GROUNDFISH COOPERATIVE RESEARCH PROJECT

Species Composition, Relative Abundance, and Movements of Important Nearshore Fish Species Along the North Central California Coast

Final Report to the Pacific States Marine Fisheries Commission

By

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Introduction

In June 2002, the Pacific Fishery Management Council (PFMC) closed ocean waters south of Cape Mendocino, California to the harvest of all shelf rockfish species because of the population status of a few depleted stocks. As a consequence of creating the rockfish conservation area (RCA), fishing pressure on nearshore species has increased. The California Marine Life Management Act requires that the California Department of Fish and Game (DGF) use best available science to actively manage nearshore fisheries to ensure conservation of nearshore species, reduce bycatch, protect habitat, and obtain estimates of abundance (Weber and Heneman 2000). It is difficult to develop appropriate regional management plans, however, without sufficient information about the abundances and movements of fishes, and fishing patterns of fishermen. In addition to fishery closures in the RCA, the State of California is considering new marine protected areas as a response to the California Marine Life Protection Act.

The waters off Bolinas, CA, are frequently fished by anglers on commercial passenger fishing vessels (CPFVs), private anglers, and commercial fishermen (Fig. 1). This area is heavily fished, yet with the exception of DFG port sampling and onboard observer data, there has been little research conducted in the waters off Bolinas. The popularity of the area for fishing, and the lack of information about it, has led to proposals that some or all of Duxbury reef be declared a marine protected area (MPA). As the Marine Life Protection Act process continues to move forward along the California coast, more information about population sizes and movements of fishes will help in the policy discussions about whether or not to develop MPAs in an area. Information about movements of fishes is especially useful, as it is important to know if an area containing a proposed MPA is a source or a sink for fishes.

In 2005 and 2006, we conducted a study to gather information about species targeted in commercial and recreational fisheries near Bolinas, CA. Our goal in this project was to combine the resources of fishermen and university scientists to learn more about populations of nearshore fishes in an area that is heavily fished by boats from the San Francisco Bay area, and provide information that will be useful for policy discussions about marine protected areas in this region. We worked with charter boat skippers and local anglers to catch, tag, and release fishes. In the process, we learned about the distribution, relative abundance, and movements of heavily fished species, and shared this information with other marine resource users.

Our specific objectives in this study were to:

- Utilize CPFV skippers, crews and vessels, and anglers from recreational fishing clubs to tag fish and collect biological data near Duxbury Reef,
- Estimate relative abundances of species commonly caught near Duxbury Reef,
- Estimate movements of tagged fish,
- Collect biological and life history information from nearshore species, and
- Discuss project results with commercial and recreational fishermen in the area.

Methods

Study Site:

Our study was conducted in ocean waters off Bolinas, just north of San Francisco. The target area for catching and tagging fish was from Duxbury Reef to Arch Rock (Fig. 2). Recent multi-beam sonar surveys of the nearshore environment in this region (conducted by Gary Greene, Moss Landing Marine Labs) indicate that the study site contains a mixture of rock, kelp, and sand habitats. The rock formations from Duxbury Reef to Double Point are comprised of sandstones of the Monterey Formation. The rock between Double Point and Arch Rock is sandstone of the Purisima Formation. Beyond Arch Rock, the bottom is primarily sand until granitic rocks are encountered at Point Reyes.

In 2005, we distributed fishing effort across the region from Duxbury Reef to Double Point to sample fish communities in the different types of rock formations. We fished in depths from 30-130 ft (10-35 m), but fished most often in water depths of 60-100 ft (20-30 m). We caught and tagged most fish at a location known as the "Towers," approximately 2 nautical miles (nm) northwest of Duxbury Reef, because we had higher catch rates in this area. In 2006, we continued to fish in the "Towers" region, but divided fishing effort into three depth ranges: 40-60 ft (12-18 m), 60-80 ft (18-24 m), and 80-110 ft (24-34 m).

Fishing Operations:

We worked with the Golden Gate Fishermen's Association to solicit bids from CPFVs in the San Francisco area. Five vessels (*CPFV Salty Lady, CPFV Blue Runner, CPFV Superfish, CPFV Flying Fish, CPFV California Dawn*), ranging from 43 ft to 56 ft were selected and chartered for a total of 23 sea days in June 2005 and 8 sea days in September 2005. We recruited volunteer anglers by posting public announcements on local fishing club websites (e.g., Coastside Fishing Club, United Anglers), bait shops, and the California Sea Grant College website. The chartered vessels departed from the Clipper Yacht Harbor in the Sausalito marina at 6 AM, and reached the study site after two hours of transit. At each skipper's discretion, "drifts" ranging from 10-60 minutes long were made across expected fish habitat within the study site (Fig. 2). The vessels typically fished five hours each day before returning to port, for a total of about 115 fishing hours in June and 40 fishing hours in September. In 2006, we chartered one vessel, the CPFV *Salty Lady,* to fish two days each month from June-September.

Volunteers fished with rod and reel gear. Fishing tackle consisted primarily of lures, shrimp flies, or barbless hooks baited with squid or anchovies. Volunteers usually fished one rod, and used 2-4 hooks per rod. Captured fishes were brought on board, and transferred immediately to a live well. When fishing was slow, individuals were transferred directly to a V-board station for processing (Fig. 3). At other times, when catch rate was high, we had as many as 50 fish on board at once. These fishes remained in the live well for up to 20 minutes before processing. Once on the V-board, each fish was identified to species, total length was recorded to the nearest centimeter, and sex was determined (if possible). In 2006, we kept a sub-sample of fish for analyses of gonads.

All target species (rockfishes, lingcod, kelp greenling, and cabezon) were tagged using external T-bar anchor tags (Hallprint Co.). Individuals exhibiting swim bladder barotrauma were vented using an 18 gauge hypodermic needle prior to release. We also experimented with another barotrauma relieving device, the Shelton Fish Descender (courtesy of Bill Shelton), a modified fishing hook and weight attached to a standard fishing rod. For all fish captured, we recorded the fish condition at release. Fish condition was coded based on the external evidence of barotrauma (no apparent damage, swimbladder vented before fish was released, eye barotrauma, stomach extruded, or mortality) and damage due to hooking or to predation by other fishes (no apparent damage, hook damage, evidence of fish predation, mortality from predation). Fishes were released at location of capture, and tag number, coordinates of release, and catch depth were recorded. We also recorded the wind speed and direction, the swell height and direction, the water temperature, and the water clarity and color each fishing day.

Advertising for Tag Returns:

In July 2005, we began advertising for tag returns in the San Francisco Bay area. We created a tag-return poster describing the study and how to report capture of a tagged fish. We also posted announcements for tag recaptures on various websites (e.g., Coastside Fishing Club, United Anglers, UC Sea Grant) and tackle shops throughout the San Francisco area. In addition, the anglers who volunteered to fish helped by communicating our request for fish recapture information to other anglers.

Commercial and recreational anglers notified us by telephone when they recaptured a tagged fish. We collected information about the date, coordinates, and depth of capture, and species and tag number from these anglers. We also looked for recaptured fish in the study area as we continued to conduct tagging operations. When a previously tagged fish was caught, we measured it, recorded tag number, noted coordinates of recapture, and released it again.

Results

Volunteers

More than 200 anglers volunteered to fish on the charter boats in 2005 and 2006, contributing 365 volunteer-days to the project (Table 1). An average of 15 volunteers fished each day. Many people volunteered more than once during the duration of the study and several individuals fished almost every trip. These anglers traveled from all over the San Francisco Bay area to participate in the study. Including travel time and vessel transit, these anglers typically contributed 12 hours of their time each fishing trip. Over the course of the study, we interacted with volunteers of both genders whom encompassed a broad range of ages and fishing experiences. Most volunteers, however, were very experienced fishermen, leading to high catch rates for the study.

Species Composition and CPUE

We fished for a total of 31 sea days in 2005 and caught 5,573 fish, comprising 21 species (Table 2). In 2006, we fished for a total of 8 sea days and caught 2,253 fish from 18 species

(Table 2). We calculated catch rate as the number of fish caught per boat per day. The catch rate varied on a daily basis (Figs. 4, 5) but was relatively consistent when averaged for a month (Fig. 6). This is in part due to a change in tagging effort in 2006, where we attempted to spread our tagging effort out evenly over the field season. As a result, the catch per day (and month) was more consistent because we would typically quit fishing for the day after we caught approximately 250 fish.

In 2005, black rockfish comprised the majority of the catch (65.6% of total fish caught, Table 2). The percentages of total catch of the next most frequently caught species in 2005 were lingcod (7.5%), brown rockfish (6.9%), blue rockfish (4.6%), and canary rockfish (3.7%). In 2006, blue rockfish dominated the catch (28.8% of total). The percentages of total catch of the next most frequently caught species in 2006 were black rockfish (21.4%), canary rockfish (14.9%), brown rockfish (8.7%), and lingcod (5.0%).

In both 2005 and 2006, species composition varied on a daily and monthly basis (Fig. 7). In order to better test differences in community composition over time, we analyzed four spatial locations where fishing effort overlapped in 2005 and 2006 (Fig. 8). These spatial areas were chosen because they contained a large number of drifts and were bounded by selected depth ranges. Spatial area 1 encompassed drifts between depths of 80-100 ft, spatial area 2 drifts between depths of 70-90 ft, spatial area 3 drifts between depths of 40-70 ft, and spatial area 4 drifts between depths of 60-90 ft. Chi-square analysis indicated that the species composition was significantly different ($p < 0.05$) between years in all these spatial areas (Table 3). Species composition and number of fish caught are shown for Spatial Areas 1-4 in Figures 9-12.

