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Site Fidelity and Movement of Eight Species of Pacific Rockfish at a High-Relief Rocky Reef on the Oregon Coast

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Abstract
We used acoustic telemetry techniques to study the movements of eight species of Pacific rockfish (genus Sebastes) inhabiting Siletz Reef, a high-relief rocky reef complex on the Oregon coast. Our primary interest was evaluating potential residence times for rockfish species in small, no-take marine protected areas (MPAs) like those recently designated for Oregon waters (337–1,502 ha). We tagged 6 black rockfish S. melanops, 31 canary rockfish S. pinniger, 9 yelloweye rockfish S. ruberrimus, 5 quillback rockfish S. maliger, and 2 copper rockfish S. caurinus, along with single specimens of china rockfish S. nebulosus, vermilion rockfish S. miniatus, and tiger rockfish S. nigrocinctus, and monitored their movements with a large (about 5,200-ha) receiver grid for over a year. Canary rockfish showed low site fidelity and wide-ranging movements that exceeded the scale of our detection grid and a wide range of vertical movements (up to 27 m). Quillback, vermilion, tiger, china, and some yelloweye rockfish showed high site fidelity, being detected only at one or two nearby receivers for a full year. The range of vertical movements of yelloweye, quillback, vermilion, and tiger rockfish was small, ranging from only 2–3 m for the single tiger rockfish to 3–13 m for four of the quillback rockfish. Black and copper rockfish showed site fidelity that was intermediate between that of canary rockfish and the other species. Black and copper rockfish showed a wide range in vertical movements (10–35 m and 2–33 m, respectively) within a month. Our results suggest that small, no-take MPAs located on high-relief rocky reefs would provide minimal protection for canary rockfish, some protection for black and copper rockfish, and greater protection for quillback, vermilion, tiger, and some yelloweye rockfish.

Understanding fish movements is essential for successful fishery management and for understanding the ecology of fish and their use of habitat. The need for a preliminary understanding of different species movements is increased by the trend towards using no-take marine protected areas (MPAs) to protect sensitive stocks (NRC 2001). Marine protected areas may be an especially useful conservation tool for Pacific rockfish Sebastes spp. because many species are thought to be sedentary (Matthews 1990; Parker et al. 2007) and may be vulnerable to overfishing or localized depletion (Yoklavich 1998; Soh et al. 2001; Hanselman et al. 2007). The Pacific rockfish include some of the longest-lived and least-resilient fish stocks captured in major fisheries in the northeast Pacific, and therefore may warrant additional protection (Parker et al. 2000; Munk 2001; Clark 2002). Seven species of Pacific rockfish have been declared overfished by the Pacific Fishery Management Council (PFMC 2008). The rationale for considering MPAs to protect some rockfish is supported by the fact that numerous species have been harvested for many years in mixed-stock commercial and recreational fisheries even though they still lack formal assessments of stock status.

The protection that MPAs of different sizes might provide for various rockfish depends on the scale and frequency of their movements. This is critical for small MPAs, like those recently designated for areas along the coast of Oregon (currently two areas: one of 337 ha, and one of 1,502 ha). For many rockfish species, little is known about movements, especially in nearshore marine environments like the open coasts of Oregon and Washington. The lack of information stems in part from difficulties inherent in studying movement of these fish with...
acoustic tagging methods in this type of habitat. Pacific rockfish are physoclist, and many species suffer severe barotrauma when brought to the surface for tagging (Starr et al. 2002; Hannah et al. 2008; Jarvis and Lowe 2008). Rockfish can also “disappear” acoustically when in crevices or rocky caves in complex habitat (Jorgensen et al. 2006). Finally, nearshore coastal reefs can also be a difficult environment in which to maintain moored acoustic receivers due to large storm waves, strong currents, and boat traffic (Parker et al. 2007). We report here on our use of acoustic tagging methods to study the movements of several rockfish species inhabiting a high-relief, nearshore, rocky reef complex along the Oregon coast. The study objectives were to (1) determine the approximate scale of spatial and vertical movements of several rockfish species, (2) determine which of the tagged species may have substantial residence times in small coastal MPAs, and (3) evaluate the limitations of using acoustic tagging methods to study demersal rockfish movements in this type of habitat.

