shifted additional fishing pressure to nearshore habitats containing species such as the black rockfish. In addition to creating an urgency to fulfill the requirements of the MLMA legislation, this increase in nearshore fishing pressure created additional urgency for the development of a fishery management plan to prevent overfishing of the black rockfish. However, the CDF&G lacks the information about stock size, natural mortality, and life-history characteristics needed to create species-specific fishery management plans. Currently, these data are not available for black rockfish populations in California.

The lack of available scientific information to develop traditional fisheries management plans for many nearshore species has led the CDF&G to consider alternative management techniques such as the use of Marine Protected Areas (MPAs). In traditional fisheries management, managers rely on the accurate assessment of population abundances and life history parameters to approximate sustainable species' harvest guidelines. However, even if sufficient biological information is available to create harvest guidelines for a species, traditional fisheries management has limitations. For example, managers rarely have the ability to predict unexpected decreases in population abundances (e.g. during poor environmental conditions), and adjust harvest guidelines accordingly (Lauck 1998). As a result, overexploitation of stocks can occur even when harvest rates are sustainable. MPAs offer complete protection from fishing, and may be a better option for managing species for which insufficient information exists to create accurate harvest guidelines. MPAs also provide permanent protection from fishing, thus reducing the need to adjust management guidelines during years when poor environmental conditions may cause declines in stock.

MPAs, in addition to being a useful short-term fisheries management strategy, offer long-term conservation benefits. The reduction of fishing mortality in an MPA may cause an increase in the number and size of adult fishes (Roberts and Polunin 1991, Dugan and Davis 1993, Bohnsack 1996). Increases in the number of fishes inside MPAs can replenish areas outside the MPA boundaries via adult movements (Carr and Reed

1993, Russ and Alcala 1996, Halpern and Warner 2003). Also, MPAs allow individual fishes to grow to large sizes and reach maturity, thus restoring the natural age structure of a population (Roberts et al. 2005). This increase in fish size, and thus reproductive potential, produces increased larval export to areas outside the MPA (Quinn et al. 1993, Man et al. 1995, Nowlis and Roberts 1999, Berkeley et al. 2004b). If populations of fishes are restored to greater densities and natural age-structure under MPA protection, then adult movements and larval export from these populations can supplement populations in areas outside the MPA.

One of the keys to the successful use of MPAs as a management tool is the extent to which fishes stay in the reserve. Thus, an accurate understanding of the movement pattern of a species is critical for the establishment of successful MPAs. To increase or maintain population abundances, an MPA boundary must encompass the daily and seasonal movements of the species designated for protection. Information about species' short and long-term movement patterns allows managers to design an MPA to encompass the movements that an individual makes to feed, reproduce, and avoid predation over its lifespan (Starr 2002, Lowe et al. 2003, Topping et al. 2006).

Historically, fisheries catch data and *in situ* SCUBA observations have provided general information about black rockfish movements and distribution. Black rockfish occur from the Aleutian Islands in western Alaska to Pt. Conception in southern California, primarily in nearshore coastal areas (Eschmeyer et al. 1983). Black rockfish larvae are planktonic for up to five months (Love et al. 2002). After this pelagic larval duration, first-year black rockfish recruit to nearshore kelp beds, seagrasses, tide pools, and estuaries during the summer (Boehlert and Yoklavich 1983). Young-of-the-year (YOY) black rockfish move from the algal canopy to benthic habitat during transition to the juvenile stage (Leaman 1976, Anderson 1983, Carr 1983). Sub-adult and adult black rockfish are semi-pelagic, inhabiting the water column and aggregating near the bottom above rock habitat in depths less than 30 m (Love et al. 2002).

Movement patterns of black rockfish have been reported from tag-recapture studies, which provide information about net movements of tagged fishes between a release and a recapture location. The results of published studies indicate that the majority of black rockfish recaptures occur within 5 km of the release location (Barker 1979, Coombs 1979, DeMott 1983, Gowen 1983, Matthews and Barker 1983, Culver 1986, Starr and Green 2007). As a result, black rockfish often are categorized with other residential nearshore rockfish species that exhibit limited movements. Yet, in these same tag-recapture studies, up to 10% of black rockfish were recaptured > 10 km from release, with some recaptured as far as 600 km from release (Barker 1979, Coombs 1979, DeMott 1983, Gowen 1983, Starr and Green 2007). These discrepancies in black rockfish movement in tag-recapture studies have potentially contrasting management implications. On one hand, black rockfish may have strong site fidelity, and be an appropriate candidate for MPA protection. Alternatively, black rockfish may be eliminated as a candidate for MPA protection based the potential of the species for long-distance migrations.

The use of acoustic telemetry can provide finer-scale understanding of the movements of black rockfish, thus clarifying differences between tag-recapture studies. Acoustic telemetry studies allow researchers to collect detailed movement data at hourly and daily time scales, providing insight into the habitat associations, seasonal migrations, ontogenetic shifts, and feeding requirements of a species (Holland et al. 1996, Zeller 1999, Meyer 2000, Lowe et al. 2003). Researchers have been successful in determining home ranges and habitat associations of several rockfish species, e.g. brown (*Sebastes auriculatus*), copper (*Sebastes caurinus*), quillback rockfish (*Sebastes maliger*) (Matthews 1990a, 1990b), yellowtail rockfish (*Sebastes flavidus*) (Pearcy 1992), bocaccio (*Sebastes paucispinis*) and greenspotted rockfish (*Sebastes chlorosticus*) (Starr et al. 2002). More recently, Lowe et al. (2009) conducted an acoustic telemetry study to quantify the site fidelity of greenspotted (*Sebastes chlorosticus*), vermilion (*Sebastes miniatus*), copper (*Sebastes caurinus*), and widow (*Sebastes entomelas*) rockfishes to offshore oil platforms in southern California. The only published acoustic telemetry study of black rockfish was undertaken by Parker et al. (2007); they established preliminary information on home ranges and vertical movements of this species off Oregon.

Few detailed movement data for the black rockfish exist, and most information is derived from studies conducted in Alaska, Washington, and Oregon. To provide information about the movement patterns of black rockfish in central California, I implanted acoustic transmitters in sub-adult and juvenile black rockfish in Carmel Bay, California. Sub-adult black rockfish were tagged to represent the sizes of black rockfish that are most frequently caught in the recreational fishery in central California (Stephens et al. 2006, Starr and Green 2007). The specific objectives of my study were to: (1) describe the daily and seasonal movement patterns of black rockfish; (2) quantify the home range and residence times of black rockfish; and (3) compare movements among juvenile and sub-adult black rockfish. This study was conducted in a small area of the black rockfish geographic range, but provided the first detailed movements of black rockfish in California, and will aid in planning for the long term sustainability of the black rockfish fisheries along the entire west coast.

MATERIALS AND METHODS

Study site

The study site was a 4 km by 2 km area located within Carmel Bay at the southern end of the Monterey peninsula in central California (Fig. 1). The study area boundaries began 1 km northwest of Pescadero Point and extended to Carmel Point in the south, and extended from the 5 to the 40 m isobath (Fig. 2). Carmel Canyon, a deep submarine canyon, bisects the southern end of Carmel Bay near Carmel Point. This canyon refracts long period ocean swells, focusing wave energy north toward the study area and south toward Pt. Lobos (MBNMS 1992).

The nearshore environment in Carmel Bay is typical of temperate marine ecosystems on the central coast of California. Benthic habitats in Carmel Bay include rock reefs and sand flats mixed with occasional rock outcrops. Rock reefs in the area contain large boulders and rock shelves up to 5 m in vertical height. Sand flats contain low relief habitat, with rock outcrops of 1–2 m in vertical height. Seasonal beds of canopy forming kelps (*Macrocystis pyrifera*, *Nereocystis luetkeana)* and perennial understory algae (*Pterygophera californica)* are abundant in the area.

Three MPAs, established in September 2007 are located in Carmel Bay (Fig. 1). The Carmel Bay State Marine Conservation Area (SMCA) allows recreational fishing but prohibits commercial fishing. The Carmel Pinnacles State Marine Reserve (SMR) and the Pt. Lobos SMR prohibit take of all marine species. The majority of the study area was within the boundaries of these MPAs.

Acoustic Monitoring

This project was part of a larger set of acoustic telemetry projects conducted at Moss Landing Marine Laboratories. As such, the study area contained an overlapping array of acoustic receivers (Vemco 69-kHZ omni-directional VR-2, Vemco Ltd., Nova Scotia, Canada; Fig. 2). In 2005, 29 acoustic receivers (Vemco 69-kHZ omnidirectional VR-2 Vemco Ltd., Nova Scotia, Canada) were deployed along the coastline between Pescadero Point and Carmel Point, in depths of 7 to 40 m (Fig. 2). Additional receivers were deployed in 2006 to cover the Carmel Pinnacles area. Receivers were individually anchored to a 40-kg mooring weight using a line that extended approximately 5 m above the sea floor. A subsurface float was attached on a line above the receiver to maintain line tension and keep the receiver upright in the water column. Temperature loggers (Onset StowAway Tidbit Underwater Data Loggers) were deployed at different depths on the same line as receivers. Nine temperature loggers were deployed among 3 depth categories, 12–16 m, 18–24 m, and 26–34 m, at 4 locations in the study area (Fig. 2).

Receivers were programmed to detect the unique signals emitted from acoustic transmitters implanted in fishes in the study area. Transmitter signal information from fish (time, date, fish ID code, and depth) was stored by the receivers. Receivers were retrieved by divers using SCUBA every four to six months. Receiver data were downloaded, and transferred to a Microsoft Access database for analyses.

Fishing and Tagging

Black rockfish were captured in the study area between August 2006 and July 2007. Black rockfish were considered sub-adults if total length of an individual was between mean length at 1st maturity (25.0 cm) and mean length at 50% maturity (41.0 cm for females, 36.0 cm for males) as described by Wyllie Echeverria (1987). Black rockfish were considered juveniles if total length of an individual was less than length at 1st maturity (25.0 cm). Black rockfish < 20.0 cm were not tagged to avoid transmitter to body weight ratios that would cause undue stress on the fish. The sex of sub-adult black rockfish was determined by the presence or absence of external papillae (Moser 1967); papillae of juvenile fish were too small to determine sex based on external characteristics.

In the fall of 2006, equal numbers of female and male sub-adult black rockfish were targeted for capture, implanted with transmitters, and released in the study area. In the summer of 2007, juvenile black rockfish were captured, and implanted with transmitters to compare movements between two size classes of black rockfish. Additional sub-adult male black rockfish also were caught and implanted with transmitters during the summer of 2007.

Fishing for black rockfish was conducted with a rod and reel. Fishing tackle consisted of an unbaited barbless hook (hook size 4/0) tied with a shrimp fly. Fish tagging procedures were modeled after other successful fish tagging studies (Starr et al. 2000, Starr et al. 2004). Caught black rockfish in good condition were selected for tagging and placed in a 10% solution of MS-222 (Tricaine Methane Sulfonate, Finiquel brand) for anesthetization. Once anesthetized, fish were transferred to the tagging board, placed ventral side up, and scales were scraped off in a 1.5 cm^2 area between the pectoral fins and anus. A small incision was made in the scraped area, and a sterilized tag was implanted into the peritoneal cavity. The incision was closed using a surgical stapler and stainless steel staples. If necessary, barotrauma symptoms were relieved by venting the swim bladder using an 18-gauge hypodermic needle. An external T-bar anchor tag imprinted with a unique tag identification number along with Moss Landing Marine Laboratories contact information was implanted into the dorsal musculature of the fish in case of angler recapture. Post-surgery, each fish was placed in a live well until fully recovered (i.e. displaying upright, oriented swimming motions). Tag number, total length (TL), sex, and condition were recorded for each fish before release. Fish were released at the location of capture, and fishing effort was distributed throughout the study area to ensure individual receivers were not oversaturated with transmitter signals.