Handling Mortality

Fish condition was recorded for each individual prior to release. The categories we used included: no apparent handling damage, inflated swimbladder (which was vented before fish was released), hook damage, eye barotrauma (eye protruding from orbit or gas bubbles occluding eye), predation (bite marks on fish), mortality, and extreme barotrauma (stomach extruded). Most of the fish we caught were vented to relieve barotrauma symptoms (49.6% in 2005 and 67.4% in 2006). We vented proportionately more fish in 2006 because we were fishing in deeper waters and more individuals had inflated swimbladders. Occasionally, we brought up fishes that had been bitten severely by larger fish (often lingcod) while on the fishing line, and these individuals were marked as mortalities and not tagged. We also observed some fish on the surface that were unable to swim down after release. In those cases, we changed the original condition of these individuals to a “mortality” condition. If we observed predation by marine mammals or sea birds after we tagged and released an individual, we considered it a mortality as well. We recorded mortalities for 119 fish in 2005 (2.4% of total) and 32 fish in 2006 (1.4% of total). For each handling category, we compared proportions of fishes released to fishes recaptured.

Movement Data

We tagged and released a total of 4,981 individuals from 13 species in 2005 and 1,944 individuals from 13 species in 2006 (Table 2). Thus far, 236 fish (3.4% of the total tagged fish) have been recaptured and reported. In the combined 2005 and 2006 data, black rockfish was the most abundant species recaptured, comprising 57% of tagged fish released and 78% of tag recaptures. Blue rockfish (5% of total returns) and lingcod (4% of total returns) provided the next highest tag returns. Five fish were recaptured on two occasions at separate locations during the study, some within minutes of initial tagging. Anglers failed to record the tag number and/or coordinates of 20 of the tag recaptures reported. We had sufficient data for analysis of movements of 216 recaptured individuals (Table 4).

Most of the tagged fish were recaptured short distances away from location of release; 81% of all fishes were recaptured less than 1 nm from release location and 95% were recaptured within 5 nm of release location (Fig. 14). The mean distance moved by all recaptured black rockfish, excluding extreme outliers (movement > 50 nm), was 0.98 ± 0.2 (SE) nm (Fig. 15). Of the recaptured black rockfish, 82% were caught within 1 nm of initial release location, and 95% were caught within 5 nm of initial release location (Fig. 16). Similarly, 90% of lingcod recaptures were within 0.5 nm of release location (Fig. 17) and 85% of the 13 blue rockfish recaptures were within 1 nm of release location (Fig. 18).

There were a few individuals that traveled much farther than the mean distance of recapture for their species. Three black rockfish were recaptured near the Farallon Islands, a popular fishing area 20 nm west of San Francisco. One black rockfish was recaptured by a commercial fisherman near Crescent City, CA, and two tagged black rockfish were recaptured in Oregon, more than 400 nm and 600 nm from the study area. One yellowtail rockfish was recaptured near the Farallon Islands, approximately 17 nm from initial release location, and a vermilion rockfish was recaptured 31 nm from initial release location near Bodega Bay, California.

Length Frequency Analysis

Total lengths were recorded to the nearest centimeter for all fishes. We compared mean lengths of fishes caught in 2005 and 2006 (Fig. 19). Whereas sample sizes were smaller in 2006 than 2005, mean lengths were similar for all species between years. For all species with sample sizes larger than 15 fish in both years, differences in mean lengths between years were less than 1.4 cm, with the exception of vermilion rockfish. There were no significant differences in mean lengths between years, except for brown and gopher rockfishes. Mean total length for vermilion rockfish was 36.1 cm in 2005 (n = 105) and 32.0 cm in 2006 (n = 42). We looked at the length frequency histograms for selected species between 2005 and 2006 (Figs. 20-27) and conducted Kolmogorov-Smirnov tests (K-S test) to determine if length frequencies in these two datasets differed significantly between years. We conducted K-S tests for black rockfish, blue rockfish, brown rockfish, canary rockfish, yellowtail rockfish, vermilion rockfish, gopher rockfish, lingcod, kelp greenling, and cabezon. Five of these species (kelp greenling, brown rockfish, gopher rockfish, black rockfish, and vermilion rockfish) showed a significant difference in length-frequency composition between years (Table 5).

Maturity Data

The length-frequency data we collected indicated that much of the catch in the study region was comprised of individuals that are probably immature. With the exception of gopher rockfish and cabezon, mean lengths of all species were at, or no more than 3 cm above, the length at 50% maturity (Fig. 28). The ages and lengths at 1st, 50%, and 100% maturity are shown for selected species in Table 6. In 2006, we fished in deeper waters to look for evidence of ontogenetic movement and larger size classes of fishes. We did not observe larger mean sizes in 2006 or higher frequencies of larger size classes of fishes in 2006. Although there were significant differences in length frequencies between years for some species (Table 5), these differences appear to be due to changing frequencies of length modes in the 26 to 32 cm length-bins rather than an increase in frequencies of larger size fishes.

In 2005, black rockfish was the most abundant species caught (n = 3,657). Length at 50% maturity for California black rockfish is reported to be 36 cm (6 yr old) for males and 41 cm (7 yr old) for females (Table 6, from Wyllie Echeverria 1987). Using the length-at-maturity curves from the literature, we estimated that 97% of the rockfish we caught were below the length of 50% maturity. We corroborated this estimate by collecting a sample of black rockfish each month in 2006 and determining the maturity stage of each fish, based on gonadal development stages (Table 7). We sampled a total of 164 black rockfish (99 females and 65 males). Maturity stages of both female and male rockfish were recorded based on descriptions from Wyllie Echeverria (1987) and Gunderson et al. (1980). Photos from Love et al. (2002) were also used as a visual reference for additional maturity stages. Using these references, we determined that 4.3% of all black rockfish sampled were mature. These fish were classified as in either a spent or resting stage. These results are consistent with our original estimate that 97% of black rockfish caught were immature.

Historical CPFV Data

We compiled historical length data from the CPFV fishery in order to compare our estimates of mean lengths to other areas in central California. We compiled mean lengths for brown, black, blue, canary, and gopher rockfishes (Fig. 29), and for lingcod, cabezon, vermilion rockfish, and kelp greenling (Fig. 30). The data were compiled from Karpov et al. (1995) and Lea et al. (1999), data available from the Pacific States Marine Fisheries Commission RecFin database, and unpublished data from the central California coast (Morro Bay to San Francisco) between 1959 and 1998 (courtesy of Deb Wilson-Vandenberg, DFG, Monterey, CA). These historical data were compared to more recent length data from this study, and a similar study conducted in Carmel Bay, California (Rick Starr, Moss Landing Marine Labs, unpublished data).

Additionally, we compiled mean lengths of black rockfish measured by onboard observers in the CPFV fishery near Bolinas and Bodega Bay from 1988-1998 (Fig. 31, Deb Wilson-Vandenberg, DFG unpublished data). These data can be treated as a similar data set to ours, because the data were collected by observers on CPFV vessels and the observers measured fish caught at sea, not landed catch. We also compiled mean lengths for black rockfish caught in the CPFV fishery between 1980 and 2004 in the counties of San Mateo (Fig. 32), Marin (Fig. 33), Sonoma (Fig. 34), and Mendocino (Fig. 35) (Pacific States Marine Fisheries Commission RecFin database). However, the RecFin data represent fish measured by dockside samplers and reported by the county in which the fish were landed. As a result, there may be a discrepancy between the county where these fish were caught and the county where they were ultimately reported as landed catch, thus we cannot be certain that the data are comparable to our records.

Discussion

Catches and Catch Rates

The number of species we caught (species richness) was similar to that recorded from CPFV fisheries in nearshore habitats in central California (Karpov et al. 1995). Species diversity was also typical (relatively low) of many CPFV fishing trips because the catch was dominated by a few species. We caught fewer species in 2006, but that was because we fished only one-fourth the amount of days, and caught 40% as many fish in 2006 as 2005. The rank order of the number of fish caught of each species changed from 2005 to 2006, caused primarily by the fact that the majority of our fishing effort in 2006 was in deeper waters (80-100 ft) than most of our fishing drifts in 2005 (60-80 ft), thus we were fishing in different habitats.

Catch rates varied as a function of weather conditions and the stage and time of the San Francisco Bay tide. CPUE varied greatly from day to day, but averaged over a month, the catch per day per boat was very consistent. The CPUE data presented in this study, however, should not be viewed as a standardized estimate of fishing catch rates, because we did not attempt to standardize fishing effort on a vessel. The number of anglers fishing on a boat varied daily and among boats, as did the type of gear and bait (or lure) used. Also, the number of anglers fishing on a boat at any one time period varied, as did the number of fishing rods and hooks used by anglers. Additionally, in 2006, we restricted the amount of fish caught in a day in an effort to keep the numbers of tagged species similar for every day we fished. We recommend that a standardized survey be conducted to quantitatively evaluate changes in catch rates with time.