METHODS

We chose the Siletz Reef complex, located off Lincoln City, Oregon (Figure 1), as our study area based on fishery catch data showing that this reef complex harbored a wide variety of nearshore rockfish. Water depths in the study area ranged from 20 to 69 m. The area contains a series of rocky reef structures, including massive, complex bedrock formations ranging in size from 0.75 to 200 ha (Donnellan et al. 2009).

Our study focused on species that shared two characteristics: minimal available information on movements in this type of habitat and a life history indicating low resiliency to harvest, such as a long life span and late age at maturity. Generally, these were also demersal species. The species of interest included two overfished species, yelloweye rockfish *S. ruberrimus* and canary rockfish *S. pinniger*. Quillback rockfish *S. maliger*, vermilion rockfish *S. miniatus*, copper rockfish *S. caurinus*, china rockfish *S. nebulosus*, and tiger rockfish *S. nigrocinctus* were also tagged as encountered. We also tagged several semipelagic black rockfish *S. melanops* as a control for our fish handling methods and grid performance, and to compare their movements in high-relief habitat with that observed in a prior study off Seal Rock, Oregon, in which tag retention, survival, and detectability were excellent (Parker et al. 2007, 2008).

Rockfish were captured by hook and line using recreational fishing gear in 2006 and 2007 at Siletz Reef. All fish were measured (cm, total length). Fish were tagged with Vemco V13-P
TABLE 1. Summary of Pacific rockfish tagged with acoustic tags at Siletz Reef, Oregon (Figure 1), by species and year of tagging. The length range (cm); number of specimens that survived, died, or had unknown status; number of tag failures; and number of specimens detected at any receiver location by time period (June 2006–June 2008) are also shown.

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<td>24</td>
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<td>11</td>
<td>4</td>
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<td>2</td>
<td>Alive 2, Dead 0, Unknown 0</td>
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*aProvided only a tidal signal in depth data, indicating mortality or shedding of tag.

bExternally tagged.

coded acoustic transmitters (Vemco; 69 kHz, 158 dB power output, 11 × 45 mm, pressure sensing [0–50 m, ±2.5-m accuracy, 0.22-m resolution, or 0–100 m, ±5-m accuracy, 0.44-m resolution]) which transmit an identification number (tag code) and depth. Coded tags used in 2006 transmitted at a random period between 150 and 300 s (nominal tag life = 500 d) and used the 0–50-m pressure sensor, while those used in 2007 transmitted between 60 and 180 s (nominal tag life = 346 d) and used the 0–100-m pressure sensor, with this transmission rate chosen to maximize detections before the study’s end in fall of 2008. All tags were tested for 24 h prior to the start of the study and retested immediately prior to field deployment.

Two surgical tagging methods were used: external attachment and implantation within the body cavity. No anesthesia was used for either method. All species tagged in 2006 other than black rockfish were tagged externally with a monofilament-wrapped tag (Table 1). For external tag attachment, we used a disinfected, hubless hypodermic needle (Jorvet; 16 ga, 102 mm) to make two penetrations through the anterior dorsal muscles. The monofilament (Jinkai; 0.87-mm diameter) ends were threaded through the needles and the needles were removed. The tag was secured by running the monofilament through a 14-mm plastic disk and 6-mm glass bead, on the opposite side of the body, and crimping on a copper sleeve (Sevenstrand; 6.7 mm). Externally tagged fish were not vented to remove excess swim bladder gas. External tagging was used initially to reduce tagging time, but the technique was abandoned in favor of internal implantation as handling times improved. All black rockfish and fish tagged in 2007 were tagged internally as per methods outlined in Parker et al. (2007). As needed based on external signs of barotrauma, these fish were vented prior to tagging using a sterile 18-ga hypodermic needle inserted through the body wall. The time on deck ranged from 2 to 8 min for all fish and averaged 4.6 min. During this surface interval, fish were partially immersed in seawater.

After tagging, fish were immediately placed in a video-equipped underwater release cage (Hannah and Matteson 2007) and released at the site of capture, at depth. The cage door was opened after we confirmed tag identification and depth transmission, and observed that tagged fish could swim and orient vertically in the cage. We used a Vemco VR100 acoustic receiver and hydrophone (VH165) to confirm tag transmission and depth of release.