Two types of acoustic transmitters were used in this study: Vemco V13P-1H-S256 and V9P-2L-S256 (Vemco, Inc., Shad Bay, Nova Scotia). V13 transmitters implanted in sub-adult rockfish were 13 mm wide by 36 mm long, with a weight in water of 6 g. V9 transmitters were implanted in juvenile fish and were 9 mm wide by 20 mm long, with a weight in water of 2 g. Each transmitter had a unique ID code and was programmed to produce a signal at 69 kHz frequency. Transmitters emitted coded signals at a random interval between 90 and 270 seconds. This random delay in signal emission decreased the possibility of acoustic collisions between tags, and also extended the battery life of the tag.

Thirteen female sub-adult black rockfish, from 29.0 to 41.5 cm TL and 10 sub-adult male black rockfish from 29.0 to 35.0 cm TL were implanted with acoustic transmitters (Table 1). Ten juvenile black rockfish from 20.0 to 25.0 cm TL were implanted with transmitters in summer 2007 (Table 1). All 10 juvenile black rockfish and 16 of the 23 sub-adult black rockfish carried pressure-coded depth transmitters, which transmitted the depth of the tagged fish in the water column. Data were collected and analyzed from sub-adult and juvenile black rockfish in Carmel Bay from August 2006 to January 2008.

Detection ranges of VR2 Receivers

The detection range of VR2 receivers was affected by physical barriers (bottom topography and submerged vegetation) and environmental variables (sea state and biological and anthropogenic noise) (Simpfendorfer et al. 2002). Range testing to determine the reception ranges of VR2 receivers in Carmel Bay was conducted in 2006 and 2007. Detection ranges of 150 m were conservatively estimated for VR2 receivers in Carmel Bay (Greenley 2009). Reference transmitters within a receiver detection range of 150 m were detected for 100% of the days, and 92% of the hours during deployment (Greenley 2009). Based on these range testing results, black rockfish recorded at a receiver location in this study were assumed to be within a 150 m radius of the receiver.

Environmental Data

Environmental data were acquired from the historical data archives of the National Oceanic Atmospheric and Administration (NOAA) National Weather Service. Wave height (m) and barometric pressure (mb) were recorded from Monterey Buoy 46042, (http://www.ndbc.noaa.gov). Tidal height (m) was recorded from Monterey station 9413450, (http://tidesonline.nos.noaa.gov/). Data for day length were acquired from the historical archives of the US Naval Observatory from Carmel, California (http://aa.usno.navy.mil/data/). Water temperature data were collected from temperature loggers deployed on receivers in the study area. Temperature loggers were programmed to record water temperature every 15 minutes.

Data Analyses

Residence times for black rockfish were calculated based on the number of days tagged fish were present in the receiver array during the study period. Daily presence in the array was defined as ≥ 2 detections in a 24-h period, termed a 'fish-day.' Residence time for black rockfish was calculated by dividing the total fish-days recorded for each individual fish by the total days available in the battery life of the transmitter (445 days from tag activation). One exception was Tag 228, which was recovered in the recreational fishery. In this case, residence time was reported as a percentage of days at liberty. Time periods when receivers were lost in storms were excluded when estimating residence times if data loss occurred on the primary receiver(s) used by a fish.

Statistical analyses were conducted to test if residence times were different between female and male sub-adult black rockfish and among different sizes of sub-adult black rockfish. Parametric tests were used for all statistical tests except when assumptions of normality and equal variance were violated. In those cases, non-parametric tests were used. A Mann-Whitney U-test was used to test the proportion of days that female sub-adult black rockfish were present versus the proportion of days that male sub-adult black rockfish were present during the study period. Regression analyses were used to test the proportion of days present against fish length for all fish combined, and for males and females separately.

Fish were assumed to be absent from the study area if there were fewer than 2 detections in a 24-h period for that individual. Absences were recorded for black rockfish during time at liberty, i.e. the date of release to date of final transmission for each individual. When transmissions ceased for an individual, (due to emigration, capture, or mortality), time at liberty for that individual ended. Number and duration of absences were calculated for each fish during time at liberty. A Mann-Whitney U-test was used to test differences between the duration of absences (in days) between female and male sub-adult black rockfish. The percentage of days absent for each fish was calculated as the number of days absent divided by the total days at liberty for each fish.

To understand how emigration, fishing rates, and natural mortality affected abundances of black rockfish, I estimated the survivorship for sub-adult black rockfish in Carmel Bay. The number of tagged sub-adult black rockfish predicted alive after one year was generated using the equation, $N_t = N_0 * e^{(-f + m)t}$ (Wilson and Bossert 1971). Inputs to the equation were N_0 (the number of fish present at the beginning of a one-year period), f (instantaneous fishing mortality), and m, (instantaneous natural mortality for black rockfish as reported from the literature, i.e. Wallace and Taggart 1999, Ralston and Dick 2003, and Sampson 2007). Black rockfish natural mortality values ranged from 0.1 to 0.2 in the literature, but I also tested higher instantaneous natural mortality values up to 0.4. For instantaneous fishing mortality, I tested values between 0.06 (based on 1 fish captured in the recreational fishery/18 total fish) as well as a double this rate (0.12) and triple this rate (0.18). N_t, the number of tagged sub-adult black rockfish that were predicted to be alive after one year, was compared to the number of tagged sub-adult black rockfish detected in the study area after one year.

Diel movement patterns were analyzed by calculating the proportion of hours a fish was detected in the study area during day versus night. Day hours began at sunrise and ended at sunset. Night periods began one hour after sunset and ended one hour before sunrise. Crepuscular hours (one hour before sunrise and one hour after sunrise), were excluded from analyses. A fish was considered present in an hour (for example, during the time period 14:00 to 14:59) if there was ≥1 detection in that hour. The proportion of hours detected per day and the proportion of hours detected per night were tallied on each date for each fish during the study. A two-sample Kolmogorov-Smirnov (KS) test was used to test the distribution of hours detected per day versus the proportion of hours detected per night on each date for each individual fish.

Oceanographic seasons were defined as upwelling (March-August), relaxation (September-November), and Davidson (December-February) (Dr. Erika McPhee-Shaw, pers. comm., Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, California 95039). To test for differences in day and night presence among oceanographic seasons, the proportion of hours per day period and the proportion of hours per night period were tested among Davidson, upwelling, and relaxation seasons for the 16 sub-adult black rockfish using a Kruskal Wallis One-Way ANOVA.

An analysis of the depths of tagged fish was conducted for all days when fish were considered present in the study area (≥ 2 detections in a 24-h period). Negative depths were assumed to be signal errors, as were recorded depths > 65 m, because they were greater than the maximum depth (40 m) of the study area. Differences in depths between female (n=12) and male (n=4) sub-adult black rockfish were not tested due to unequal sample size. To calculate daily depth anomalies, the average daily depth for each fish on each date of the study was subtracted from the grand mean depth for that individual. Negative depth anomalies indicated that an individual fish was shallower on that date than average, and positive depth anomalies indicated that the fish was deeper on that date than average. Daily depth anomalies were averaged across all fish on each date of the study and plotted. A Kruskal Wallis One-Way ANOVA was used to test for differences in daily depth anomalies of each fish among seasons for a one-year period (October 1, 2006 to September 30, 2007) for each fish.

Mean day and night depths were compared for each individual fish using the same protocol to select day and night hours as in the diel movement analyses. The mean depth during the daytime of each fish on each date was compared with the mean depth at night of each fish on each date with a two-sample KS test. Average night depths were subtracted from average day depths for each fish on each date. Negative values indicated that mean depth of a tagged fish at night was shallower than the mean depth during the daytime, and positive values indicated that fish were deeper at night than in the day. The number of days with positive values and the number of days with negative values were tallied for each fish during the study period to compare the number of days when fish were deeper in the night versus the number of days when fish were deeper in the day.

Movements of sub-adult black rockfish were compared with environmental data, including water temperature, temperature stratification, tidal stage, wave height, and barometric pressure. Data from temperature loggers were pooled into three depth categories: 12–16 m; 18–24 m; and 26–34 m. Average temperature was calculated for each depth category for each hour of the study. The change in temperature, (Δ T), was calculated as the temperature difference between the deepest depth category (26–34 m) and the shallowest depth category (12–16 m). Mean wave height (m^2), mean tidal stage (m), and mean barometric pressure (mb), were recorded for each hour of the study. Average depth in each hour of the study for each fish was regressed against the hourly average of each of the independent variables (water temperature in each of the three depth categories, Δ T, tidal stage, wave height, and barometric pressure).

Activity space of black rockfish was defined as the area in which an individual spent 90% of the hours in the receiver array during time at liberty. For each hour that a fish was present ($\geq$ 1 detection per hour), a geographic location was assigned based on the location of the receiver(s) that recorded signals from that tagged fish. The number of hours detected at each receiver location was tallied for each fish. Receiver locations were ranked in descending order based on tallied number of hours. Receiver locations that ranked in the 90^{th} percentile of the total hours that a fish was recorded for during time at liberty were included in the activity space of that fish. The receiver locations that were considered part of the activity space of each fish were selected in ArcGIS, and a polygon of best fit was drawn around the area that incorporated both the receiver locations and the 150 m estimated detection radius. Activity space area for each fish was determined by calculating the area (km^2) of this polygon using the ArcGIS spatial analyst extension, XToolsPro. Areas of activity space of male and female sub-adult black rockfish were compared using a Mann-Whitney U-test. Regression analyses were used to compare fish length versus activity space area for all sub-adult black rockfish combined, and for males and females separately.

RESULTS

Fishing and Tagging

A total of 33 black rockfish, 23 sub-adults and 10 juveniles, was captured, tagged, and released in the study area between August 2006 and July 2007. Mean total length of the 23 sub-adult black rockfish was 32.7 cm ± 0.7 (SE). Mean total length of the 10 juvenile black rockfish was 23.5 cm ± 0.6 (SE). Of the 23 sub-adult black rockfish implanted with transmitters, 13 were females and 10 were males. Mean length of the 13 sub-adult female black rockfish was 33.7 cm ± 1.0 (SE) and mean length of the 10 sub-adult male black rockfish was 31.5 cm ± 0.6 (SE).

Some black rockfish were excluded from analyses because of too few data. Tag 92 was only present in the study area for 2 days, whereas Tag 81 was only present for 23 days. There were no complications for Tag 92 during surgical procedures, and this fish was observed swimming upon release. Tag 81 was detected for three distinct time periods in the array, sometimes up to nine days continuously, but with long periods of absence in between. Tagged fish (Tag 92 and Tag 81) were considered alive, but were excluded from the majority of the analyses due to lack of data.

One tagged sub-adult black rockfish was a confirmed fishing mortality. One tagged fish (Tag 228) was captured by a recreational angler on June 30, 2007, after 198 days at liberty. This was the largest female sub-adult black rockfish (41.5 cm) released in the study, and was recaptured near the Pinnacles SMR, close to the site where it was originally released.

Of the 10 juvenile fish that were tagged and released in 2007, only three fish were detected in the study area > 7 days. Surgical procedures for all juvenile fish were successful, and all fish swam away upon release. Potential predators such as sea lions (*Zalophus californianus*) or harbor seals (*Phoca vitulina*) were not observed in the release area. All individuals were released within reception range of a known receiver location, thus should have been detected immediately following release. Of the 7 juvenile fish detected ≤ 7 days in the study area, signals from one fish (Tag 200) were never detected. One possibility is that this tagged fish was eaten by a predator, and transmissions were never detected. Another possibility is that this fish was alive, but the tag malfunctioned and never transmitted any acoustic signals. For the other 6 juvenile black rockfish that were present for ≤ 7 days, insufficient data were available to determine if these fish died or emigrated from the study area.

Receiver Array

During the 2006–2007 winter, 8 VR-2 receivers broke free of their moorings. Three of these receivers were found on Carmel beaches, and were still operational. Data were recovered from these receivers, and the receivers were redeployed within two weeks. The other 5 receivers (Locations 5, 6, 18, 20, and 23) were permanently lost, resulting in 4–6 months of data loss at these locations.