Species Composition

Species composition varied by month and by year, but was influenced greatly by fishing location. In 2006, for example, we fished in deeper waters and caught more blue and yellowtail rockfish than we did in 2005, when we fished in shallower waters. Species composition for a day was also skewed by occasional drifts in which we would catch high numbers of one or two species (e.g., blue, brown, or yellowtail rockfish) that may have been temporarily aggregating near the location of our fishing drift. Averaged over time, all four spatial locations that were analyzed separately showed a difference in species composition between 2005 and 2006. However, these data are difficult to interpret because the sample sizes were greatly different in each year. When the sample size was large, the species composition of the sample was characterized by a higher proportion of the most frequently caught species (e.g., blue or black rockfish) than when fewer fish were caught. Apparently, the longer we fished in our study area, the more likely we were to encounter large schools of semi-pelagic rockfishes. When that happened, catch rates of one or two species increased, and species diversity became skewed.

Since 2002, the Pacific Fishery Management Council has closed much of the continental shelf to fishing because of the population status of several overfished species. The low abundance of canary rockfish, has contributed to the closure of much of the shelf in Central California. In 2005, while fishing in waters less than 100 ft deep, we encountered many more small canary rockfish (mean length = 28 cm) than would have been predicted for the area we fished, based on the presumption of a low canary rockfish population. In 2006, we fished more often in waters out to 120 ft deep, and canary rockfish comprised a relatively high proportion of the catch (14.9 %). The high catch rates in 2006, combined with the length frequency histograms we generated and length at age relationships published by Lea et al. (1999), indicate that the study area currently contains one or two strong year-classes canary rockfish. Our data corroborate the presence of a strong-year class of canary rockfish identified in NMFS larval surveys (Steve Ralston, NMFS, personal communication).

Handling Mortality

For each handling category, we compared proportions of fishes released to fishes recaptured. These proportions were similar, indicating that handling condition did not have an effect on fish survival. In some cases, we received recapture information for fish that had been originally been recorded as "mortality," indicating that some of the fish we observed on the surface did in fact swim down and survive to be recaptured at a later date. Handling mortality was relatively low in 2005, but we were able to reduce the rate of handling mortality in 2006 by fishing more slowly and holding fishes on deck for a shorter time; we learned that the probability of mortality increased the longer a fish was held. In 2006, we often asked anglers to stop fishing so we could reduce the amount of time a fish was likely to be kept in the live well before tagging.

Fish Recaptures and Movements

About 3.4% of tagged fishes have been recaptured and reported to date. This rate of tag returns is typical of many recapture studies in which rewards are not provided. Several people told us that they knew of tagged fish that were caught but not reported in the recreational and CPFV fisheries. There was also one commercial fisherman working in the area, but we only received one tag that was caught in the commercial fishery (the tagged fish was purchased from a live-fish market in San Francisco). We assume from these comments that some tagged fish were caught but not reported, but do not know the proportion of unreported tags.

Most tagged fish exhibited strong site fidelity, as 80% of all fish recaptured were caught within 1 nm of their release location and 95% were caught within 5 nm of release location. This provides good evidence that the majority of species we caught have relatively small home ranges. We envision a situation in which most species are either staying in one small location or are "milling about" but staying within a few miles of a home base. Our data indicate, however, that there may be some interchange between the populations of black and yellowtail rockfishes at Duxbury Reef area and those at the Farallon Islands. Also, there is probably some interchange between Duxbury Reef and similar habitats off Point Reyes, as indicated by the movement of one vermilion rockfish recaptured near Bodega Bay. There were some notable exceptions, however, to this pattern of relatively localized movements. The three black rockfish that were caught greater than 300 km away probably were advected northward by northerly currents caused by the frequent and strong storms we experienced in the winter of 2005-2006. In many fish tagging studies, a very small percentage of the tagged fish move much greater distances than other fish. This is probably an evolutionary strategy to enable populations to respond to localized disasters and to provide genetic mixing of meta-populations. It is easy to envision a black rockfish swimming along with a water-mass as the water is transported northward during a strong winter storm.

Length Frequency and Maturity Stages

The mean lengths of all species were similar between years, but length frequency distributions were significantly different for five species. These differences can be attributed to either an incoming year-class (e.g., brown rockfish in 2005) or greatly different sample sizes between the two years. The relationship between mean lengths of almost all species and their corresponding lengths at 50% maturity is potentially meaningful. Fishing can truncate the size and structure of fish populations, at times leading to localized depletions. Even in highly fecund and productive fishes, there are benefits to having large females in the population. Berkeley et al. (2004a) suggested that a broad spectrum of sizes and ages in a population is at least as important as spawning biomass in maintaining long-term sustainable populations. A primary reason for this is that Berkeley et al. (2004b) showed that older, larger female rockfishes produce larvae that can survive under a broader range of ocean conditions compared to larvae from younger females. They suggested that recruitment may come from only a small fraction of the spawning population each year, and that age truncation from fishing may have severe consequences for long-term sustainability of fish populations.

We considered and investigated six different hypotheses as to why the study area contained fish populations with mean lengths that are below the length at 50% maturity:

1. The rockfishes in the study area are maturing earlier than the published maturity-length relationships for each species.
2. There was a strong recruitment pulse for each species of rockfish 2-5 years ago and the mean lengths of each species in the population is skewed by a large mode of small individuals.
3. Recreational fishing gear is selective for smaller fish; the larger fish are not caught with rod and reel fishing gear.
4. The study area is a nursery ground for small fish; adult rockfish are found in deeper waters outside the study area.
5. There is a seasonal migration of larger adults and our sampling was conducted during months when larger fish live somewhere else.
6. The truncated length structure of species we caught is due to excessively high rates of fishing and as a result, the natural age structure of the population has been altered and the fish are younger and smaller.

For Black rockfish, the most abundant fish caught in the study area, the hypothesis that the fish in the study area are maturing at a smaller size than in the literature does not appear to be true. The gonads we sampled and evaluated indicated that only 4.3% of Black rockfish were mature. We dissected fish collected primarily from summer months, however, so our preliminary results may be incorrect. There is evidence that black rockfish are maturing at a younger age in other areas (Worton and Rosenkranz 2003). The most recent maturity-length relationships for central California black rockfish were generated in the early 1980s. It is also possible that there has been a small decrease in the size at maturity in this region, but more samples are needed to detect this difference.

The hypothesis that the low mean lengths are due to a strong recruitment pulse for each species is a probably true for some species. Mean lengths of lingcod in 2005 and 2006, for example, were just below the length at 50% maturity (Silberberg et al. 2001), but the size distribution included larger fish. This is an example of the mean length being affected by strong incoming year-classes. Several species of rockfish experienced good recruitment pulses from 1999-2002 (John Field, National Marine Fisheries Service, personal communication). These recruitment episodes would affect the mean length. The length frequencies of most rockfishes, however, showed a lack of larger fish. Only very small percentages of most species caught were greater than the length at 50% maturity.

The hypothesis that recreational fishing gear does not catch large fish is unlikely because large rockfish are caught with hook and line gear in many locations, and the people fishing in this study are very accomplished anglers. Also, historical records show that anglers caught larger fish. Nevertheless, there is a small possibility that larger fish occur in the region, but were not in the area when we fished, as there is evidence that some species, such as black rockfish and lingcod, are at times segregated by sex or size (Worton and Rosenkranz 2003, Starr et al. 2005).

Our study was not designed to fully evaluate the hypothesis that Duxbury Reef is a nursery ground. We fished in a variety of areas and did not catch larger fish, but it is possible that the adults seeding the study area are located elsewhere. Wing et al. (2003) identified the area south of Point Reyes as a retention zone. With this type of ocean circulation, the adults seeding the habitats near Duxbury reef could easily be located in rocky habitats north of Point Reyes. If Duxbury Reef is a nursery ground, then we might expect to see evidence of a migration of larger adults. The few larger fish we tagged and recaptured did not move at different rates or distances than smaller fish, but that does not preclude the idea that fish leave the area after growing to a specific size. We did not detect any change in the size composition of the catches over a five-month time period, however, indicating that if adults were migrating differentially, they would be moving opposite to what would be expected. That is, instead of moving offshore in winter to avoid storms, the larger adults would be moving into shallow waters in winter and moving offshore in summer – an illogical assumption.

The last hypothesis we evaluated was that the truncated length structure of species caught is due to excessively high rates of fishing. To evaluate that possibility, we compared the trends over time in the mean lengths of fishes caught, and measured at sea by onboard observers, in Central California. We also compared the historical lengths of fishes landed in the CPFV fishery and measured at the dock. Our purpose was to see if the trends in mean lengths of fishes caught in our study were different than in adjacent areas. We reasoned that if the mean lengths of fishes in the study area were declining faster than adjacent areas, we could attribute the observed truncated length structures to excessive fishing. All of the data sets we reviewed showed a similar pattern. The data support Reilly's (2001) and Mason's (1998) observations that mean lengths and weights of most species in Central California consistently declined from about 1980 until about 1994. Since that time, however, the mean lengths of most rockfish species have changed little and shown no statistically significant trend. The length frequencies of most species we caught contained primarily fish less than 5 years old, and only a small percentage of fish we captured were mature adults. If our study area has contained few adults since 1994, then the study area is receiving fish recruitment from other areas along the coast and fishing may be preventing fish from getting old enough to spawn in this location. It is important to note that the mean lengths of lingcod exhibited a recent declining trend, but that can be attributed to several strong recruitment years that occurred in 1999 and 2000. Sample sizes of the other species for which mean length is declining (i.e., cabezon, kelp greenling, vermilion) were too small to provide a realistic estimate of mean lengths.