For our receiver grid, we used moored Vemco VR2 and VR2W single-channel acoustic receivers (Vemco, Halifax, Nova Scotia) deployed at the Siletz Reef complex and also at nearby Government Point Reef off Government Point, Oregon (Figure 1). Receivers were tested and determined to be functional prior to deployment. Government Point Reef is located 4 km south of Siletz Reef and was monitored to determine if fish leaving the Siletz Reef complex might show up at this nearby rocky habitat.

Design of the detection grid for our study was influenced by several factors. The detection range of acoustically tagged demersal fish in this type of habitat was likely to be very site specific. We chose to initially separate our receivers widely enough to eliminate simultaneous detections at multiple receivers so that a new detection of a fish at a receiver would definitively indicate movement. In the western portion of the grid (where depth is greater and the habitat has less relief), initial grid spacing was
based upon prior range testing at Stonewall Bank (> 1-km range; Oregon Department of Fish and Wildlife, unpublished data), an acoustically quiet, offshore reef complex with similar water depths, located about 22 km west of Newport, Oregon. In the eastern portion of the grid (where depths are shallower and habitat is more complex), initial grid spacing was based upon range testing conducted in a prior movements study at nearby Seal Rocks Reef complex (350–500-m range, 9–40-m depth; Parker et al. 2007). Periodic downloads of the detection grid were used to monitor which tagged fish were being detected by the initial grid. We also actively searched for missing fish using a Vemco VR100 tracking receiver and hydrophone, and deployed groups of moored receivers for multiple short-term (2-h) deployments. As we located “missing” fish within the study area, we added receivers to the grid to generate better information on vertical movements and site fidelity. In several instances, this resulted in receivers being located in close proximity to each other. For the purposes of analysis and clarity of presentation, when receiver moorings were located within 600 m of one another, detections were treated as if they came from a single receiver located at the average position of the group of receivers (Figure 1) and were screened to eliminate simultaneous detections within the grouped receivers.

The initial detection grid was deployed in June–July 2006 as 18 receiver locations at Siletz Reef and three at Government Point (Figure 1A). An additional eight receiver locations were added in August–September 2006 (triangles, Figure 1A). All moorings were removed for the winter in October 2006 to avoid loss of receivers from winter storms. The grid was redeployed in June 2007 and included 30 receiver locations (Figure 1B).

The detection grid was reduced for November 2007 to March 2008 to include just the primary area of tag detections at the Siletz Reef complex (Figure 1C). This configuration enabled monitoring of the majority of remaining tagged fish over the winter storm period while reducing the potential for receiver loss. The detection grid was expanded again for April through September 2008 (Figure 1C).

With multiple acoustic tags operating in the same area, tag transmissions that overlap in their arrival time at a receiver can cause tag decoding errors, such as false-positive detections for known codes as well as errors in depth data (Pincock 2008). Prior to analysis of geographic movements, acoustic tag detections were screened to eliminate false positives. Techniques for eliminating false positives are a compromise between the risks of discarding valid movement data and interpreting false positives as valid detections (Pincock 2008). We chose an approach that erred toward rejecting data that might have been a false positive, in part because of the large number of individuals tagged in our study, making acoustic collisions more likely. We accepted tag detections if and only if they occurred as part of at least three detections at a single receiver, each separated by no more than 3,600 s.

We analyzed both the horizontal and vertical movements of tagged fish. The scale and frequency of movement of individual specimens influenced how the data were best analyzed. For specimens that mostly remained within the detection grid for long periods, we compared horizontal and vertical movements on a monthly basis. Vertical movements were based on the depth data transmitted by each tag, and since these data were comparable regardless of the detection grid layout in place at that time, data from all receivers were used. To estimate the range of vertical movement of each fish, we first regressed fish depth at a specific time against concurrent 6-min sea level height measurements at South Beach, Oregon (about 28 km south of the study area) to remove the influence of tidal variation. Then, using the regression residuals, we calculated the 99th percentile range of vertical movement on a monthly basis. The 99th percentile range was chosen, rather than simply the range, to reduce the influence of decoding errors in the depth data, as noted above, that can create infrequent, unrealistic “spikes” in depth. To make sure that low sample sizes did not allow depth decoding errors to bias estimates of vertical range, we also estimated the 99th percentile vertical range only for months with at least 400 observations of depth for an individual fish. To assess posttagging survival, we considered either vertical movements or movement between receiver locations as evidence of survival.