In the 2007–2008 winter, 14 receivers broke free from their moorings. However, receiver loss was patchy, and the signal reception of tagged black rockfish in some locations was not affected at all. In some cases, coverage was maintained by receivers with detection ranges that overlapped in areas where receivers were lost. Other receivers washed ashore after storm events. One of these receivers (Location 16) was recovered on Carmel Beach. Another receiver (Location 11) washed ashore in a mass of kelp at Stinson Beach, California, approximately 175 km from the study site. A third receiver (Location 7), was found laying on the seafloor, near the site of original deployment. There were pieces of plastic buoy fragments and a broken line near this receiver. The line attaching this receiver to the mooring may have failed during a storm event, but more likely, during mooring deployment from the boat, the mooring dropped so rapidly that the buoy hit the bottom and exploded on impact, leaving the receiver resting on the bottom. In all cases, data were recovered from these receivers and receivers were redeployed to the study area.

Residence Times

Residence times of sub-adult black rockfish in the study area were < 1% to 100% of days (2 to 546 fish-days; Fig. 3). Mean residence time of sub-adult black rockfish was 272.0 days ± 33.0 (SE). Of the 23 sub-adult black rockfish released, 14 fish were highly residential, i.e. detected for > 75% of days possible during transmitter battery life. Of these 14 sub-adult black rockfish, 8 fish were detected in the receiver array between 75–95% of days, and 6 fish were detected for > 95% of days. The remaining 9 sub-adult black rockfish were present in the study area for 6 months (34.8% of days) or less before permanent departure (Fig. 3). Regression analyses revealed no significant relationship between fish length and residence time for all sub-adult black rockfish combined, for females or males separately ($P > 0.05$). There were no differences between residence times of female and male sub-adult fish ($P > 0.05$).

Of the 10 juvenile black rockfish released in the study area, only 3 were present in the study area for time periods sufficient for analyses. These 3 juvenile black rockfish (Tags 204, 211, and 201) were detected for 55, 60, and 70 fish-days, respectively. Mean residence time of these juvenile black rockfish was 61.0 days ± 6.0 (SE). Residence time estimates of all juvenile black rockfish were < 20% of fish-days possible in the transmitter battery life.

Absences from the study area

Absences (< 2 detections in a 24 h period) from the study area were calculated for sub-adult and juvenile black rockfish. Of the 23 sub-adult black fish, 7 fish were detected continuously during time at liberty without absence. Of the 16 sub-adult black rockfish that did exhibit absences from the study area, 7 fish were absent < 7% of the total time at liberty, 4 fish were absent < 15% of the total time at liberty (Fig. 4). The remaining 5 sub-adult black rockfish had longer absences (26–84% of total time at liberty; Fig. 4). The average number of absences (> 24 h) for sub-adult black rockfish was 7.8 ± 2.0 (SE). Average duration of discrete absences for all sub-adult black rockfish combined was 2.9 days ± 0.2 (SE). Mean duration of absences for female sub-adult black rockfish was 2.8 days ± 0.2 (SE) and 3.2 days ± 0.5 (SE) for males. There were no differences between the duration of absences for males and females ($P > 0.05$). Juvenile black rockfish averaged 6.7 ± 1.5 (SE) absences (> 24 h from the study area) with a mean duration of 2.4 days ± 0.4 (SE).

Mortality Estimates

Using the equation, $N_t = N_0 * e^{\wedge(-f + m)t}$, an instantaneous fishing mortality rate of 0.06, and an instantaneous natural mortality rate of 0.2, 14 of the 18 sub-adult black rockfish present on October 1, 2006, were predicted to be alive one year later. I also tested higher instantaneous fishing and natural mortality rates. At the highest instantaneous fishing rate of 0.18, and the highest instantaneous natural mortality rate of

0.4, the equation predicted that 10 of the 18 sub-adult black rockfish would be alive one year later. After September 30, 2007 however, only 8 of 18 tagged sub-adult black rockfish released in Carmel Bay were detected in the study area. Mortality estimates were not calculated for juvenile black rockfish.

Diel Movements

Sub-adult black rockfish were detected for a greater number of hours in the study area during nighttime than during daytime periods. Sub-adult black rockfish were detected an average of 82.2 % ± 0.0 (SE) of night hours and 40.4 % ± 0.0 (SE) of day hours. The proportion of hours detected during nighttime was significantly greater than the proportion of hours detected during daytime for 18 of 22 sub-adult black rockfish (83%; $P < 0.05$; Fig. 5). In late May, detections of sub-adult black rockfish began to increase during day hours. In August 2007, presence of sub-adult black rockfish during the day peaked (all fish were detected in 75% of day hours), compared with a minimum in April 2007 (all fish were detected in 24% of day hours; Fig. 6).

The average proportion of hours detected per night for sub-adult black rockfish was constant among seasons: Davidson (73.7% ± 6.4 (SE)), upwelling (77.6% ± 6.9 (SE)), and relaxation (78.7% ± 5.4 (SE)). However, hours detected per day was significantly different among seasons ($P<0.05$): Davidson (24.5 % ± 3.9 (SE)), upwelling (44.2% ± 5.1 (SE)), and relaxation (37.1% ± 4.1 (SE)). For 10 sub-adult black rockfish, presence during the day in the Davidson season was less than the upwelling and relaxation seasons, and for 6 sub-adult black rockfish, presence during the day in the Davidson season was less than either the upwelling season or the relaxation season.

Vertical Movements

Mean annual depths for individual sub-adult black rockfish during the study was 4.3 m to 15.5 m (Table 2). Mean depth of all sub-adult black rockfish was 11.6 m ± 0.8 (SE), and mean depth of 3 juvenile black rockfish was (11.0 m ± 0.0 (SE)). Due to limited sample size, further analyses were not conducted for juvenile black rockfish. Vertical movements of sub-adult black rockfish were variable at hour, day, and month time scales. Sub-adult black rockfish were observed making depth changes (5–10 m) during relatively short time intervals (5–20 minutes). The average difference between daily minimum and maximum depths for sub-adult black rockfish during the study period was 6.4 m ± 0.1 (SE) (Table 2).

Mean daily depth anomalies for sub-adult black rockfish were plotted to observe seasonal changes in depth use (Fig. 7). To test differences in depths among seasons, the depth anomalies for each fish were grouped by oceanographic season and tested using a Kruskal Wallis One-Way ANOVA. There were significant differences among seasons for 12 of 15 sub-adult black rockfish that were present in all three seasons ($P < 0.001$), but post-hoc testing revealed no consistent patterns among individuals. Differences in depths among oceanographic seasons were primarily driven by deeper depths recorded for sub-adult black rockfish in March and April 2007 (Fig. 7). For 43% of sub-adult black rockfish, monthly mean depth anomaly was greatest during March and/or April 2007. For all sub-adult black rockfish combined, the mean monthly depth anomaly was 1.2 m ± 0.1 (SE) greater than the annual mean depth in March and April 2007.

Day and night depths were compared for each of 16 sub-adult black rockfish in a two-sample KS test. Day depths were significantly deeper than night depths for 8 sub-adult black rockfish, and night depths were significantly deeper than day depths for 2 sub-adult black rockfish ($P < 0.05$; Table 3). When day depths were compared with night depths for each 24 h period, 56% of the sub-adult black rockfish were deeper in the daytime than nighttime for > 50 % of days (Table 3).

Environmental Data Records and Movements

Environmental data were evaluated in response to vertical movements for sub-adult black rockfish. No significant relationships ($P < 0.05$) were detected among hourly fish depth and environmental variables (mean temperature, Δ T, wave height, or barometric pressure) for any sub-adult black rockfish. With the exception of Tag 81 ($r^2 = 0.72$, $P < 0.001$), no significant relationships were found between mean hourly tidal stage and hourly fish depth.

Activity Space of Sub-adult Black Rockfish

Activity spaces of sub-adult black rockfish were small, and centered near original site of release for each fish (Fig. 9). Sizes of activity spaces for sub-adult black rockfish were 0.07 km^2 to 0.56 km^2. Average activity space for 21 sub-adult black rockfish was 0.25 km^2 ± 0.04 (SE) (Table 4). An average of 2.6 ± 0.3 (SE) receiver locations accounted for 90% of the hours detected for sub-adult black rockfish. Mean size of activity space for the 13 female sub-adult black rockfish was 0.28 km^2 ± 0.05 (SE), and 0.20 km^2 ± 0.05 (SE), for the 8 male sub-adult black rockfish. There were no differences in mean activity space size between male and females ($P > 0.05$) in a two-sample t-test, and no relationship between total length and activity space areas for all sub-adult black rockfish combined ($P > 0.05$), nor by sex ($P > 0.05$).

Of the 3 juvenile black rockfish with sufficient data for analyses, average activity space was 0.07 km^2 ± 0.0 (SE). Some juvenile black rockfish exhibited greater movements before permanent departure from the study area. One juvenile (Tag 211) vacated the study area in October 2007, and then was detected at a location 2.5 km from the previous detection location almost 5 months later. Another juvenile black rockfish (Tag 209) departed the study area for almost 2 months before returning to a location approximately 2.7 km from original release location. A third juvenile black rockfish (Tag 210), moved 0.5 km in the 48 hours following release, and was not detected in the study area again.

DISCUSSION

Factors Affecting Data Interpretation

The loss of receivers in the study due to storms prevented continuous data collection in the study area. Carmel Bay faces west and receives little protection from west and northwest swells. Receiver locations 1–11 on the north end of the bay were most exposed to winter swells, and were subject to wave heights of > 10 m during the study. Receiver loss was disproportionately high in this area, and most likely caused by mooring failure due to wave action or dislodged by giant kelp plants, which can tangle around mooring lines and cause breakage. Drag from a kelp plant also may have caused moorings to move from their original locations, thus preventing retrieval of receivers by SCUBA divers. For all receivers that were lost in the winter of 2007–2008 and recovered on beaches, receiver data revealed that the last transmissions occurred on either December 4, 2007 or January 5, 2008. On these dates, wind speeds in excess of 48 km/h were recorded and swell heights exceeded 5 m for > 24 h.

Although receiver loss in the 2007–2008 winter was high, the majority of black rockfish carried transmitters with batteries set to expire between mid-November and late December. Thus, no more than a few months of data were lost for any one fish in 2007 or 2008. When receivers were lost within an area that an individual fish used, usually coverage was maintained by nearby receivers, and estimates of times of residence and absence were not affected. In areas where receiver loss would have resulted in "false absences" of an individual and biased residence estimates, data sets were truncated to exclude dates receiver loss. Due to these factors, estimates of residence times for black rockfish are conservative; the number of fish-days present may have been slightly greater had we not experienced data loss due to missing receivers.

Movements of sub-adult and juvenile black rockfish

Ontogenetic movements, i.e. shifts in habitat use with age or size, are common in fishes (Roberts and Sargant 2002). Ontogenetic movements are usually associated with change in shelter requirements, prey abundance, or feeding patterns. A common trait observed in rockfishes is the use of shallow water habitats as juveniles and a transition to deeper water habitats as adults (Moser and Boehlert 1990, Wakefield and Smith 1990). For example, juvenile rockfish may settle in sheltered habitats such as estuaries, bays, or drift kelp. These sheltered habitats provide additional protection during this vulnerable life stage (Lowe and Bray 2006). Segregation of juveniles and adults in different habitats can minimize intraspecific competition for resources (Persson 1983). Habitat preferences of adult and juvenile fish also may be driven by differences in food requirements among age classes (Clady 1974, Grossman 1980).

Ontogenetic shifts in habitat may be reflected in smaller home ranges and greater site fidelity with increased age (Schoener and Schoener 1982, Meyer and Holland 2005). For example, Pacific halibut are mobile as juveniles, yet relatively sedentary as adults (P.N. Hooge and S.J. Taggart, unpublished data, USGS, Alaska Biological Science Center, Glacier Bay Field Station, P.O. Box 140, Gustavus, Alaska 99826). Adult fish in some reef-associated species have greater site fidelity and increased homing ability than juvenile fish (Young 1963, Hallacher 1984, Hartney 1996). Craik (1981) reported that homing ability in the tidepool sculpin increased with age, indicating that extensive movements of tidepool sculpin during early development were associated with learning and memorizing the local area. Similarly, Hallacher (1984) suggested that the ability of adult rockfishes to maintain small home ranges was associated with learning local landmarks during settlement to a home site.