Summary

This project proved to be a successful collaborative research endeavor involving commercial passenger fishing vessels, recreational anglers, and university scientists. All people involved contributed greatly to the collection of scientific information, and information was shared among participants and to a broader audience via web-based communications. Based on the high catch rates experienced in this study, and that have continued over the past few decades, we believe the Duxbury Reef area is a productive location for nearshore rockfishes. This productivity was highlighted by the observance of a large incoming year-class of canary rockfish. The large majority of species caught in this study moved short distances and probably are residential to the area. These data are based on net movements of recaptured fishes, however, and may not accurately reflect how much an individual fish moves over time.

Both descriptions of historical catches from charter boat skippers and published fishery data indicate that in the early 1980s, mean lengths of most fish species were once much larger in the study area than they are now. It is most likely that the decline in mean lengths was accompanied by a removal of large fishes and consequent truncation of the natural size and age structures of fish populations. Clearly, the sizes and ages of most rockfishes in the study area are very small relative to what they would be in an unfished or lightly fished population. If the study area contains closed populations of rockfishes, then new modeling from Kaplan et al. (2006) would suggest reasons for long-term concerns about sustainability of rockfish populations near Duxbury Reef.

The mean lengths of most species that were caught in this study, however, have not significantly changed since about 1995, a pattern similar to that generated from CPFV fisheries in other areas in Central California. Also, charter boat skippers say that the catch rates in the study area have not changed in the past ten years or so. These observations indicate that the current population size and age structures of fished species may be in equilibrium with the current rate of fishing, and that almost all fish are caught before they reach the size at 50% maturity. Without evidence of mature adults in the population, the logical way catch rates of small fishes could be maintained would be for the study area to receive an influx of juvenile fishes from other areas. If this is the case, the question about whether or not the current level of fishing is appropriate to maintain the population size and age structure of a species in a long-term sustainable manner will not be answerable until we know where recruitment is coming from and the level of fishing pressure on the adults in those locations that are seeding the study area. Additional information about the location and abundance of reproductive adults is needed, as is a longer time series of quantitative data about the abundance, natural mortality, fishing mortality, and movements of fishes in the study area and other parts of Central California. Better demographic information would enable the development of population models to evaluate the long-term sustainability of nearshore rockfish populations in Central California.

Literature Cited

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Table 1. Number of volunteers fishing per day in 2005 and 2006.

Date	No.Volunteers
06/13/05	11
06/14/05	16
06/15/05	13
06/16/05	12
06/17/05	10
06/20/05	20
06/21/05	30
06/22/05	28
06/23/05	25
06/27/05	8
06/28/05	7
06/29/05	14
09/12/05	22
09/13/05	12
09/19/05	20
09/20/05	13
06/12/06	17
06/13/06	11
07/10/06	20
07/11/06	19
08/07/06	11
08/08/06	11
09/06/06	11
09/07/06	4
Average No. per Day	15
Total Volunteer-Days	365

Table 2. Number and percentages of species caught and tagged in 2005 and 2006.

Common Name	Scientific Name	No. 2005	% 2005	No. 2006	% 2006	Tagged 2005	Tagged 2006
Black Rockfish	*S. melanops*	3657	65.6	482	21.4	3508	469
Lingcod	*O. elongatus*	419	7.5	113	5.0	415	113
Brown Rockfish	*S. auriculatus*	386	6.9	195	8.7	348	191
Blue Rockfish	*S. mystinus*	255	4.6	650	28.8	141	499
Canary Rockfish	*S. pinniger*	208	3.7	335	14.9	187	314
Yellowtail Rockfish	*S. flavidus*	159	2.9	298	2.8	38	224
Gopher Rockfish	*S. carnatus*	136	2.4	47	2.1	121	46
White Croaker	*G. lineatus*	107	1.9	20	<1		
Vermilion Rockfish	*S. miniatus*	105	1.9	42	1.9	97	40
Kelp Greenling	*H. decagrammus*	67	1.2	20	<0.1	65	19
Cabezon	*S. marmoratus*	29	0.5	2	<0.1	29	2
China Rockfish	*S. nebulosus*	24	0.4	15	<0.1	22	13
Copper Rockfish	*S. caurinus*	9	0.2	13	<0.1	9	13
Chinook Salmon	*O. tshawytscha*	4	0.1	5	<0.1		
Staghorn Sculpin	*G. tricuspis*	2	<0.1				
Grass Rockfish	*S. rastrelliger*	1	<0.1	1	<0.1	1	1
Grunt Sculpin	*R. richardsoni*	1	<0.1				
Pacific Mackerel	*T. symmetricus*	1	<0.1				
Pacific Sanddab	*C. sordidus*	1	<0.1	1	<0.1		
Walleye Perch	*H. argenteum*	1	<0.1				
Wolf Eel	*A. ocellatus*	1	<0.1				
Jack Mackerel	*S. japonicus*			12	<0.1		
Spiny Dogfish	*S. acanthias*			2	<0.1		
Total		5,573	100	2,253	100	4,981	1,944
Number Species		21		18		13	13
H (Diversity)		1.39		1.94			
J (Evenness)		0.44		0.66			

Table 3. Contingency Chi-square analysis comparing species composition between years in each of the five spatial areas shown in Figure 12. Asterisks indicate significant differences in species composition between 2005 and 2006.

Spatial Area	Chi-square	df	P-value
1	203.89	10.0	<0.001*
2	147.99	9.0	<0.001*
3	20.56	7.0	0.004*
4	97.77	10.0	<0.001*
5	34.36	9.0	<0.001*

Table 4. Number of fish recaptured in 2005 and 2006 by species.

Common Name	Scientific Name	No. Recaptured
Black Rockfish	*S. melanops*	172
Lingcod	*O. elongatus*	10
Brown Rockfish	*S. auriculatus*	7
Blue Rockfish	*S. mystinus*	13
Canary Rockfish	*S. pinniger*	7
Yellowtail Rockfish	*S. flavidus*	2
Vermilion Rockfish	*S. miniatus*	4
Cabezon	*S. marmoratus*	1
	Total	216

Table 5. Kolmogorov-Smirnov (K-S) Test for pair wise differences in length frequency by species between 2005 and 2006. Asterisks indicate significant differences in length-frequency between years. Mean Length is listed in cm.

Species	No. 2005	Mean Length	No. 2006	Mean Length	P-value
H. decagrammos	66	32.1	20	30.9	0.04*
O. elongatus	418	52.6	112	53.4	0.56
S. auriculatus	384	28.3	195	29.7	0.01*
S. carnatus	136	27.6	46	26.2	0.03*
S. caurinus	9	30.4	13	26.9	0.27
S. flavidus	159	24.4	294	24.1	0.94
S. marmoratus	29	43.1	2	38.0	0.90
S. melanops	3647	29.4	482	29.7	0.00*
S. miniatus	105	36.1	41	32.0	0.00*
S. mystinus	254	25.3	640	26.0	0.22
S. nebulosus	24	28.8	15	25.7	0.38
S. pinniger	207	28.2	334	28.0	0.51

Table 6. Age and total lengths at 1st, 50%, and 100% maturity for males and females of selected species. (Wyllie Echeverria 1987, Silberberg et al. 2001, Starr et al. 2002)

Males:

Maturity	1st		50%		100%	
Species	Age	TL (cm)	Age	TL (cm)	Age	TL (cm)
H. decagrammos			3-4	30		
O. elonagtus			3	47	6	61
S. auriculatus	3	26	5	31	10	38
S. carnatus	4	17	4	17	5	21
S. caurinus	3	30	4	32	7	40
S. flavidus	4	30	6	35	11	43
S. marmoratus			2	34		
S. melanops	3	25	6	36	10	43
S. miniatus	5	35	5	38	8	43
S. mystinus	4	22	5	27	9	32
S. nebulosus	3	26	4	27	6	30
S. pinniger	4	28	7	40	9	45

Females:

Maturity	1st		50%		100%	
Species	Age	TL (cm)	Age	TL (cm)	Age	TL (cm)
H. decagrammos			3-4	30		
O. elonagtus			3-4	57	4-5	68
S. auriculatus	3	26	5	31	10	38
S. carnatus	4	17	4	17	5	21
S. caurinus	5	31	6	34	8	41
S. flavidus	4	27	7	36	11	42
S. marmoratus			2	34		
S. melanops	5	30	7	41	11	48
S. miniatus	5	37	5	37	9	46
S. mystinus	5	22	6	29	11	35
S. nebulosus	3	26	4	27	6	30
S. pinniger	4	27	9	44	13	54

Table 7. Number of mature black rockfish sampled at Duxbury Reef in 2006.

Month	Total No. Sampled	No. Mature
April	76	4
June	24	0
July	39	2
August	15	1
September	10	0
Total Number	164	7
	Percent of Total	4.3

Figure 1. Map of study area near Duxbury Reef, off Bolinas, California.