Changes in the layout of the detection grid and periodic loss of receiver moorings complicated the analysis of horizontal movement, especially for comparing movements between fish and estimating home range. To compare detections quantitatively between fish requires that, for any time period being considered, all detections reference a constant receiver layout. For example, adding a new receiver to an area in which a particular tagged fish is present creates the appearance in the data that the fish has moved into this area when, in fact, it may not have moved at all. We addressed this problem by carefully selecting the detection data to use for comparisons. First, we identified multi-month time periods during which a constant receiver grid could be used to analyze movement on a monthly basis. These time periods were July through October 2007 (Figure 1B), November 2007 through March 2008 (filled circles, Figure 1C) and April through June 2008 (all circles, Figure 1C). Next, to remove the influence of changes in the receiver grid for each time period, we screened out all detections at receivers that were not present for large portions of any of these time periods.

To evaluate site fidelity across species, we first assigned a primary location for each tagged fish for every hour that it was detected, based on the receiving location with the largest number of detections. Ties between receiver locations in number of detections in a single hour were resolved by random assignment. Based on these primary receiver locations for each hour, we identified the receiver location at which each tagged fish was most frequently located during each of the three multi-month time periods discussed above. This was then considered the “home” receiver for that tagged fish within that period. We compared horizontal movements based on the mean percentage...
of available hours in a month during which a fish was located at its home receiver in comparison to all other receivers. This approach minimizes the effect of differing detectability between semipelagic and demersal fish, but it can also mask some very high frequency movements that may occur within a single hour. Despite this limitation, we chose this approach as the best method for making comparisons between specimens. In evaluating relative site fidelity, we considered tagged fish that were primarily detected at their home receivers for the duration of the study to have high site fidelity. Tagged specimens that showed evidence of movements exceeding the size of our detection grid were considered to have low site fidelity. Fish that were detected mostly at their home receiver but that were periodically located at other receiver locations, or showed a definitive shift in home receiver location, were considered to have intermediate site fidelity. Given the initial objectives of our grid design and the limitations discussed above, we chose not to try and estimate home range size from our study data.

Detection data from June through October 2006 were not used to compare monthly movements because many tagged fish were not frequently being detected with the initial grid layout (Figure 1A). We do present some movement data from this and some later time periods in graphic form for selected fish that were mobile and well detected for short periods of time. It should be noted that although these data were screened for false-positive detections, it wasn’t possible to screen these brief sets of detections for the infrequent errors in decoding of depth data.

RESULTS

We acoustically tagged a total of 6 black, 31 canary, 9 yelloweye, 5 quillback, and 2 copper rockfish as well as single specimens of china, vermilion, and tiger rockfish (Table 1). All tagged fish showed an ability to orient vertically at release, indicating some potential for survival despite capture-related barotrauma. Initial receiver downloads from 2006 showed that while most of the black rockfish were being detected consistently, many tagged fish of species considered to be more demersal were not (Figure 1A). Additional active tracking and brief deployments of additional receivers showed that many of the “missing” fish were present within the study area but were located in areas of high relief, where they were not being detected consistently, even by nearby gridded receivers. The addition of moored receivers in close proximity to the located fish resulted in more frequent detections (compare Figures 2–4 and receiver locations added between Figure 1A–C). This was most notable as increased detections of black rockfish 30, copper rockfish 29, china rockfish 24, quillback rockfish 215, tiger rockfish 184, and vermilion rockfish 31 after receivers were added at D6, C6, C7, and B9 (Figure 1).

Maintaining receiver moorings at the Siletz and Government Point Reef complexes was generally successful; however, periodically, receiver moorings were lost. Over the course of 19 months, including 10 downloads of the receiving grid, 12 receivers disappeared from the array; however, five of these were recovered with usable data intact. The absence of receivers created some gaps in the spatial and temporal coverage of portions
FIGURE 3. Mean ± SE percentage of hours per month that each tagged specimen was detected at its home receiver location and at any other receiver location within the study grid (Figure 1C), November 2007–March 2008. The home receiver for each specimen is shown in parentheses.

FIGURE 4. Mean ± SE percentage of hours per month that each tagged specimen was detected at its home receiver location and at any other receiver location within the study grid (Figure 1C), April–June 2008. The home receiver for each specimen is shown in parentheses.
specimens with failed tags showed enough movement between receiver locations to demonstrate posttagging survival, detections were treated as reliable data on horizontal movements.