In my study, juvenile black rockfish had lesser site fidelity and potentially greater home ranges than sub-adult black rockfish released in Carmel Bay. Sub-adult black rockfish in Carmel Bay repeatedly returned to the study area after short daily forays outside the study area. There was no evidence of homing behavior for juvenile black rockfish; most juvenile fish vacated the study area within a few days of release, and did not return for the duration of the study. Hallacher (1984) hypothesized that decreased homing ability of juvenile black-and-yellow rockfish relative to adults was because juvenile fish did not have the same navigation ability of older conspecifics. If this hypothesis is true, than lesser site fidelity of juvenile black rockfish in this study also may be a result of underdeveloped navigation skills. Alternatively, if young rockfish have not yet established a home site, home ranges may be larger as they continue to search for suitable habitat in which to settle (Matthews 1990a). Data recorded in this study indicate that juvenile black rockfish had lesser site fidelity and were capable of moving long distances, but more study is needed to accurately compare home range sizes between juvenile and sub-adult black rockfish.

Residence Time and Absences from the Array

The residence time of an individual fish to a given area is related to many factors, including life history characteristics, ontogeny, environmental variability, and resource availability (Lowe and Bray 2006). Most nearshore rockfishes have high site fidelity (Matthews 1990a, 1990b, Lowe et al. 2009). Parker et al. (2007) also documented patterns of greater site fidelity and long residence times for most black rockfish tagged in an acoustic telemetry study in Oregon. Typically, a few tagged fish depart the study area within a few months of release, but these are anomalies rather than the norm (Matthews 1990a, 1990b, Parker et al. 2007, Lowe et al. 2009). In my study, however, all juvenile and more than one-third of sub-adult black rockfish had short residence times (< 6 months).

Short residence times for black rockfish in Carmel Bay could be caused by recapture in the recreational fishery, tag malfunction, mortality due to tagging or natural causes, or emigration from the study area. At least one sub-adult black rockfish in this study (Tag 227) was recaptured by a recreational fisherman, and it is possible that other tagged fish were caught but not reported. Mortality after tagging also may have contributed to lesser residence times, but mortalities due to tagging complications would be most likely to occur in the first week after release (Starr et al. 2000). Only one fish (Tag 92) was detected for less than 3 months in the study area. This fish may have died because of tagging, or it may have simply emigrated from the study area.

Emigration from the study area is the most likely reason for tagged black rockfish to have exhibited short residence times. For example, increased rates of fish emigration have been documented with onset of winter storm activity for juvenile rockfish (Johnson et al. 2001) and in summer flounder (Sackett et al. 2007). In some tag-recapture studies, movements were more frequent for fish at liberty during tropical storms than periods without storms (Patterson 1999, Ingram et al. 2001). In Carmel Bay, 10 sub-adult black rockfish was last detected during a major storm event. Eight sub-adult black rockfish were last detected during storm events on December 4, 2007 and January 5, 2008. An additional two sub-adult black rockfish were last detected a few days before a major storm event on March 28, 2007. On all occasions, storm events were characterized by sustained swells > 4.5 m over a 24-h period, with recorded maximum wave heights up to 10 m (http://www.ndbc.noaa.gov). I could not determine if emigration of juvenile black rockfish was associated with storm events, but all tagged juvenile black fish vacated the study area within 3 months of release.

Many of the sub-adult black rockfish that were last detected on major storm dates had previously exhibited strong site fidelity, including the ability to return despite repeated daily departures from the study area. The January 5, 2008 storm produced wave action and water currents sufficient to transport a receiver 175 km north of Carmel Bay to Stinson Beach, California. It is possible that large swells and strong currents associated with major storm events also resulted in emigration of sub-adult black rockfish. Parker et al. (2008) speculated that black rockfish maintain small home ranges by making frequent descents to the bottom for visual spatial reference. However, strong currents and wave action during storm events may have advected black rockfish north or south from the study area so that they were unable to navigate back to their home range. Had these major storm events not occurred, I suspect that these sub-adult black rockfish would have remained in the study area for a greater period of time.

Mortality estimates for sub-adult black rockfish in Carmel Bay support the hypothesis that storm events affected the residence time of sub-adult black rockfish during the study. All of the values of instantaneous natural and fishing mortality rates that I tested in the survivorship equation predicted a greater number of sub-adult black rockfish to be alive at the end of year 1 than were actually detected. These results indicate that emigration was the most likely hypothesis to explain the short residence times of sub-adult black rockfish in Carmel Bay.

Diel Movements

Differences in habitat use during day and night periods have been documented in many fish species (e.g. Parsley et al. 2008, Tolimieri et al. 2009). In coral reef fishes, crepuscular ‘commutes’ between distinct day and night habitats are common (Holland et al. 1996, Meyer 2003, Meyer et al. 2007). During certain times of the year, sub-adult black rockfish in Carmel Bay used different day and night habitats. Sub-adult black rockfish typically departed the study area in the morning crepuscular hours and remained outside the study area during the next 10–12 hours before returning to the study area in the evening. With the exception of one individual, all sub-adult black rockfish had diel departures at some point in the study. Similar diel departures from the kelp forest habitat have been documented for juvenile black rockfish (Leaman 1976, Carr 1983).

In Carmel Bay, when sub-adult black rockfish moved during the day, they were outside of receiver reception range. The mean depth of tagged fishes enabled me to determine direction of movements. Deeper depths during daytime than nighttime would indicate movement offshore during the day, whereas shallower depths during daytime than nighttime would indicate movement inshore of the receivers. Although depth data recorded during daytime were limited to crepuscular periods when fish were entering and exiting the array, I was able to detect a 1–2 m increase in mean depth during the day for > 50% of the sub-adult black rockfish. These deeper depths during the day indicate that sub-adult black rockfish in Carmel Bay moved to deeper waters outside the kelp forest during daytime, and returning to shallower depths inside the kelp forest at night.

Seasonal movements

Seasonal movements of fishes may be driven by food availability (Allen and DeMartini 1983), water temperature (Terry and Stephens 1976, Stephens and Zerba 1981, Stephens et al. 1994), or mating (Babel 1967, Nakano 1994). For rockfishes, the summer upwelling season is an important feeding time in which they increase their fat reserves for winter (Guillemot 1985). In my study, seasonal patterns were observed in diel movements for sub-adult black rockfish in Carmel Bay. Diel movements out of the study area were greatest in the winter and spring. Greatest daytime occupancy occurred in the summer upwelling season for sub-adult black rockfish.

Seasonal changes in sub-adult black rockfish presence in the study area were likely influenced by prey availability. Increased day-time presence of sub-adult black rockfish in the shallow kelp habitats of the study area during the summer upwelling season coincided with the arrival of YOY *Sebastes spp.* to the kelp forest. Peak YOY *Sebastes* densities on the California coast occur in June, July, and August (Miller and Geibel 1973, Hallacher and Roberts 1985, Hobson et al. 2001, Studebaker and Mulligan 2008). A large portion (up to 73%) of the black rockfish diet is composed of YOY *Sebastes spp.* in the summer upwelling season (Hallacher and Roberts 1985, Hobson et al. 2001). Decreased black rockfish densities in Carmel Bay kelp forests during the non-upwelling season, along with a prey switch from fish to invertebrates during the non-upwelling season were observed by Hallacher and Roberts (1985). The seasonal dietary switch, accompanied by an increase in the percentage of empty black rockfish stomachs led them to speculate that food is a limiting resource for black rockfish during the non-upwelling season. Seasonal changes in diurnal habitat use of sub-adult black rockfish in Carmel Bay may also be related to seasonal prey availability.

Depth Distributions

Many fish species respond to changes in ambient water temperature by changing depths (Shrode et al 1982, Hinke et al. 2005a). Coldest ambient water temperatures in Carmel Bay occurred March through July 2007, with the least mean monthly temperature recorded in April. Average depth anomalies for sub-adult black rockfish in my study were deepest in March and April, with some individuals exhibiting depth anomalies up to 4 m deeper than the annual mean. Seasonal changes in sub-adult black rockfish depths may be a response to decreased water temperatures signaling a shift in upwelling conditions in Carmel Bay. Hallacher and Roberts (1985) reported that black rockfish were significantly closer to the bottom during fall and winter, during which time polychaetes comprised a large proportion of black rockfish diets. If black rockfish are relying mostly on benthic invertebrates such as polychaetes for food during the non-upwelling season, changes in seasonal depth distributions of sub-adult black rockfish observed in my study may be related to prey depth distributions.

Alternatively, changes in the seasonal depth distribution of sub-adult black rockfish also may have been a response to seasonal environmental conditions such as increased storm activity. For example, blue rockfish move to deeper waters to avoid winter storm turbulence (Miller and Geibel 1973). Hallacher and Roberts (1985) and Parker (2007) reported that black rockfish were significantly closer to the bottom in winter. Another possible reason for the deeper depths for black rockfish during the winter and spring, therefore is that black rockfish are avoiding increased water turbulence from wave action.

Movement patterns of male and female sub-adult black rockfish

Some species of fish exhibit sex-related differences in movement, e.g. male lingcod defending territories (Jagielo 1990), or female black rockfish moving offshore for parturition (Dunn and Hitz 1969, O'Connell 1987, Welch 1995). Male black rockfish do not defend territories (Hallacher 1984), and differences in movement patterns between male and female black rockfish are likely related to reproduction (Field 1984, Wallace and Tagart 1994, Worton and Rosenkranz 2003). Differences in movement patterns and home range areas were not observed for male and female sub-adult black rockfish in Carmel Bay in this study; but this is to be expected as movement differences between female and male sub-adult black rockfish that are not reproductively active are unlikely.

Activity Space of Sub-adult Black Rockfish

Differences in the activity space among individuals of a species can vary with habitat quality, seasonal variations in food availability, fish size, geographic location, and environmental conditions (Lowe and Bray 2006). Individual fish behavior also affects activity space patterns. For example, even for relatively sedentary species, a small percentage of tagged fish will move greater distances than other fish. Although the black rockfish is typically described as a residential species throughout its geographic range, long-distance movements (as far as 600 km) have been documented for some black rockfish individuals in tag-recapture studies (Barker 1979, Coombs 1979, DeMott 1983, Gowen 1983, Starr and Green 2007). Data from my acoustic study, and from a tag-recapture study at Duxbury Reef near Bolinas, California (Starr and Green 2007) indicated that between 10% and 40% of sub-adult black rockfish had minimal site fidelity, and in some cases, made extensive movements. A better understanding of the variability of black rockfish movements in different geographic locations and among age classes is necessary before describing the black rockfish as a species with limited movements.

To determine if differences in movement patterns exist among populations of black rockfish in different locations, I compared black rockfish movements from my acoustic telemetry study to data collected in an acoustic telemetry study in Oregon. Mean activity space of black rockfish in Oregon (Parker et al. 2007) was twice that of sub-adult black rockfish in my study. However, black rockfish in my study had lesser residence times than black rockfish in Oregon, and movements of tagged black rockfish could not be estimated for individuals that vacated the study area in Carmel Bay.

Differences in habitat quality between the study sites in Oregon and California may have influenced activity space size of black rockfish. High relief, complex habitats typically support greater prey biomass and increased substratum and shelter than low relief habitats (Allen 1985). Lowe and Bray (2006) hypothesized that fish residing in high relief, complex habitats may not need to range as far for resources. Matthews (1990a) found that home ranges were considerably less for rockfishes in high-relief rock reefs than for rockfishes on low-relief rock reefs. Most sub-adult black rockfish in Carmel Bay were released in complex habitat containing high-relief rock reefs and kelp forests. The smaller home ranges of sub-adult black rockfish in Carmel Bay than Oregon may be due to the greater availability of high quality (high relief) habitat in Carmel Bay relative to central Oregon.