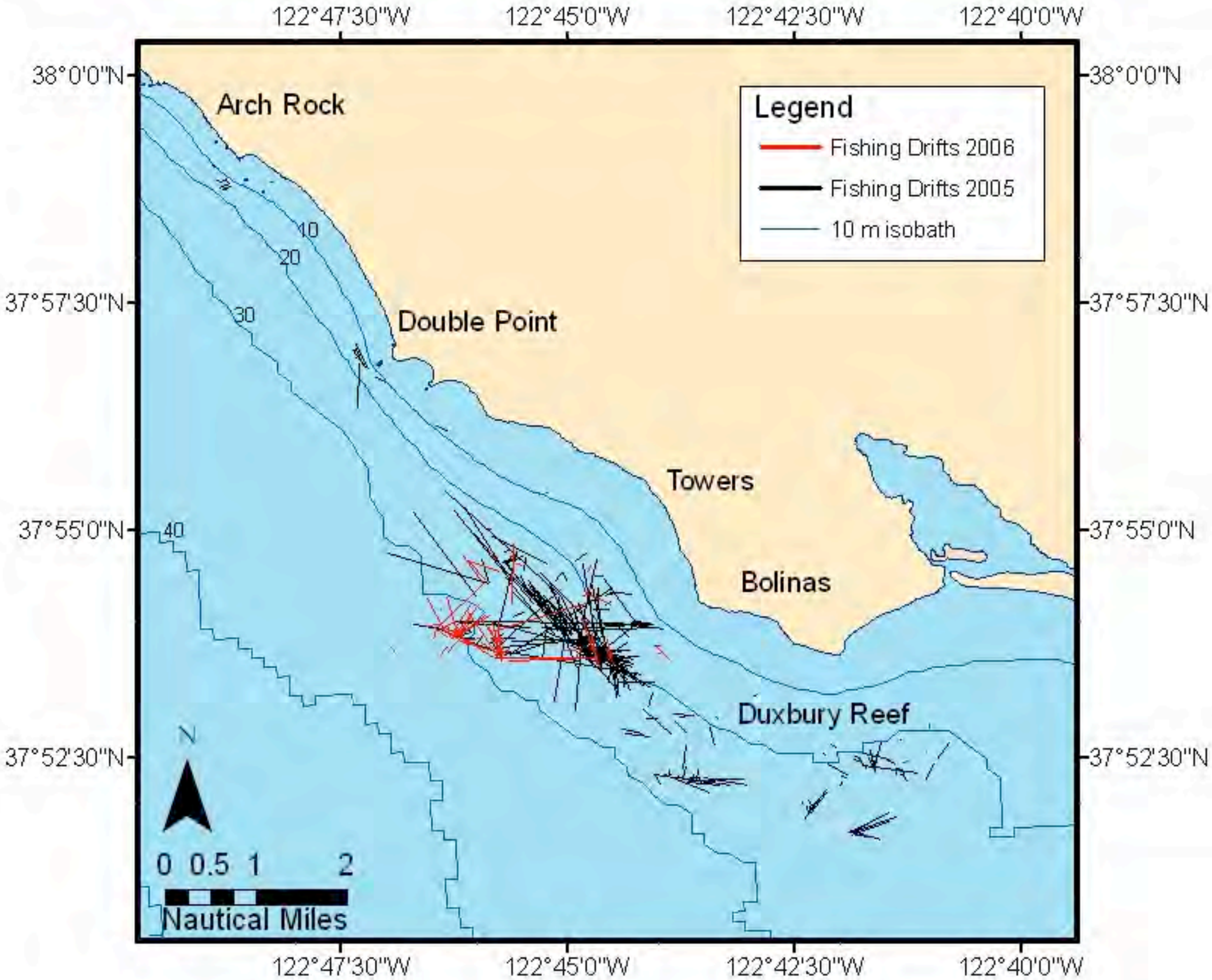

Figure 2. Fishing drift locations in 2005 (black lines) and 2006 (red lines).

Figure 3. Lingcod being measured at V-board tagging station.

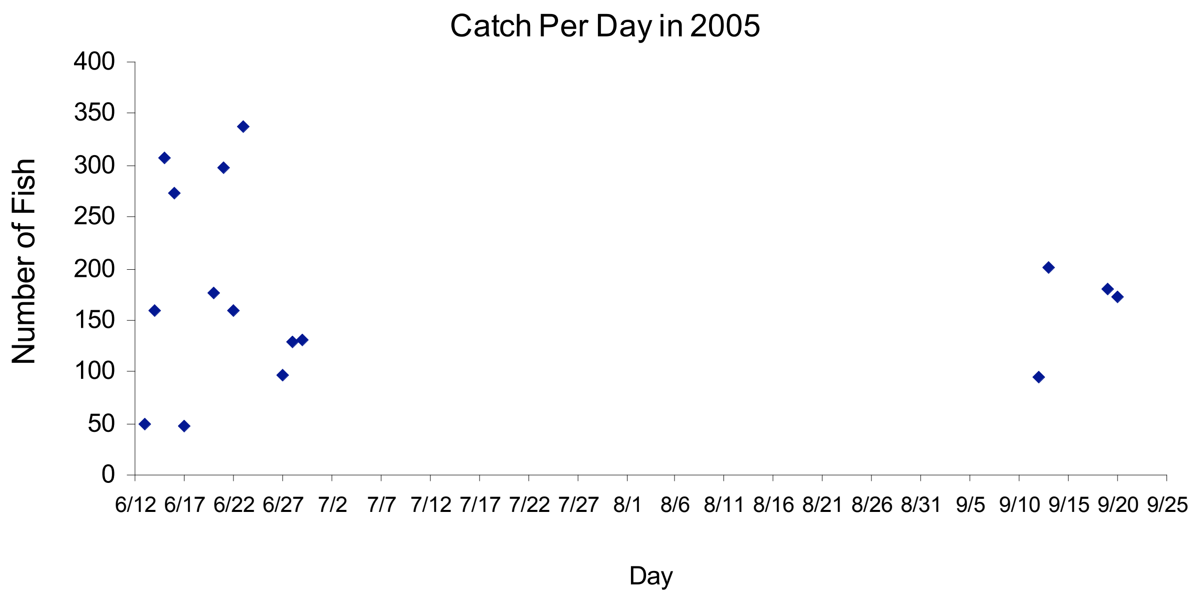

Figure 4. CPUE (catch per day per boat) in 2005.

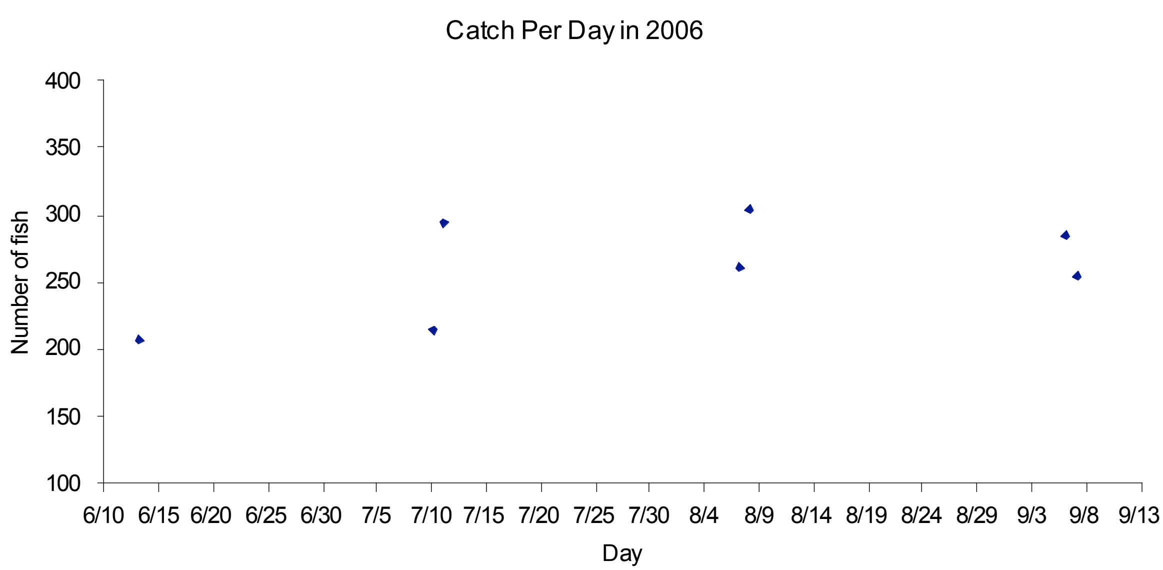

Figure 5. CPUE (catch per day per boat) in 2006.

Figure 6. Mean CPUE (catch per day per boat) by month in 2005 and 2006.

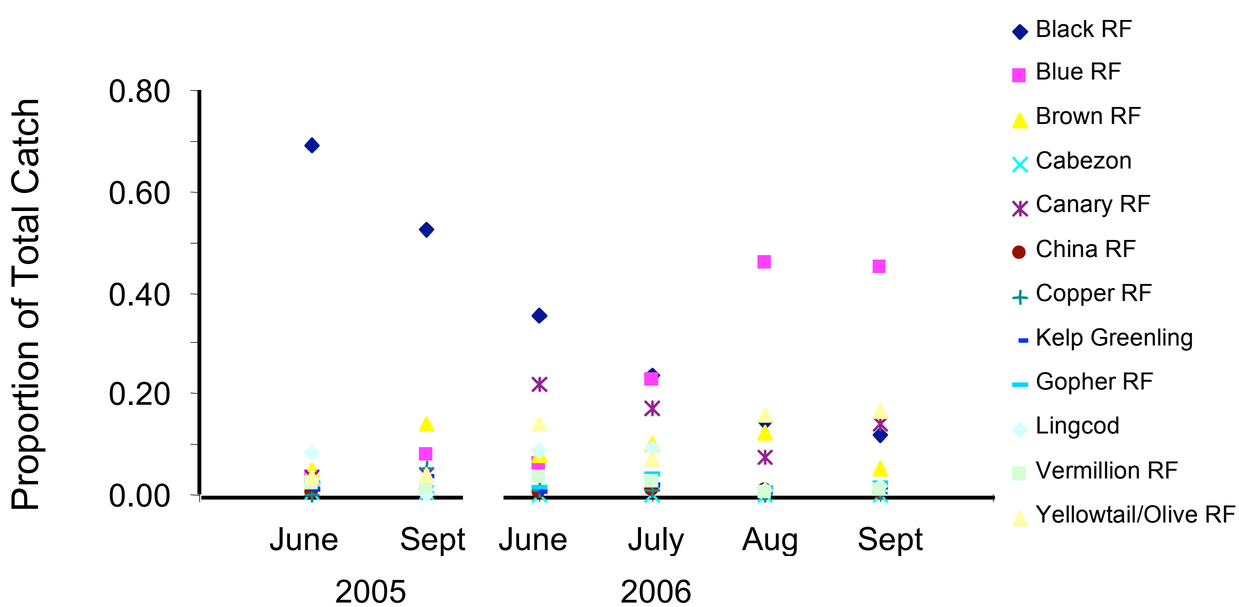

Figure 7. Species composition of catch by month in 2005 and 2006.