All six acoustically tagged black rockfish survived the tagging procedure. Black rockfish showed evidence of intermediate site fidelity, along with variability in movement between individuals and periodic changes in home receiver location (Figures 2–4). For example, black rockfish 19 was primarily detected at receiver location C5 for all three time periods, spanning an entire year (Figures 2–4). Black rockfish 26 was most frequently detected at receiver D4 in all three time periods (Figures 2–4) but traveled to seven different receiver locations in October 2007 and relocated to the vicinity of C5 during November 2007 to January 2008 (not shown). Similarly, black rockfish 30 was consistently detected at receiver locations D6 and D5 for a full year (Figures 2–4), but during about 1.5 h on October 6, 2007, this fish was detected to the north, at receiver locations D2, C3, and D4, before returning to D6 a few hours later. Then after being consistently detected at D6 until October 9, 2007, black rockfish 30 went undetected for 2 d, after which it was next detected on October 11, 2007, at D2, followed by C3 and D4, after which it returned to D6. Tagged black rockfish showed a large 99th percentile vertical range on a monthly basis, varying from about 10 to 35 m (Figure 5).

Of the 31 acoustically tagged canary rockfish, 16 showed evidence of having survived at some point following tagging (Table 1). Seven canary rockfish provided depth data showing a clear tidal signal, indicating they had either shed the tag or failed to survive (Table 1). For several canary rockfish, tag failure or a lack of detection data prevented any firm conclusion on even short-term survival (Table 1).

The tag detections that were obtained from canary rockfish that survived and spent some time within the study area provided a possible explanation for the lack of detection data for many of the tagged canary rockfish. Movements of these individuals showed low site fidelity and very rapid travel across much of the detection grid, suggesting that some of the tagged canary rockfish may have simply left the study area quickly and not returned. For example, canary rockfish 20 visited 17 different receiver locations in just 41 d, visiting several of the sites twice during this period, and then went undetected for the remainder of the study (Figure 6). The latter portion of this string of movements demonstrates the speed with which some canary rockfish travel. Between receiver location E5 and B13 on October 18, 2006, this specimen traveled at least 13.5 km in just under 14 h (Figure 6). This specimen exited the study area to the south after being detected last at B13, the northernmost receiver at Government Point Reef (Figure 1). Canary rockfish 196 and 197 were detected at 10 and 9 different receivers, respectively, each within just 10 d (Figure 6). These two fish also showed rapid rates of movement at times. For example, between July 22 and 24, 2007, canary rockfish 196 visited eight receiver locations, covering a combined minimum linear distance of about 14.7 km in just 2 d (Figure 6).

A few canary rockfish showed a different pattern of movement, consisting of periodic detections being made within the grid spanning many months. Canary rockfish 213 was detected periodically for more than a year at receiver locations C9 and B9 (Figures 2–4). However, it is unknown how far this fish may have ranged during the majority of the time when it was not detected within the study area (Figures 2–4).

Canary rockfish also showed evidence of a wide range of vertical movements, some of which may be movements off of the bottom. The few canary rockfish that provided enough depth data to estimate the 99th percentile vertical range on a monthly basis showed a vertical range of up to 27 m (Figure 5). The depth data for tagged canary rockfish 20, 196, and 197 (Figure 6) show large and rapid changes in depth as well as some time spent at very shallow depths, sometimes in areas that have little, if any, shallow substrate. For example, canary rockfish 196 spent some time on July 26, 2007, at receiver location A10 (Figure 6) at a depth of less than 20 m. The water depth at location A10 is 56.7 m, and there is no substrate shallower than 20 m within any reasonable tag detection range of that receiver. Similarly, canary rockfish 20 was detected at receiver location C12 on September 14, 2006, at a depth of just 10 m (Figure 6), however, there are no nearby areas with this shallow of a water depth.
Four of the five acoustically tagged quillback rockfish survived and provided movement data for more than a year (Table 1). The status of quillback rockfish 28 was unknown because the tag failed shortly after release and all subsequent detections were at a single receiver location. The other four quillback rockfish showed variability in the percentage of hours detected per month, ranging from low detection rates for quillback rockfish 27 to more continuous detection for quillback rockfish 215 in some time periods (Figures 2–4). Individual quillback rockfish were generally detected at only one receiver location or, at most, two closely spaced receiver locations for the duration of the study, indicating high site fidelity (Figures 2–4). The monthly vertical ranges observed for quillback rockfish ranged from about 3 to 13 m (Figure 5). One individual showed very modest vertical movement (quillback 202) and another showed vertical ranges of more than 10 m in some months (quillback 206).