Variability in black rockfish prey availability also may have affected the activity space of black rockfish between the study sites. Activity spaces of sub-adult black rockfish in Carmel Bay were smaller during the productive summer months when YOY rockfishes were abundant, whereas increased activity spaces during the non-upwelling season may have been necessary to locate patchy food resources. Parker et al. (2007) reported atypical oceanographic conditions and delayed upwelling during his acoustic telemetry study of black rockfish. Larger activity spaces for black rockfish in Oregon may have been a response to increased foraging for limited food resources in poor upwelling conditions.

An increase in activity space with increased fish size has been documented for some fishes (Morrissey and Gruber 1993, Kramer and Chapman 1999). The majority of tagged black rockfish released in Oregon were reproductively mature adults, whereas all the black rockfish released in Carmel Bay were classified as sub-adult black or juveniles, based on length at 50% maturity. Increased activity spaces of black rockfish in Oregon compared with black rockfish in Carmel Bay may be attributed to differences in the size and/or maturity of tagged black rockfish between studies. Differences in size classes of black rockfish between Parker et al.'s (2007) study and my research may also explain the shorter residence times observed for sub-adult black rockfish released in Carmel Bay compared with black rockfish released off Oregon. The lesser residence times observed for sub-adult black rockfish in Carmel Bay may be evidence of ontogenetic changes in movement patterns as these fish transition to maturity.

IMPLICATIONS FOR MANAGEMENT

Black rockfish are an important component of the commercial and recreational fishery along the entire west coast of the United States. Currently, Alaska, Washington, and Oregon have harvest quotas specific to black rockfish (Wallace et al. 1999, Worton and Rosenkranz 2003, ODF&W 2007), whereas California has a specific quota only north of Cape Mendocino (Ralston and Dick 2003). The harvest quotas for black rockfish in Washington, Oregon, and California are based on two recent stock assessments. Wallace et al. (2007) conducted a stock assessment for the U.S.-Canadian border to Cape Falcon, Oregon, and Sampson (2007) assessed the area from Cape Falcon, Oregon to Point Piedras Blancas, California. The stock assessments in each area indicated that the spawning potential of black rockfish stock was above the Pacific Fisheries Management Council's management target (40% of the unexploited biomass). Although these stock assessments indicated that the spawning potential of the black rockfish was at a sufficient level to maintain meta-populations of black rockfish over large geographic ranges, local populations of black rockfish may be less stable.

In California, there has been a decline in the mean length of black rockfish caught in the recreational fishery since the 1980s, which may indicate increased fishing mortality (Mason 1998). During the early 1990s, landings of black rockfish increased dramatically and the mean length of black rockfish decreased precipitously (Reilly 2001). The mean length of black rockfish in central California has since stabilized, but at a mean length that is well below 50% maturity (Love 1996, Reilly 2001, Starr and Green 2007).

For the black rockfish, there is a direct linear relationship between fecundity and female mass (Bobko and Berkeley 2004), thus the absence of large, reproductively mature black rockfish in the recreational catch may indicate decreased spawning potential. In addition to producing greater quantities of larvae, larger, older female black rockfish produce greater quality larvae that can survive under a broader range of ocean conditions compared with larvae from younger females (Berkeley et al. 2004b). O'Farrell and Botsford (2006) estimated that shifts in the size structure of black rockfish populations since the 1980s have resulted in serious declines in the available lifetime egg production, which is used as a proxy to measure persistence of fish populations.

The lack of adult spawners in the black rockfish recreational catch data in California has generated concerns about the existence of an adequate recruitment source for black rockfish populations. There are several hypotheses that may explain apparently stable black rockfish populations despite the decreased numbers of mature black rockfish. The first hypothesis is that excessive fishing is responsible for the truncated age structure in black rockfish populations, and the continued removal of large black rockfish will eventually result in a population crash. The second hypothesis is that fishing has removed a percentage of mature black rockfish, but the current numbers of mature black rockfish still provide sufficient spawning output to sustain population abundances. The third hypothesis is that greater numbers of reproductively mature black rockfish are present, but these individuals are located in areas rarely visited by recreational fishermen, thus not observed in the recreational catch.

The first hypothesis that I investigated was that fishing removal is causing the altered size-structure in black rockfish populations. Historical recreational catch data for black rockfish landings among ports in central California indicate that black rockfish above the length at 50% maturity were present in the recreational catch before the 1980s (Karpov et al. 1995, O'Farrell and Botsford 2006). In the 1980s, the lengths and weights of black rockfish decreased from about 1980 until 1994 (Reilly 2001). The sudden decline of large black rockfish in the recreational fishery was likely related to the expansion of the nearshore fishery in the 1980s. However, the consistent absence of adult black rockfish in the landing data since the 1990s indicates that fishing pressure is continuing to prevent black rockfish at these locations from reaching sizes that would allow reproduction. Whereas these data indicate greater fishing rates have altered the size structure of black rockfish populations, the relatively great abundance of black rockfish imply that there is still sufficient recruitment to maintain these black rockfish populations.

The second hypothesis is that the current proportion of mature black rockfish in California populations is sufficient to maintain local abundances may be evidence of a shifting baseline. Greater proportions of mature black rockfish in local populations may have existed historically, but the increase in fishing pressure in the late 1980s caused this proportion to shift to a new baseline level. Although less, the proportion of mature black rockfish observed in the catch since the mid-1990s is relatively stable (Reilly 2001). Berkeley et al. (2004b) suggested that the majority of recruitment in the black rockfish population may come from only a small fraction of the spawning population each year. If this is the case, then the small percentage of reproductively mature black rockfish observed in the recreational catch may provide enough annual larval output for sufficient recruitment under normal conditions. However, relying on the larval output from only a small fraction of mature female fish has long-term risks. The larval output from a small fraction of mature fish may not be sufficient to replenish populations during successive years of poor recruitment caused by unfavorable oceanographic conditions, or in the event of an environmental disaster.

A third hypothesis is that reproductively mature black rockfish exist in California, but they are located in areas that are not easily accessible to recreational fishermen, thus are not represented in the recreational catch. For example, black rockfish could be present in offshore waters that are deeper than the range of depths that recreational fishermen typically target fishes. To investigate this hypothesis, Starr and Green (2007), conducted fishing outside the range of depths (>30 m) typically fished by the recreational charter boat industry, but did not observe a greater proportion of mature black rockfish in the catch. Large black rockfish have not been observed in deeper water using visual surveys, i.e. submersible video data (Dr. Rick Starr, pers. comm., Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, California 95039). Whereas surveys for mature black rockfish in deeper waters have not been conducted in all areas of the coast, nor during all seasons, the current data do not support this hypothesis.

Alternatively, mature black rockfish may be located in remote areas of the coastline that are not readily accessible to fishermen. If these populations are unfished or lightly fished, then the black rockfish in these populations should exhibit natural age and size structure. Theoretically, the greater proportion of larger, older female fish present in these populations could be a significant proportion of the total black rockfish spawning biomass in California. These source populations of black rockfish may be sustaining heavily fished or sink populations of black rockfish via long distance larval transport.

Although the hypotheses presented to explain the absence of mature black rockfish in the recreational catch data are not mutually exclusive, the possibility that large, mature black rockfish located in lightly fished areas contribute disproportionately to the total black rockfish spawning biomass in California is likely. The persistent great abundance of black rockfish caught in the recreational fishery, relative to the number of mature black rockfish observed in these populations, indicates that a reliable recruitment source exists. Fewer than 7% of the black rockfish caught in fisheries-independent studies on the central coast of California between Point Reyes and Point Buchon are above the length at 50% maturity (Starr and Green 2007, Dr. Rick Starr, unpublished data, Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, California 95039). This small proportion of mature fish seems inadequate to sustain great population abundances. Still, neither catch records nor anecdotal observations have provided sufficient evidence indicate that mature black rockfish are present in greater numbers in other populations along the coast. Until a definitive recruitment source for black rockfish populations in central California is identified, conservative approaches should be taken towards management of the black rockfish.

Small MPAs may be an effective fisheries management technique for the sizes of black rockfish that are typically seen in California (i.e. sub-adults), if the management goal is to protect a proportion of the population but allow some spillover of individuals. For a MPA to adequately protect a species, the activity space of the individuals within that species must be encompassed within the MPA boundaries. Sub-adult and juvenile black rockfish had small activity spaces during the time they were present in my study area, a good characteristic for MPA protection. Yet, over one-third of sub-adult black rockfish and all of the juvenile black rockfish had low overall residence times to the study area. The evidence from this study indicates that residence times of sub-adult black rockfish in California area are variable among individuals, and may be affected by oceanographic conditions, habitat quality, food availability, and ontogeny. Thus, MPAs may provide protection for the proportion of black rockfish that exhibit small activity spaces and high residence times, but managers need to be cautious in assuming that black rockfish have equivalent activity spaces and site fidelity throughout their geographic range and among age classes.

Long-term MPA protection may be necessary to restore the natural age structure of black rockfish populations. Through time, if the majority of sub-adult black rockfish that have small activity spaces and high residence times remain within the MPA boundaries, a more stable population of black rockfish will be established. As these individuals grow and reach maturity, the natural size and age structure of the black rockfish population within the MPA will be restored. If large, reproductively mature female black rockfish remain within reserve boundaries, a major benefit of MPA protection for black rockfishes in California would be the retention of a local source of larval supply.

The seasonal and diel movement patterns documented for sub-adult black rockfish in my study in Carmel Bay should be considered in management plans for the black rockfish. Sub-adult black rockfish in Carmel Bay typically exhibited a diurnal activity space expansion during daytime, exiting the study area towards deeper offshore waters. This trend was most prevalent during the non-upwelling conditions (October to May). Activity spaces were estimated for sub-adult black rockfish in Carmel Bay during the time they were in the study area, but I could not account for movements of individuals during temporary trips outside the receiver reception range. I anticipate that diurnal movements were short, as sub-adult black rockfish always returned to the same location in the study area after short diurnal absences. The potential underestimation of black rockfish activity space is an important caveat to consider in management. For example, MPAs designed to protect black rockfish should encompass potential seasonal and diurnal activity space expansion. Alternatively, additional fishing restrictions could be considered to protect the black rockfish during home range expansion in the non-upwelling season.

The removal of older, larger black rockfish has generated concerns about the potential decrease in the long-term reproductive potential of black rockfish populations (Berkeley 2004b). Fisheries restrictions, which limit the maximum and/or minimum size at which individuals can be legally harvested, can be used to protect specific size classes within a species. The enforcement of a maximum size limit for black rockfish would be an effective way to retain older, larger, reproductively mature fish (Berkeley et al. 2004). As all *Sebastes spp*., black rockfish have a closed swim bladder, which they use to regulate buoyancy in the water column by releasing and reabsorbing swim bladder gases. Rapid ascent during fishery capture can result in barotrauma by overexpansion of swimbladder gases in closed body cavities. In my study, I used a hypodermic needle to vent the swimbladders of black rockfish and release barotrauma-inducing gases. This was critical to the high survival rate of tagged black rockfish released in Carmel Bay. Other laboratory and field studies of black rockfish indicate that quick recompression and return to depth resulting in greater survivorship (Parker et al. 2006, Starr and Green 2007). The mandatory release of large black rockfish caught in California is recommended to protect reproductively mature individuals from fishing mortality and to increase the spawning potential of black rockfish populations.

SUMMARY

In California, black rockfish are an important component of the commercial and recreational fishery, which has led to concerns about the potential overexploitation of black rockfish populations. Sampson's (2007) assessment of the black rockfish indicated that the unit stock of black rockfish off California and Oregon is in healthy condition. However, stock assessments conducted over large geographic areas may mask disturbing trends in population abundances and size-structure at smaller spatial scales. For example, the size-structure truncation of local black rockfish populations in California indicates that black rockfish populations may not be stable in all areas of the coast (Mason 1998, O'Farrell and Botsford 2006). The black rockfish has historically been managed as part of a species complex in the area south of Cape Mendocino, California, thus there has been little opportunity to address concerns about the status of black rockfish via species-specific harvest quotas or management over smaller spatial scales (Ralston and Dick 2003). Via MLMA legislation, the CDF&G has the opportunity to address these concerns by creating and implementing a species-specific management plan for the black rockfish.