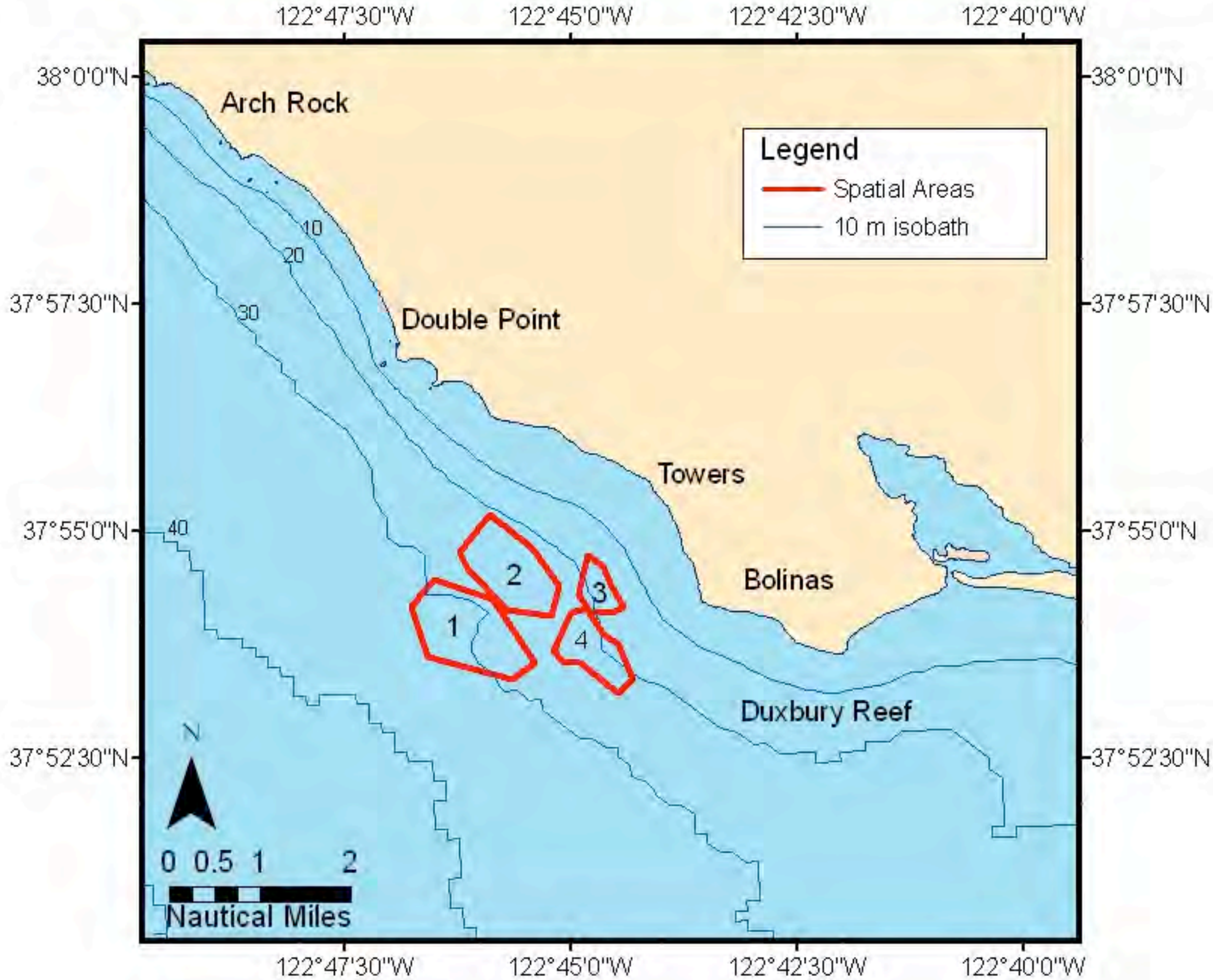

Figure 8. Spatial locations for comparison of species composition in 2005 and 2006.

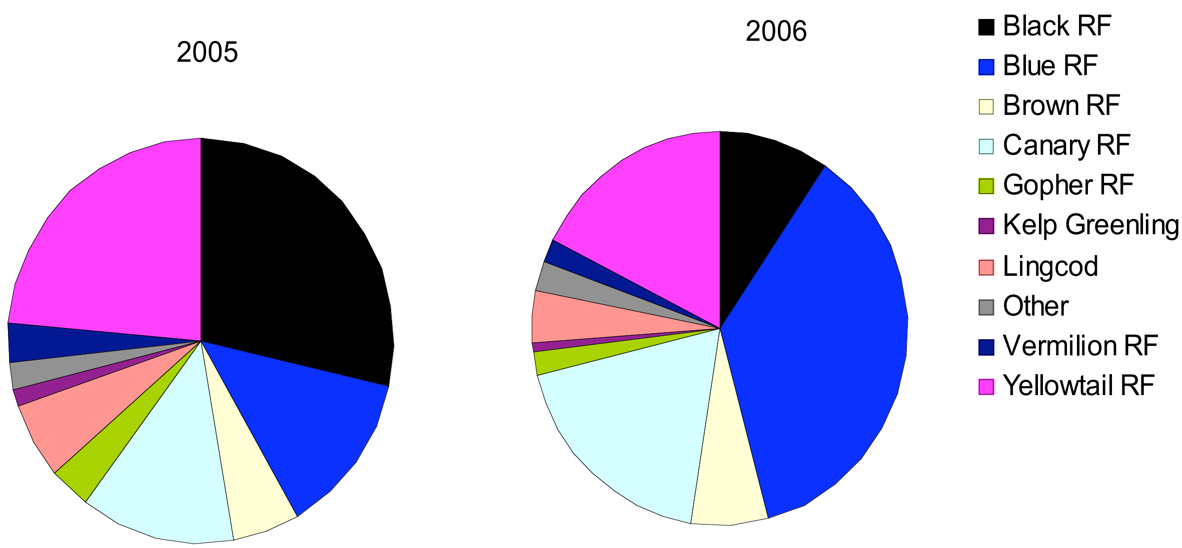

Figure 9. Species composition of catches in spatial area 1 in 2005 (n = 376) and 2006 (n = 1477). Depth range is between 80 and 100 ft.

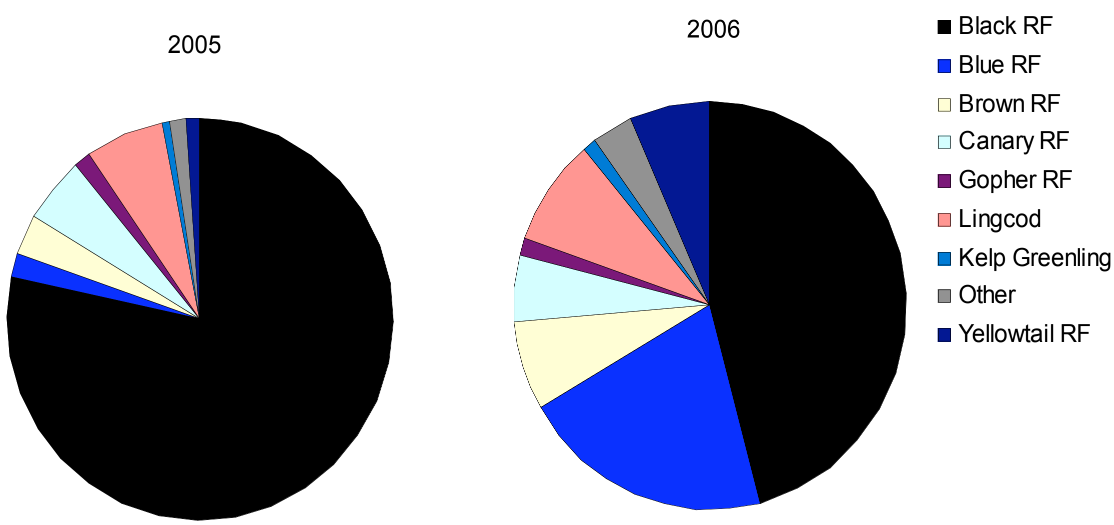

Figure 10. Species composition of catches in spatial area 2 in 2005 (n = 685) and 2006 (n = 198). Depth range is between 70 and 90 ft.