Of the nine yelloweye rockfish tagged, two died or shed the tag within our study area (Table 1). Of the remaining yelloweye rockfish, three survived and provided movement data for over a year and three had “unknown” status either due to tag failure.
PACIFIC ROCKFISH SITE FIDELITY AND MOVEMENT

The three fish that survived and were well detected within the receiver grid showed high site fidelity, generally being present at one or two adjacent receivers in any time period (Figures 2–4). The receiver locations for these yelloweye rockfish did not vary much throughout the year. For example, yelloweye 205 was primarily present at location C11 and occasionally present at an adjacent receiver, and this pattern can be seen to persist across the full year (Figures 2–4). These three fish also showed some of the highest levels of detectability in the entire study, as shown by high levels of detection across all three time periods and a consistent lack of detections at nonhome receivers (Figures 2–4). These three yelloweye rockfish also showed very modest vertical movements as shown by monthly 99th percentile vertical ranges between 3 and 7 m (Figure 5). Yelloweye rockfish also showed much less month-to-month variability in vertical range than canary, black, or even quillback rockfish, supporting a strong affinity for the substrate.

Both of the tagged copper rockfish survived and provided some data on movements (Table 1). Variability in the mean percentage of hours detected at the home receiver location for copper 29 (Figures 2–4), as well as the movements of both copper rockfish over shorter time periods (Figure 7), suggest intermediate site fidelity. These two copper rockfish were also undetected for long periods, consistent with movement outside the study area; however, this could also simply be highly variable detectability due to close association with complex substrate. The former interpretation is supported, however, by the wide ranging movements shown by both fish during short time periods in which they were well detected within the receiver grid (Figure 7). Copper rockfish 7 visited four receiver locations between August 23, 2006 and October 25, 2006 (Figure 7), after which it was not detected within the receiver grid. Copper rockfish 29 made very wide-ranging movements between January 31, 2008, and February 19, 2008, visiting five different receiver locations, many repeatedly (Figure 7). Between February 10 and 17, 2008, a period of very consistent detection, copper rockfish 29 moved repeatedly between five different receiver locations, covering a combined minimum linear distance of 6.3 km in 7 d. This fish also showed seasonal variability in site fidelity and wide-ranging movements at times as mentioned, in combination with nearly continuous detection at receiver location C7 from April through July 2008 (Figure 4). The patterns of vertical movements for both fish, but especially for copper 29 (Figures 5, 7), show that copper rockfish can have a wide range in vertical movements, ranging from 2 to 33 m within a month (Figure 5). The changes in depth seen in copper rockfish often changed gradually, which would be expected when a demersal fish follows terrain changes as it moves between areas of varying bottom depth, although off-bottom movement cannot be ruled out.

The single tagged tiger rockfish survived and provided movement data for most of the ensuing year (Table 1). This fish was not well detected by the receiver grid that was in place initially following tagging (Figure 2). After a receiver was added at location C6 (Figures 3–4), this fish was moderately well detected for the remainder of the study. The lack of detections at other receiver locations suggests a lack of large-scale movements by this specimen. This specimen also showed the smallest range of vertical movement in this study—only about 2–3 m (Figure 5).

The single tagged vermilion rockfish also showed high site fidelity. This specimen was consistently detected at receiver location B9 (Figures 2–4) and was only rarely and briefly present at an adjacent receiver. This fish showed a monthly vertical movement range of 4–6 m (Figure 5). This is larger than that of the tiger rockfish and within the range observed here for yelloweye rockfish (Figure 5).

**FIGURE 7.** Depth and location of detection (receiver location code; see Figure 1) for two acoustically tagged copper rockfish: (A) copper rockfish 7 in 2006 and (B) copper rockfish 29 in 2008. The width of the white or shaded band indicates the duration of detection at the receiver location indicated. [Figure is available in color online.]
The single tagged china rockfish also showed high site fidelity. This specimen was poorly detected with the initial receiver grid layout but was better detected with the added receivers (Figures 2–4). The early tag failure prevented the gathering of usable data on vertical movements (Table 1).