The movement patterns documented for juvenile and sub-adult black rockfish in this study have important implications for management. My study corroborates evidence in previous tag-recapture studies that sub-adult black rockfish exhibit a bimodal distribution in movements. Most tagged sub-adult black rockfish in my study had small activity spaces and long residence times in the study area. However, a second group of tagged sub-adult black rockfish (and all tagged juvenile black rockfish) emigrated from the study area within six months of release. In tag-recapture studies, the sub-adult black rockfish that exhibit long-distance movements have typically been considered anomalies and ignored in management. Yet, information from my acoustic study, and from a tag-recapture study in central California (Starr and Green 2007), indicates that 10% to 40% of sub-adult black rockfish have minimal site fidelity, and potentially migrate long distances. From a management perspective, these results indicate the need to reconsider categorizing the black rockfish as a residential species.

The diurnal movements exhibited by sub-adult black rockfish to areas outside the study warrant further study. It would be valuable to use acoustic telemetry techniques to actively track black rockfish individuals during a 24-h period. An active tracking study would provide daytime activity space information for sub-adult black rockfish, and test my hypothesis that sub-adult black rockfish are moving offshore to deeper waters during the day. Diurnal movements of sub-adult black rockfish were often tightly in phase with sunrise and sunset and occurred almost daily from October to

May for most individuals. The consistency of sub-adult black rockfish diurnal movements outside the study indicates daytime foraging behavior, but more study would be needed to confirm that black rockfish are actively feeding during day hours.

Emigration of sub-adult black rockfish from long-distances may be a source of connectivity among populations of black rockfish in California. Recent genetic and otolith microchemistry studies indicate that for black rockfish, larval exchange only among populations at small spatial scales (Miller and Shanks 2004, Miller et al. 2005). In addition, biogeographic barriers in California, i.e. Cape Mendocino, may inhibit larval dispersal, thus preventing mixing between sub-populations of rockfish in certain areas (Cope 2004). Given evidence for limited larval dispersal in black rockfish, the long-distance movements of sub-adult black rockfish may be an important contributor to genetic mixing of the black rockfish meta-population, as well as to the replenishment of locally depleted black rockfish populations.

Black rockfish have complex movement patterns, which may differ by geographic location, among size classes, with food availability, and environmental conditions. The detailed movement information presented for juvenile and sub-adult black rockfish in this study will aid managers in developing appropriate area-based fisheries management plans to ensure the long-term viability of black rockfish populations in California.

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Table 1. Tag numbers of black rockfish released in Carmel Bay. Sex of black rockfish denoted as F (female), M (male), or U, (unidentified). Total days detected (det.) is the number of days with > 2 detections in a 24-h period for an individual black rockfish. Residence time (Res. Time) is the total number of days (d) detected for each fish divided by the total number of days available in the battery life of a transmitter.

Tag	TL (cm)	Sex	Class	Release Date mm/dd/yy	Total days det.	Res. Time (% of d)
78	31.5	F	Sub-adult	9/28/2006	88	21.2
80	35.0	F	Sub-adult	10/5/2006	366	82.2
81	33.0	M	Sub-adult	8/22/2006	23	5.2
82	34.0	F	Sub-adult	8/29/2006	369	82.9
83	33.0	F	Sub-adult	10/3/2006	336	81.0
84	32.0	M	Sub-adult	10/5/2006	427	96.0
85	30.0	F	Sub-adult	8/28/2006	391	88.7
86	38.0	F	Sub-adult	10/3/2006	115	27.7
87	29.5	F	Sub-adult	10/5/2006	382	85.8
88	33.5	F	Sub-adult	9/11/2006	70	15.7
89	36.5	F	Sub-adult	9/4/2006	446	100.0
90	34.5	M	Sub-adult	9/1/2006	433	97.3
91	32.0	M	Sub-adult	10/7/2006	100	25.6
92	29.0	M	Sub-adult	10/9/2006	2	0.4
93	30.0	M	Sub-adult	10/11/2006	372	83.6
94	35.0	F	Sub-adult	10/11/2006	409	91.9
95	32.0	M	Sub-adult	10/9/2006	446	100.0
200	25.0	U	Juvenile	7/17/2007	0	0.0
201	22.0	U	Juvenile	6/20/2007	70	18.7
202	22.0	U	Juvenile	6/20/2007	4	1.1
203	23.0	U	Juvenile	6/20/2007	1	0.3
204	25.0	U	Juvenile	6/19/2007	51	13.6
205	25.0	U	Juvenile	7/3/2007	3	0.8

Table 1., Continued

Tag	TL (cm)	Sex	Class	Release Date mm/dd/yy	Total days det.	Res. Time (% of d)
208	20.0	U	Juvenile	7/17/2007	1	0.3
209	23.0	U	Juvenile	7/12/2007	7	1.9
210	25.0	U	Juvenile	7/17/2007	2	0.5
211	25.0	U	Juvenile	7/12/2007	62	16.5
227	30.5	F	Sub-adult	10/11/2006	446	100.0
228	41.5	F	Sub-adult	10/15/2006	216	86.4
229	29.0	F	Sub-adult	10/15/2006	423	95.1
4054	29.5	M	Sub-adult	6/20/2007	53	10.2
4058	29.0	M	Sub-adult	6/20/2007	168	32.3
4060	34.0	M	Sub-adult	6/7/2007	181	34.8

Table 2. Mean annual depth, mean and minimum daily depths, and mean daily depth range for sub-adult and juvenile black rockfish in Carmel Bay over a one-year period (October 1, 2006 to September 30, 2007). Mean annual depth (m) is the annual mean depth for each individual black rockfish. Mean Daily Min. Depth (m) is the annual mean of the minimum depth recorded on each date for each individual black rockfish. Mean Daily Max. Depth (m) is the annual mean of the maximum depth recorded on each date for each individual black rockfish. Mean Daily Depth Range (m) is the annual mean of the difference between the minimum and maximum depth recorded on each date for each individual black rockfish.

Tag	Class	Mean Annual Depth (m)	Mean Daily Min. Depth (m)	Mean Daily Max. Depth (m)	Mean Daily Depth Range (m)
78	Sub-adult	14.6	13.4	14.9	1.5
80	Sub-adult	10.3	8.4	17.9	9.5
83	Sub-adult	13.4	13.0	18.7	5.7
84	Sub-adult	15.7	12.9	19.0	6.1
85	Sub-adult	3.9	3.1	8.6	5.5
86	Sub-adult	13.8	13.6	15.9	2.3
87	Sub-adult	14.9	12.1	17.1	5.0
88	Sub-adult	7.3	4.5	14.8	10.3
89	Sub-adult	9.5	9.1	13.7	4.6
90	Sub-adult	11.2	10.7	13.4	2.7
93	Sub-adult	14.4	12.8	16.3	3.5
94	Sub-adult	10.7	8.1	16.7	8.6
95	Sub-adult	8.3	5.2	19.1	13.9
227	Sub-adult	14.5	10.4	19.6	9.2
228	Sub-adult	11.3	9.0	13.0	4.0
229	Sub-adult	11.6	10.8	14.9	4.1
201	Juvenile	13.3	11.8	15.1	3.3
204	Juvenile	10.4	9.5	11.0	1.5
211	Juvenile	10.1	9.6	11.3	1.7

Table 3. Mean day and night depths for sub-adult black rockfish over a one-year period (October 1, 2006 to September 30, 2007). Mean Day Depth (m) is the mean annual day depth for each individual black rockfish. Mean Night Depth (m) is the mean annual night depth for each individual black rockfish. Day Depth> Night Depth (% of d) is the percentage of days in the year in which the mean day depth of a tagged fish was greater than the mean night depth of that fish on a particular date. Asterisks indicate a significant difference between mean day and night depths in a two-sample KS-test (* indicates P < 0.05, ** indicates P<0.001).

Tag	Mean Day Depth (m)	Mean Night Depth (m)	Day Depth> Night Depth (% of d)	P-value
78	14.9	13.9	61.4	0.02*
80	11.1	10.6	44.4	0.07
83	16.8	14.6	73.2	0.00**
84	16.6	15.5	81.6	0.00**
85	4.8	4.3	61.1	0.01*
86	14.7	14.5	56.9	0.1
87	14.6	15.0	26.8	0.00**
88	7.6	7.1	45.3	0.72
89	10.1	10.5	29.8	0.01*
90	11.6	11.6	40.4	0.00**
93	14.2	15.0	33.5	0.00**
94	11.8	11.0	56.0	0.00**
95	10.1	7.8	77.8	0.00**
227	15.2	15.2	49.0	0.92
228	11.5	10.2	51.4	0.00**
229	12.4	12.5	55.6	0.75

Table 4. Activity space (km^2) of sub-adult and juvenile black rockfish during time at liberty in the study area. Sex of black rockfish is denoted as F (female), M (male), or U, (unidentified). Number of receiver locations (# Rcvr. Loc.) is the number of receivers in which an individual was recorded for 90% of the total hours during time at liberty. Activity Space (km^2) is based on the area encompassed by the expected reception radius of the receivers needed to account for 90% of the total hours during time at liberty.

Tag	TL (cm)	Sex	Class	# Rcvr. Loc.	Activity Space (km^2)
78	31.5	F	Sub-adult	3	0.36
80	35.0	F	Sub-adult	4	0.40
81	33.0	M	Sub-adult	1	0.07
82	34.0	F	Sub-adult	2	0.15
83	33.0	F	Sub-adult	4	0.51
84	32.0	M	Sub-adult	2	0.15
85	30.0	F	Sub-adult	1	0.07
86	38.0	F	Sub-adult	3	0.31
87	29.5	F	Sub-adult	2	0.15
88	33.5	F	Sub-adult	1	0.07
89	36.5	F	Sub-adult	2	0.15
90	34.5	M	Sub-adult	3	0.27
91	32.0	M	Sub-adult	1	0.07
92	29.0	M	Sub-adult	2	0.12
93	30.0	M	Sub-adult	1	0.07
94	35.0	F	Sub-adult	2	0.15
95	32.0	M	Sub-adult	3	0.19
227	30.5	F	Sub-adult	3	0.19
228	41.5	F	Sub-adult	4	0.51
229	29.0	F	Sub-adult	4	0.56
4054	29.5	M	Sub-adult	2	0.17
4058	29.0	M	Sub-adult	2	0.17
4060	34.0	M	Sub-adult	5	0.49
200	25.0	M	Juvenile	N/A	N/A
201	22.0	M	Juvenile	1	0.07
202	22.0	M	Juvenile	N/A	N/A
203	23.0	M	Juvenile	N/A	N/A
204	25.0	M	Juvenile	1	0.07

Table 4., Continued.