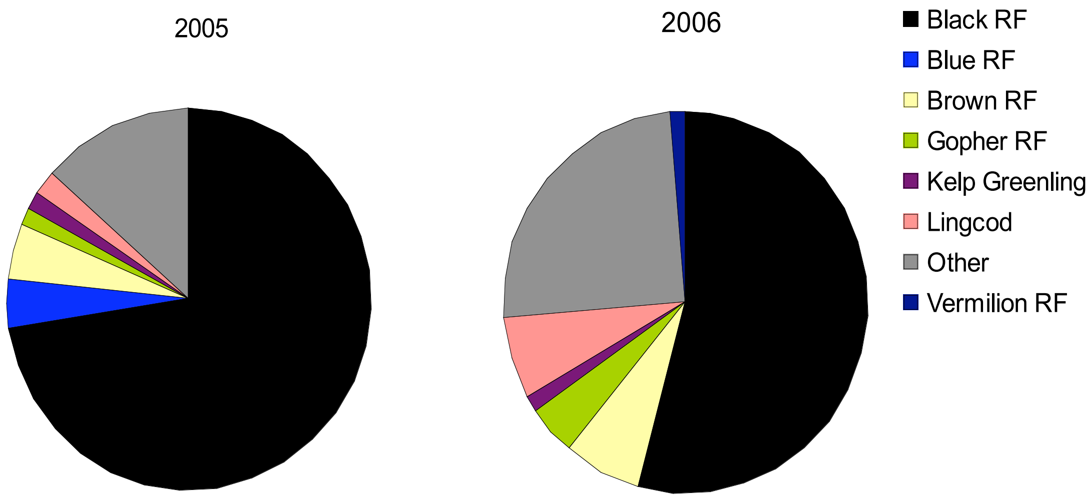

Figure 11. Species composition of catches in spatial area 3 in 2005 (n = 237) and 2006 (n = 72). Depth range is between 40 and 70 ft.

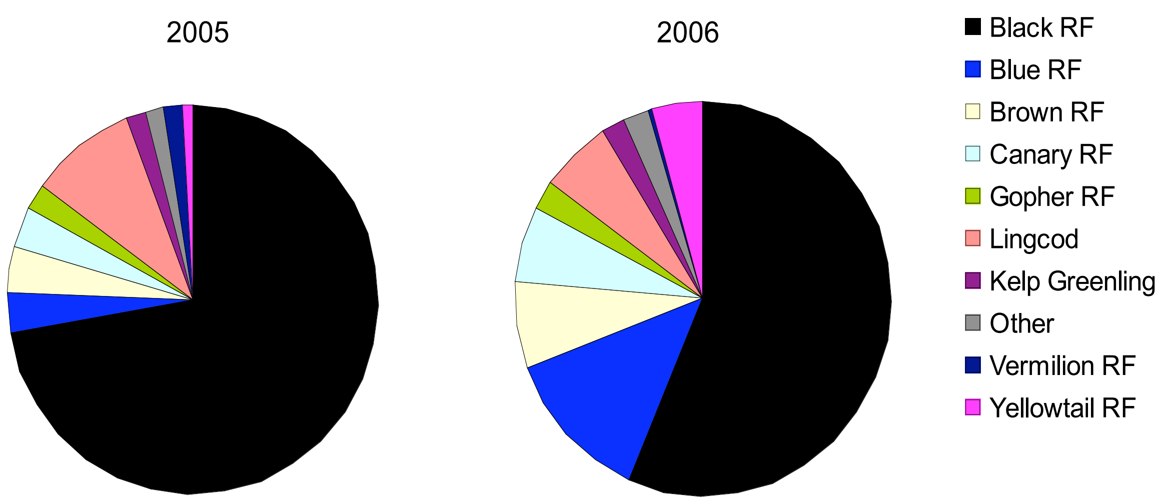

Figure 12. Species composition of catches in spatial area 4 in 2005 (n = 2104) and 2006 (n = 316). Depth range is between 60 and 95 ft.

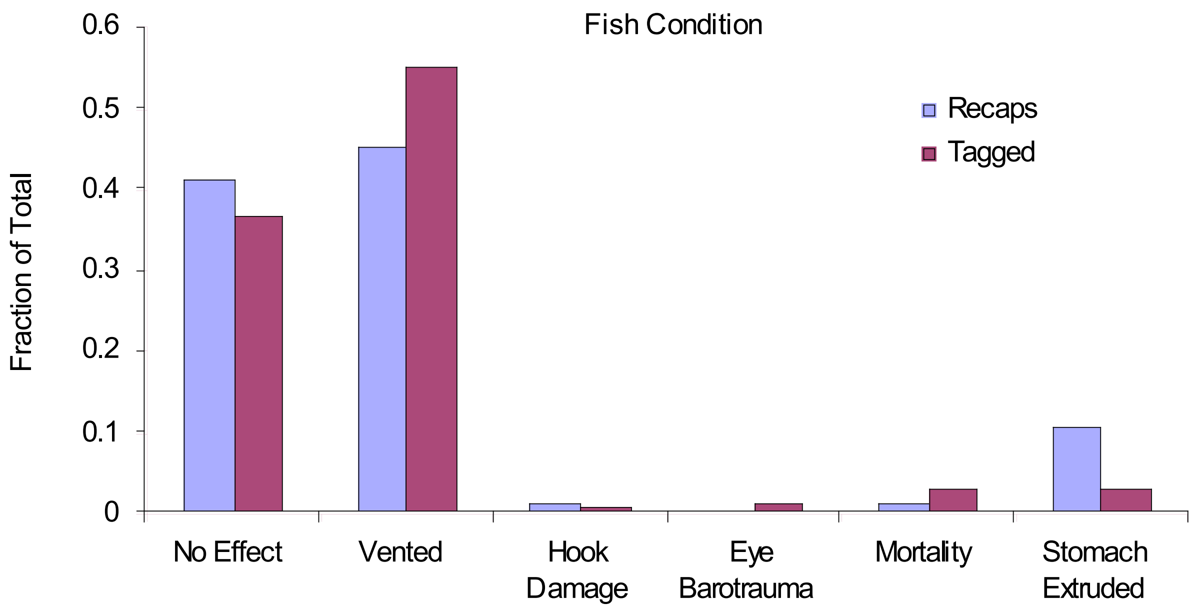

Figure 13. Handling effects on tagged fish versus recaptured fish in 2005 and 2006, expressed as a proportion of total recaptures for each handling condition.

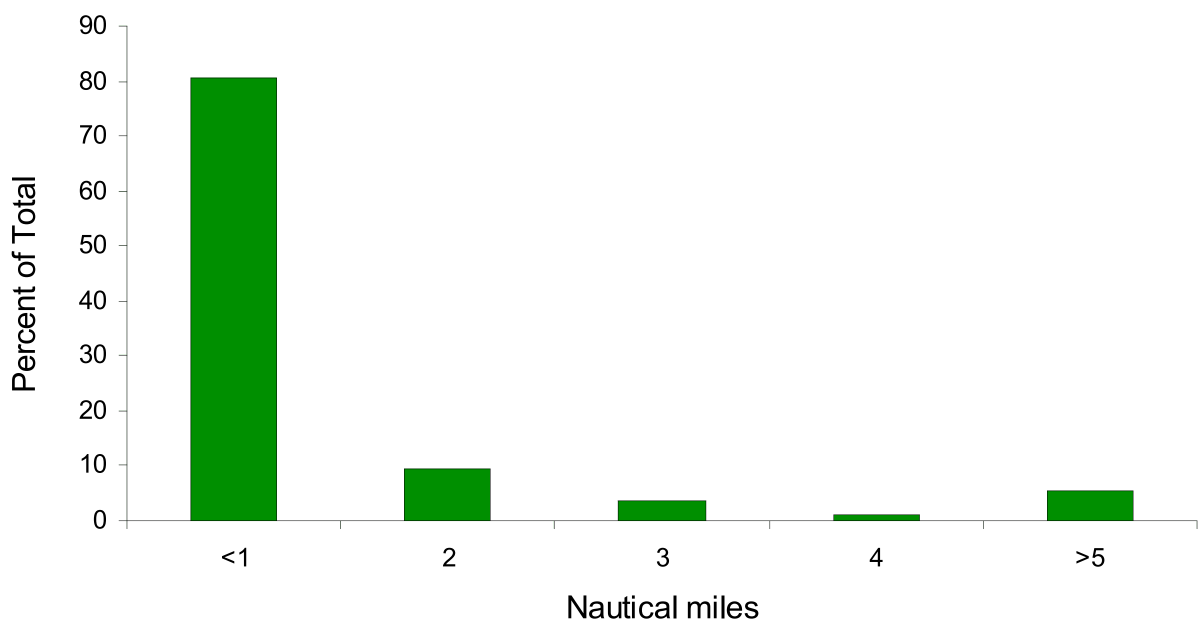

Figure 14. Frequency distribution of distance between release and recapture locations for all recaptured fish, grouped in 1 nm bins.