**DISCUSSION**

Fish movement data inferred from patterns in acoustic tag detections at fixed receiver locations are based on a series of assumptions that are reasonable but, in many specific applications, are also untestable. Accordingly, a full understanding of a species' movements requires multiple studies across a variety of habitats and conditions, hopefully producing data that are consistent. For some of the rockfish studied here, the data from this study represent a “first approximation” of movement tendencies in this type of high-relief habitat, which should be further evaluated through additional study. Our interpretation of detection data also relied on several assumptions. We assumed that if a tagged fish were consumed by a predator, the effect on our movement data would be minimal because the tag would be excreted within, at most, a few days, and then generate a recognizable tidal signal in depth data. It is also possible, however, that tags that were either shed or consumed and excreted by a predator could have fallen into crevices where they would remain undetected. We also assumed that consistent detections of a tagged fish at one receiver location, in combination with a lack of detections at nearby and distant receivers, was a reliable indicator of high site fidelity. Conversely, we assumed that a rapid decline in detections within our study area for multiple tagged individuals of a species, in combination with data showing wide-ranging movements for some specimens over shorter time periods, reliably indicated low site fidelity.

One interesting finding of this study is the evidence for wide-ranging spatial and vertical movements of canary rockfish (Figures 5–6), a species for which little is known about movements, especially on time scales of days to months. Large-scale movements (100s of kilometers) following multiyear periods at large have been reported for single tagged specimens of canary rockfish (Love et al. 2002) and for several individual specimens following periods of several months to years at large (DeMott 1983; Lea et al. 1999). The data presented here show evidence for large-scale movements as perhaps a typical pattern for the species on shorter time scales of days to months, probably including some excursions above the sea floor. This information is significant because, combined with evidence that canary rockfish form large aggregations, it may help to explain the highly variable trawl survey catches for this species (Stewart 2008) as well as the highly variable nature of canary rockfish bycatch in trawl fisheries (Hannah et al. 2007).

The combination of intermediate site fidelity, variability in site fidelity between individual fish, periodic relocations in the activity center, and the large vertical range of movement (Figures 2–6) observed here for black rockfish is consistent with prior movement studies off Seal Rock, Oregon (Parker et al. 2007, 2008). Our movement data for yelloweye, quillback, vermilion, tiger, and china rockfish (Figures 2–6) are generally consistent with the concept that some Pacific rockfish are typically sedentary species with high site fidelity, small home ranges, and a strong affinity for rocky substrate (Lea et al. 1999; Love et al. 2002). Our copper rockfish data, though limited, support a scale of movement for this species that can be larger at times, but still smaller than the scale of movement shown by canary rockfish. Where other data on movements exist, our findings with regard to yelloweye, quillback, vermilion, and china rockfish are generally consistent with those of prior work. For vermilion rockfish, our findings do conflict with the much lower site fidelity shown by Lowe et al. (2009) at offshore petroleum platforms in the Santa Barbara Channel, California. However, this difference is only based on a single specimen in our study, and there is some question regarding differentiation between two cryptic forms of vermilion rockfish in California waters (Hyde et al. 2008) that may have influenced movement data in the study by Lowe et al. (2009). Conventional tagging studies for yelloweye rockfish showed very low return rates but support high site fidelity (Coombs 1979; DeMott 1983), consistent with our results for three tagged specimens. In light of the lack of data from six of the nine yelloweye rockfish we tagged, we remain cautious about generalizations regarding movement tendencies for this species. Tagging studies of quillback and copper rockfish in Puget Sound, Washington, found very small home ranges (most < 10 m²) for these species living on high-relief rocky reefs and larger, but still small (<4,000-m²) home ranges on low-relief reefs (Matthews 1990). Tolimieri et al. (2009), also working with these two species in Puget Sound, Washington, estimated home range to be about 1,500–2,500 m². Tag returns of vermilion rockfish and china rockfish off central California also suggest very little movement (Lea et al. 1999). For copper rockfish, our data are more consistent with the findings of Lowe et al. (2009), who described copper rockfish as having comparatively low site fidelity at offshore oil platforms in the Santa Barbara Channel, and with tag return data from Lea et al. (1999) showing movements up to 2.78 km. These differences between studies in movement tendencies of copper rockfish support the contention of Tolimieri et al. (2009) that broad generalizations about movements for some fish species may be very difficult to develop. Our data for copper rockfish 29 show that in addition to variability between specimens and habitats, movement can vary seasonally for an individual specimen, making generalizations about movements from short-term studies potentially misleading. In a similar vein, studies of the movements of just a few individual specimens, like a few species in this study, should also be used cautiously. However, one of the primary strengths of the data developed in this study is that specimens were monitored for a longer time period than for many studies—for a full year, in some cases.