Tag	TL (cm)	Sex	Class	# Rcvr. Loc.	Activity Space Area (km^2)
208	20.0	U	Juvenile	N/A	N/A
209	23.0	U	Juvenile	N/A	N/A
210	25.0	U	Juvenile	N/A	N/A
211	25.0	U	Juvenile	1	0.07

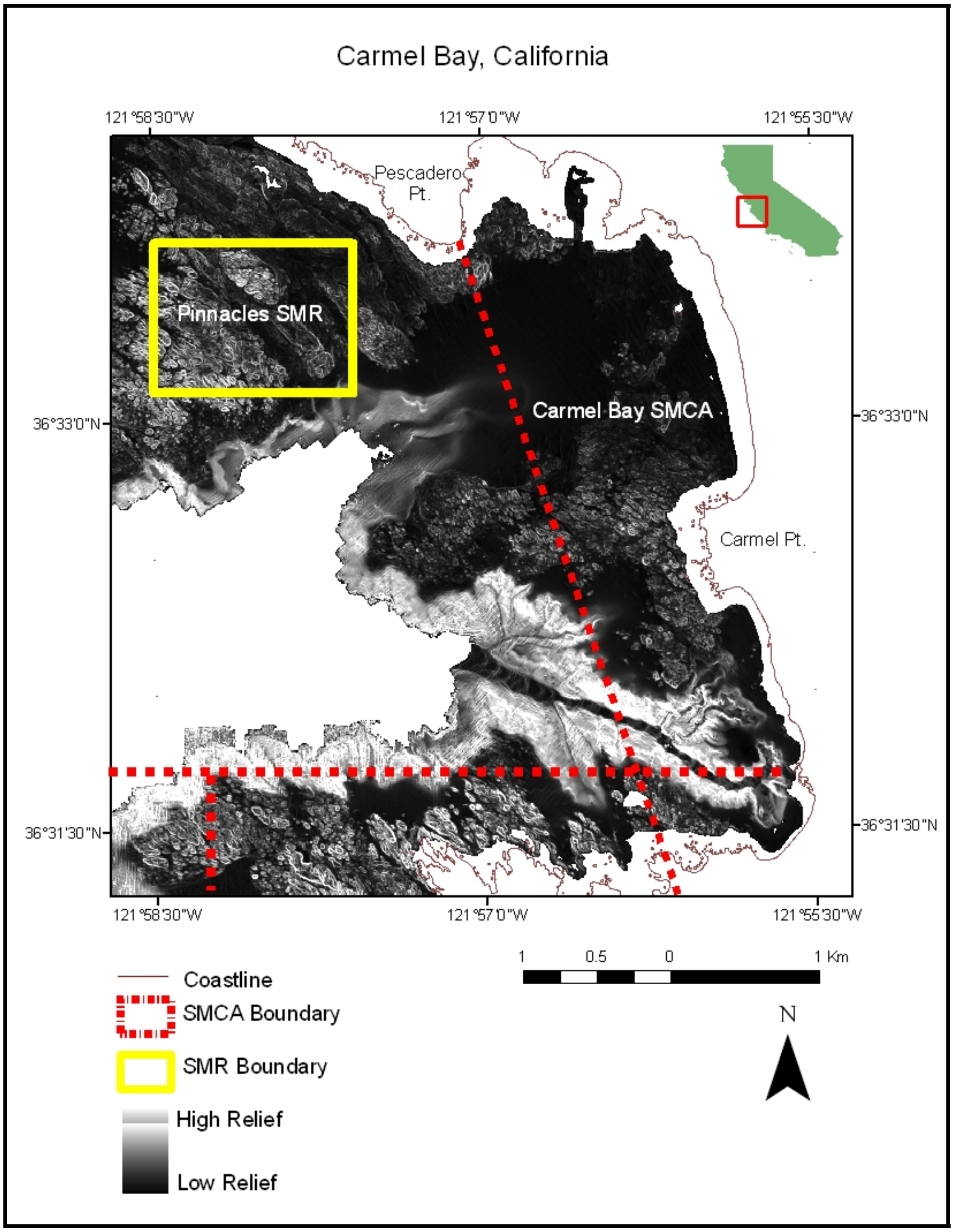

Figure 1. Multibeam bathymetry imagery of Carmel Bay with Marine Protected Area boundaries. SMCA denotes State Marine Conservation Area and SMR denotes State Marine Reserve (Data were acquired from the Seafloor Mapping Lab of California State University of Monterey Bay).

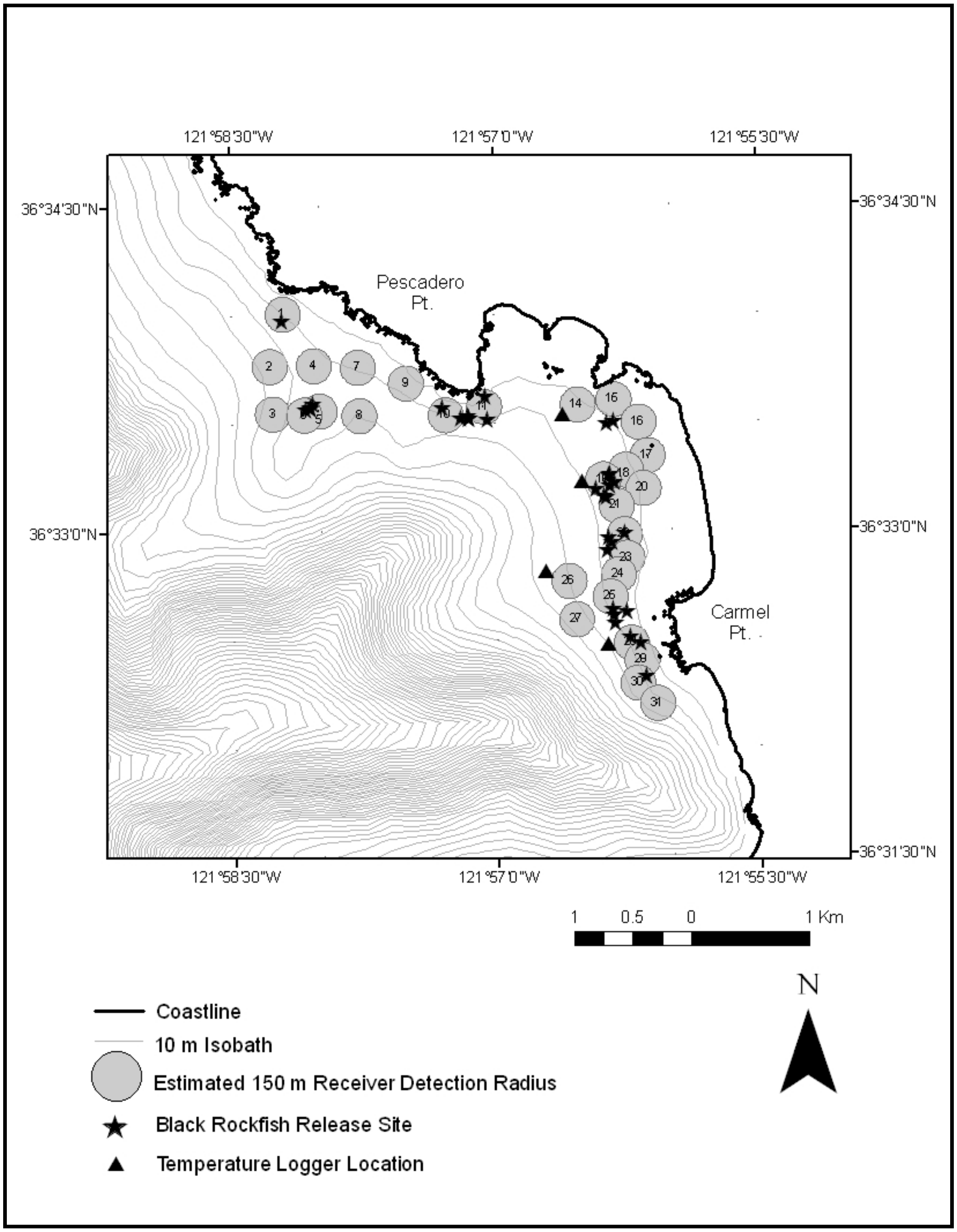

Figure 2. Configuration of VR2 receiver array with estimated 150 m detection ranges. Numbers indicate receiver locations, and circles around the numbers indicate the estimated 150 m detection radius around a moored receiver. Stars indicate release locations of tagged fish, triangles indicate location of temperature loggers.

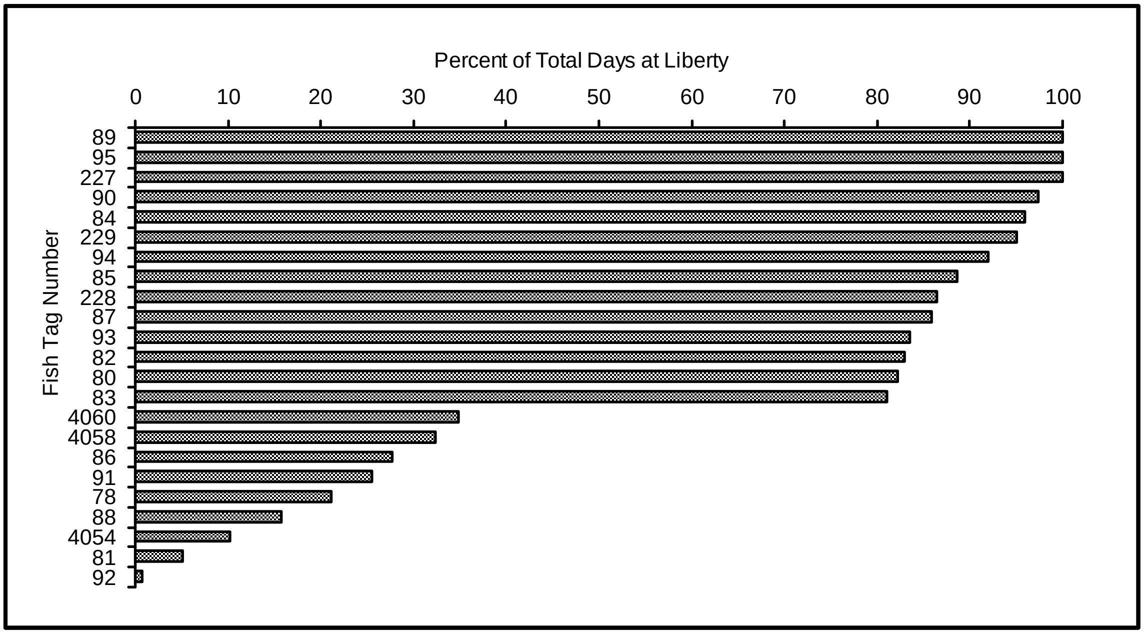

Figure 3. Percentage of days at liberty recorded in the array for 23 sub-adult black rockfish from August 2006 to January 2008.

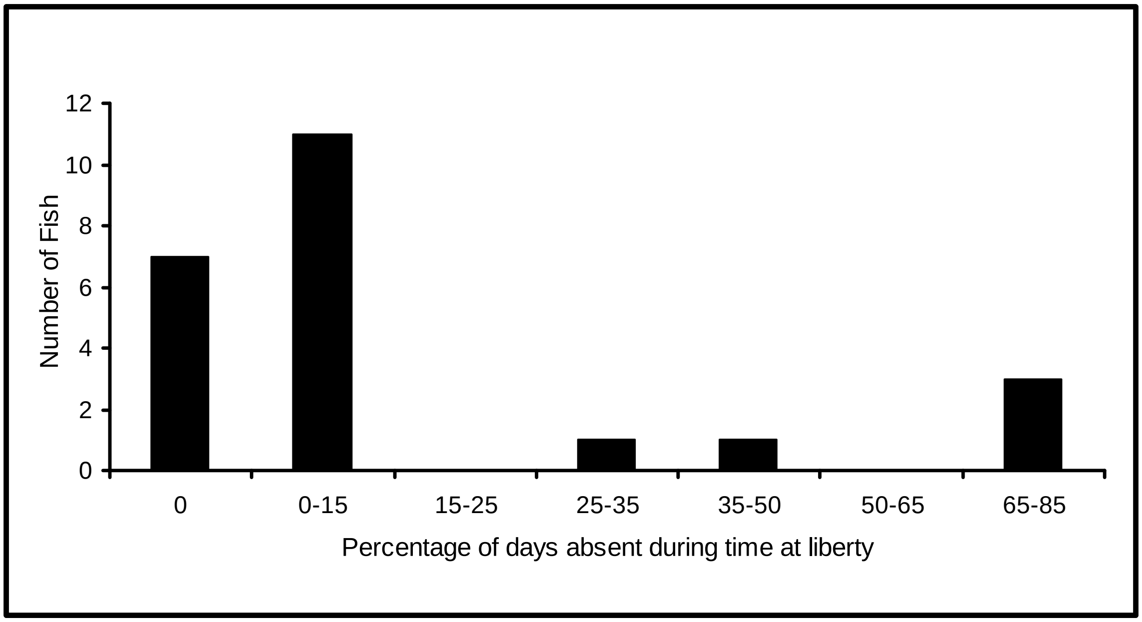

Figure 4. Frequency histogram of the percentage of days absent during time at liberty for 23 sub-adult black rockfish.