Our data show that different rockfish species inhabiting Siletz Reef utilize space in both starkly and subtly different ways.
Space utilization ranged from transient use of the reef (many of the canary rockfish) to nearly continuous presence through all four seasons of the year, and virtually no large-scale movements (three yelloweye rockfish). Subtle differences in vertical movements were also apparent, even between species that are considered demersal. The best example of this is the larger vertical ranges observed for three quillback rockfish in some months in comparison with very limited vertical movement of all three yelloweye rockfish in all but a few months (Figure 5). These differences in how species use space at Siletz Reef probably contribute to niche differentiation, in combination with other ecological factors such as diet and interspecific behaviors. A better understanding of how differences in movement may contribute to niche differentiation at Siletz Reef will require methods that allow description of spatial movements at a much finer scale than in our study.

The data from this study show that it is feasible to use acoustic telemetry techniques to study the movements of some demersal Pacific rockfish living on high-relief rocky reefs along the open Oregon coast. Our initial grid design, in combination with some added receivers, enabled us to acquire preliminary information on movements for some rockfish species for which very little information existed. One major benefit of having this preliminary information is that it facilitates the design of future movement studies, such as those employing more sophisticated telemetry techniques to analyze detailed movements of sedentary species or presence–absence studies aimed at the more mobile species like canary rockfish. Even with significant capture-related barotrauma in many specimens in our study, many fish survived and some useful information on site fidelity was obtained. However, we did encounter some problems that limited the use of our detection data. Our initial grid design worked well in detecting the movements of semipelagic black rockfish and the large-scale movements of some canary rockfish that spent time in the study area; however, it also left detection “holes” in areas of complex habitat that were particularly problematic with strongly demersal fish. Augmentation of our receiver grid lessened the problem, but did not eliminate it. In future studies, receiver grid designs should be configured to eliminate these dead spots by the placement of additional receivers based on locating tagged specimens with a mobile hydrophone or short-term deployments of moored receivers. Also, spatially extensive range testing of moored tags and detection efficiency tests, including tag depth as a variable, could be used to better-define detection range as a function of location in three dimensions (Heupel et al. 2006). Future studies of sedentary rockfish species in this type of habitat could also perhaps benefit from the use of newer telemetry technology that generates triangulated positional fixes for individual fish from multiple receivers spaced more closely. The lack of movement of many of the demersal species we tagged also suggests that acoustic tags that provide depth data are very helpful for differentiating between a tagged specimen that failed to survive and a surviving fish that is sedentary.

The movement data developed here have some implications for the species-specific effectiveness of the small MPAs (337–1,502 ha) recently designated for nearshore waters off Oregon and also for conservation generally of some potentially vulnerable rockfish species living on nearshore rocky reefs. The movement data for canary rockfish in this study suggest home ranges that frequently exceed the size of the northern portion of our study area (about 5,200 ha). Clearly, this scale of movements is too large to expect a meaningful reduction in mortality rates for this species as a result of small MPAs. Most canary rockfish would not be expected to remain within small MPAs long enough to gain much protection. However, the evidence for large-scale movements of canary rockfish also suggests a sufficient level of population mixing to prevent localized depletion of canary rockfish at nearshore reefs. This high level of movement by individuals also supports the current approach of conducting stock assessment and management on geographically large stock units (Stewart 2008). The high site fidelity shown here for some yelloweye and quillback rockfish, and possibly for vermillion, tiger, and china rockfish, suggests that some reduction in fishing mortality rates of groups of individuals could be realized in small MPAs, if properly located. The high site fidelity of these species also suggests a strong potential for localized depletion in areas open to fishing, further supporting a positive role for no-take MPAs in maintaining biodiversity. It also suggests that stock assessments based on smaller geographic units may be more appropriate for these more sedentary species.

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