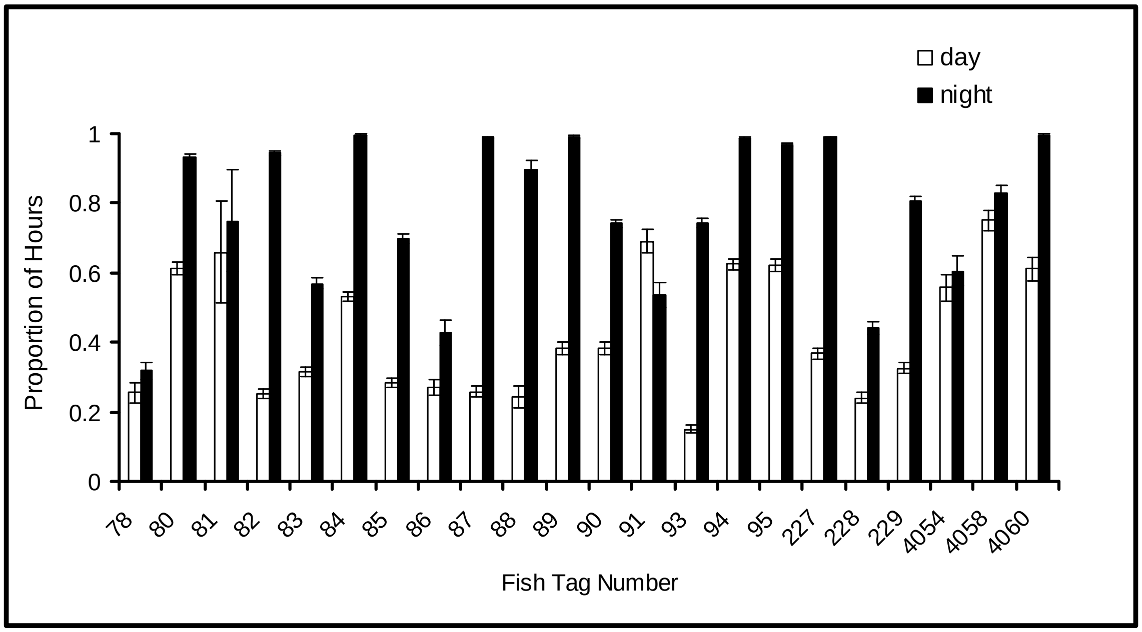

Figure 5. Mean proportion of hours detected in the array in the night period versus day period for tagged sub-adult black rockfish. Day periods began one hour after sunrise and ended one hour before sunset. Night periods began one hour after sunset and ended one hour before sunrise. Data were collected for a one-year period from October 1, 2006 through September 30, 2007. Error bars are SE.

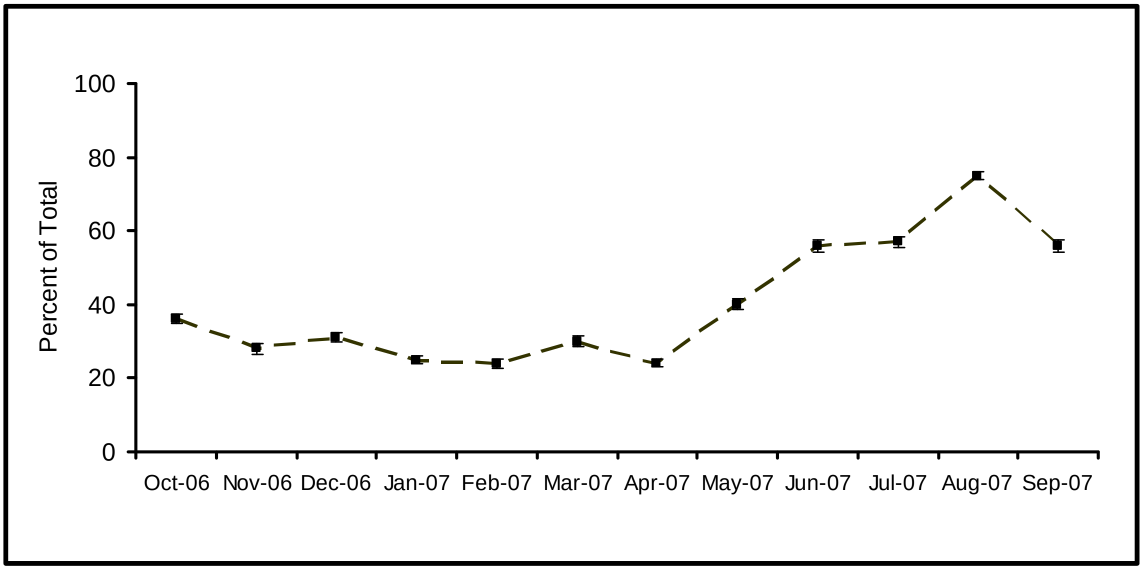

Figure 6. Mean monthly percentage of hours that sub-adult black rockfish were present in the study area during the day (night periods were excluded from analyses). Day hours began one hour after sunrise and ended one hour before sunset. Data were collected for a one-year period from October 1, 2006 through September 30, 2007. Error bars are SE.

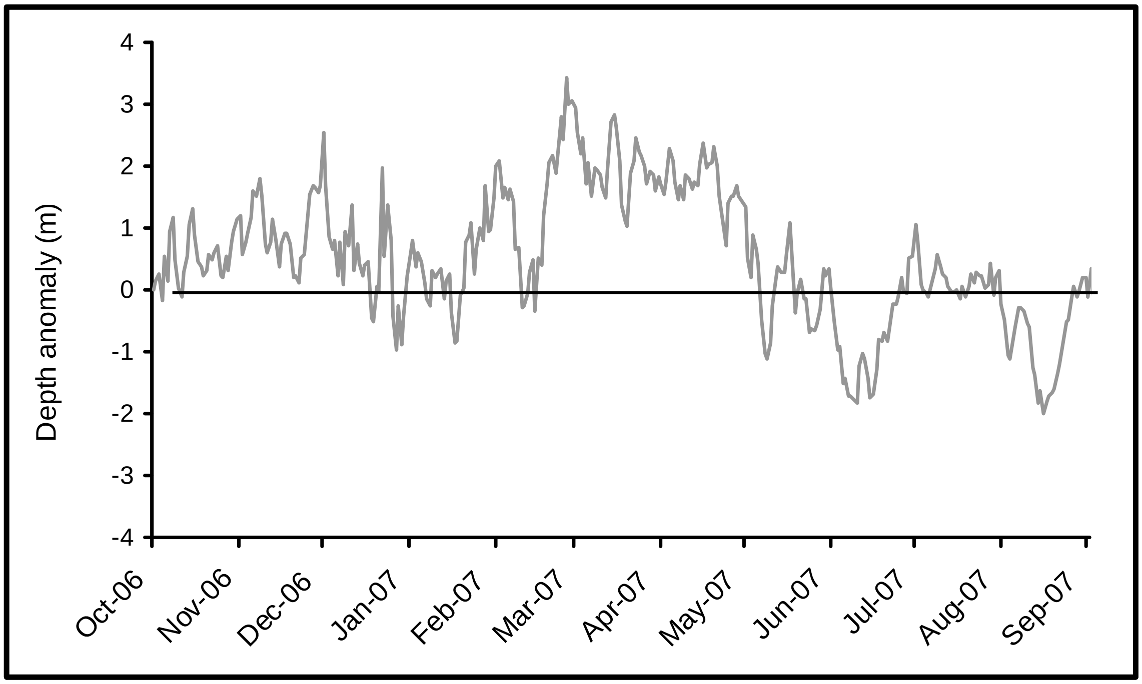

Figure 7. Mean daily depth anomaly (m) for sub-adult black rockfish during the period October 1, 2006 through September 30, 2007. A daily depth anomaly was obtained by subtracting the mean depth of a fish in a day from that individual's annual mean depth. Depth anomalies were then averaged and plotted as a function of time. Positive anomalies represent deeper average depth than the annual mean depth, negative anomalies represent shallower depth average than the annual mean depth.

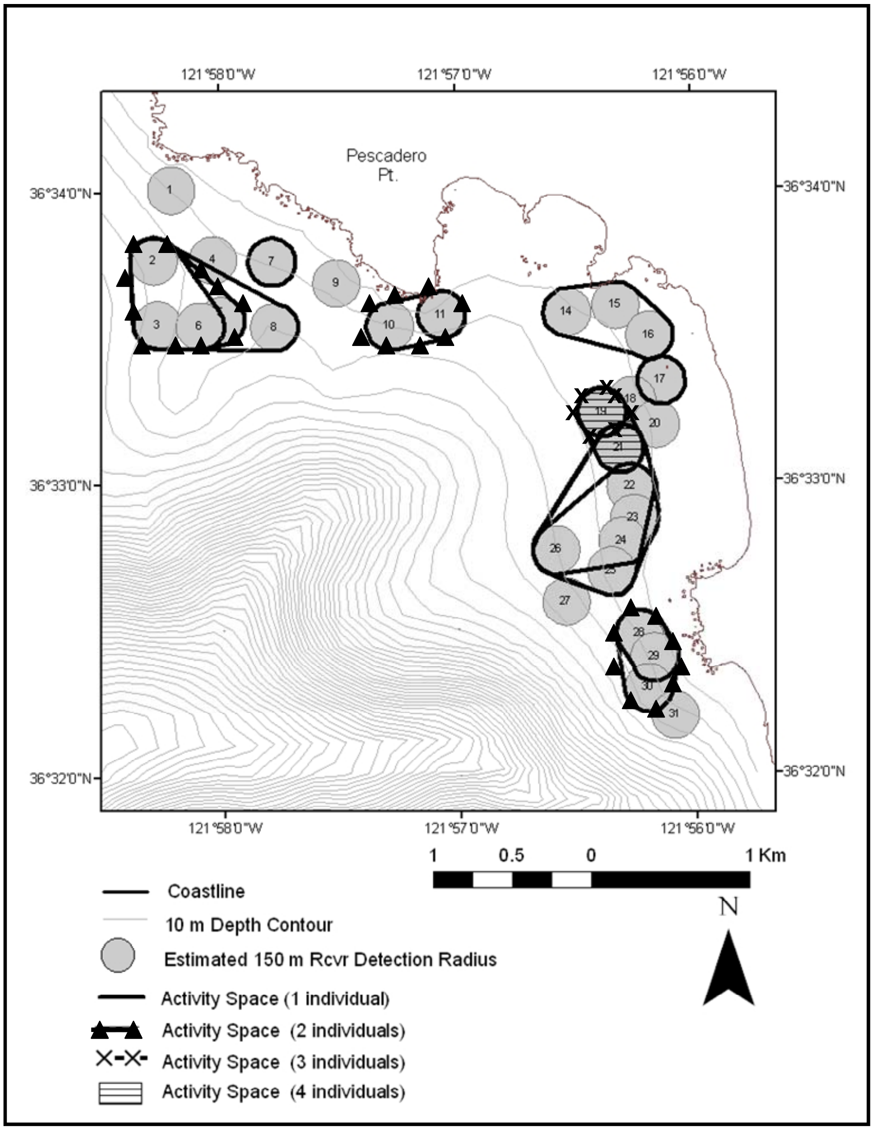

Figure 8. Estimated activity spaces for tagged sub-adult black rockfish in the study area. Each polygon represents the activity space based on the receiver locations where the individual was recorded during 90% of hours during time at liberty. In areas where more than one tagged sub-adult black rockfish used an activity space, symbols are used to represent the number of sub-adult black rockfish in that area. Polygon shapes with a solid black outline represent an activity space used by one individual, polygons outlined with triangles represent the activity space used by 2 individuals, polygons outlined with x's represent activity space used by 3 individuals, and the polygon filled with stripes represents an activity space used by 4 individuals.