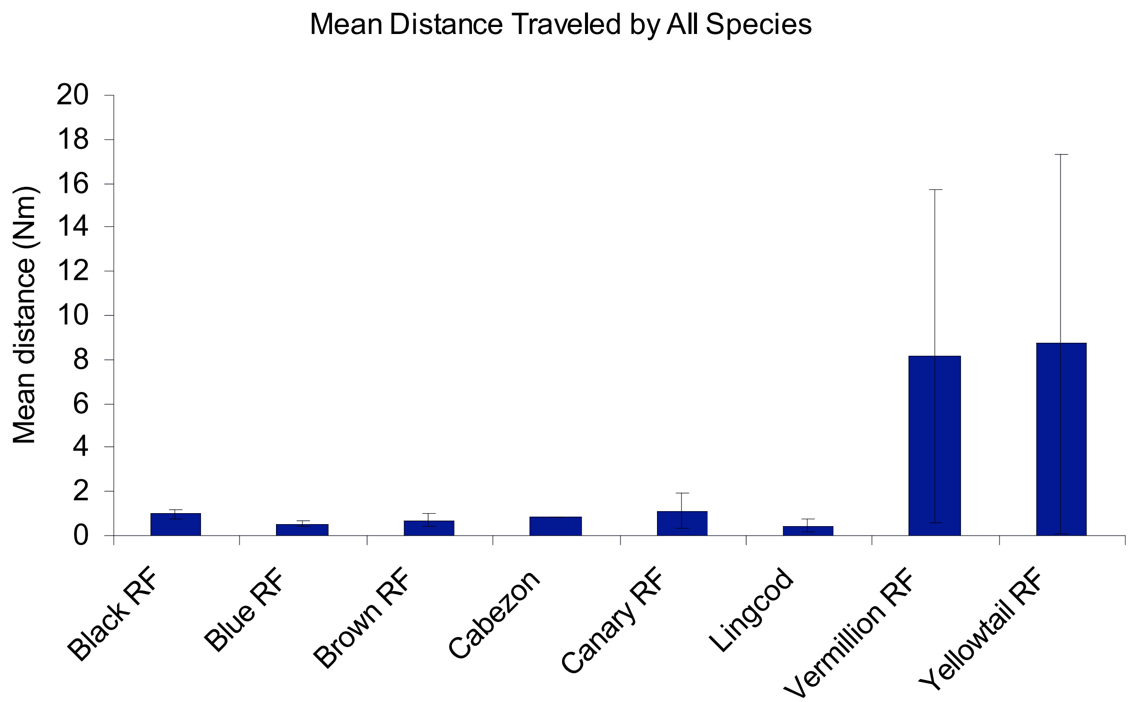

Figure 15. Mean (and SE) distance between release and recapture location for all recaptured fishes (n = 216). Data do not include three black rockfish that were recaptured greater than 280 nm, 400 nm, and 600 nm away, respectively.

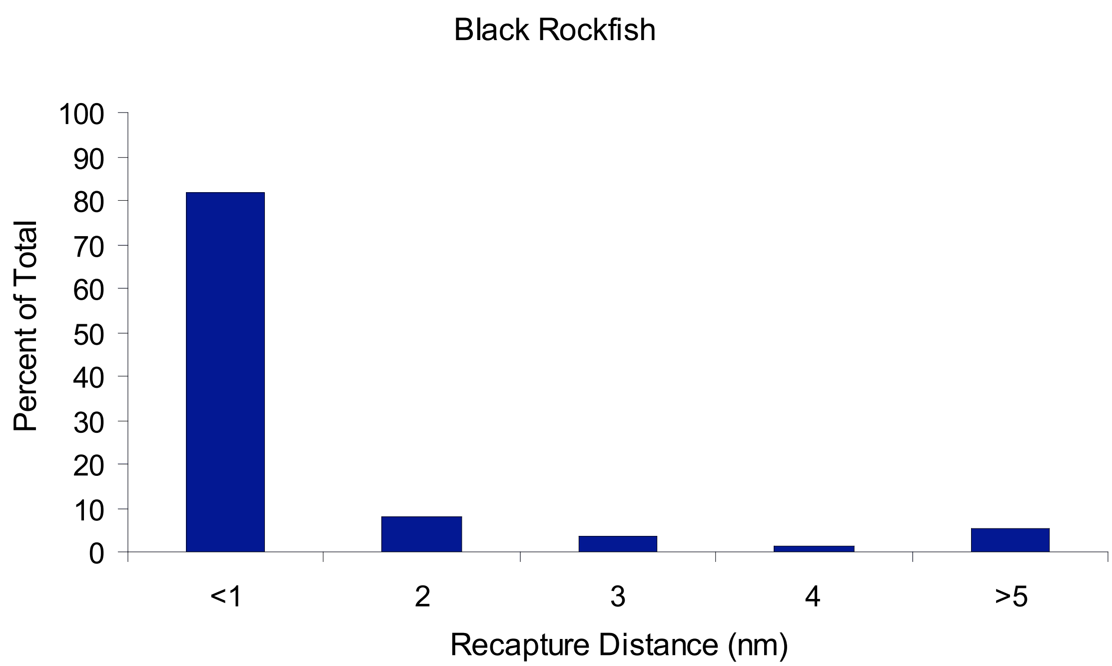

Figure 16. Frequency distribution of distance between release and recapture locations of tagged black rockfish (n = 172), grouped in 1 nm bins. The category > 5 nm includes one black rockfish captured 280 nm away and two black rockfish captured > 400 nm away.

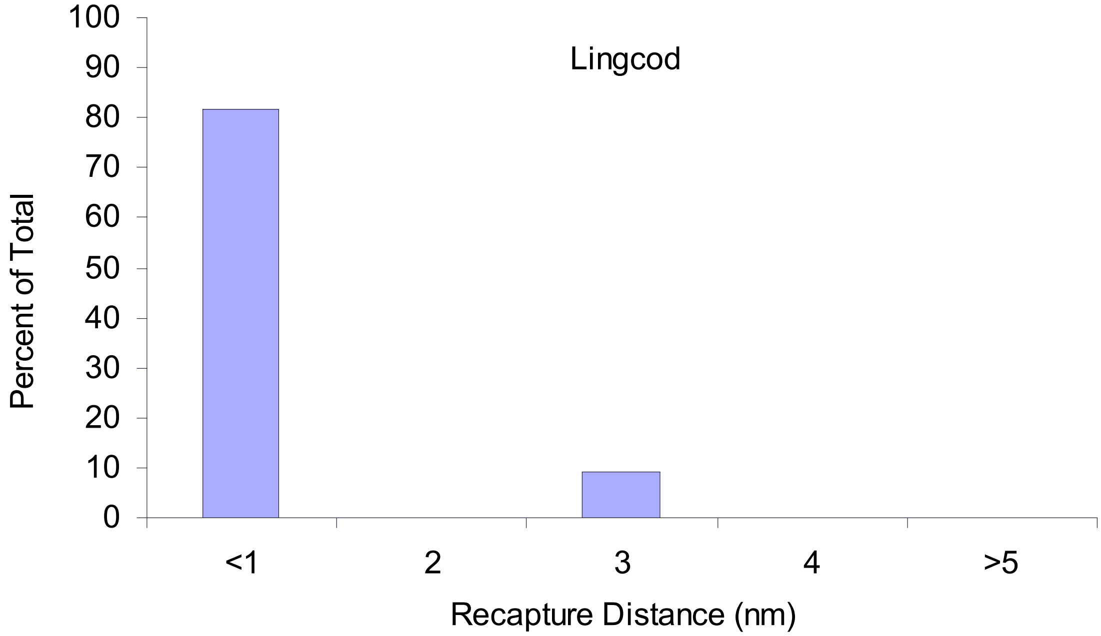

Figure 17. Frequency distribution of distance between release and recapture locations of tagged lingcod (n = 10), grouped in 1 nm bins.

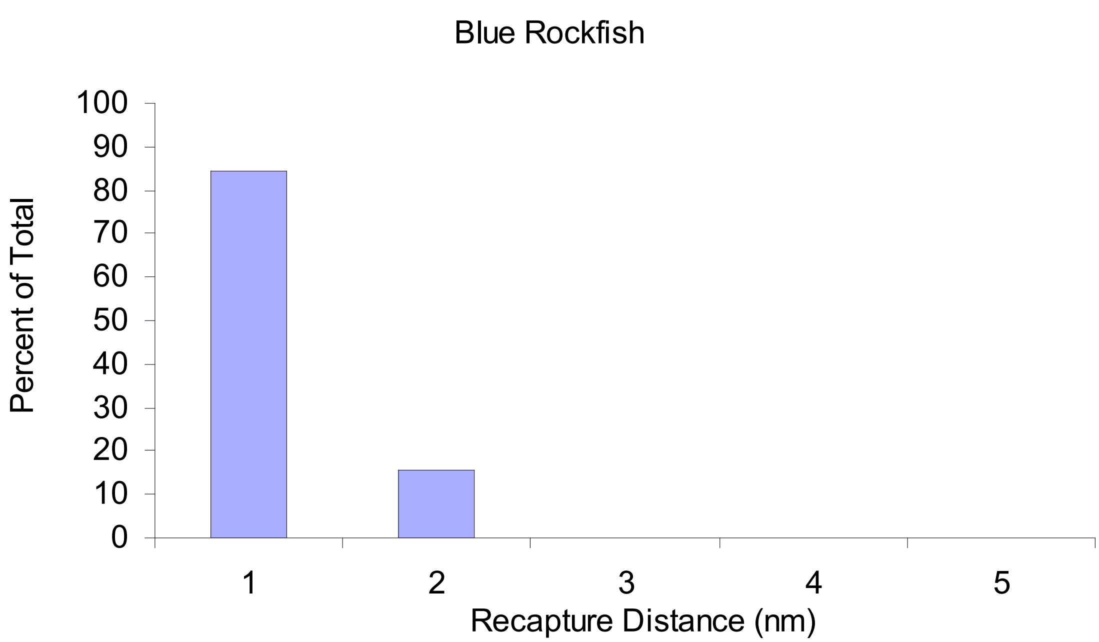

Figure 18. Frequency distribution of distance between release and recapture locations of tagged blue rockfish (n = 13), grouped in 1 nm bins.

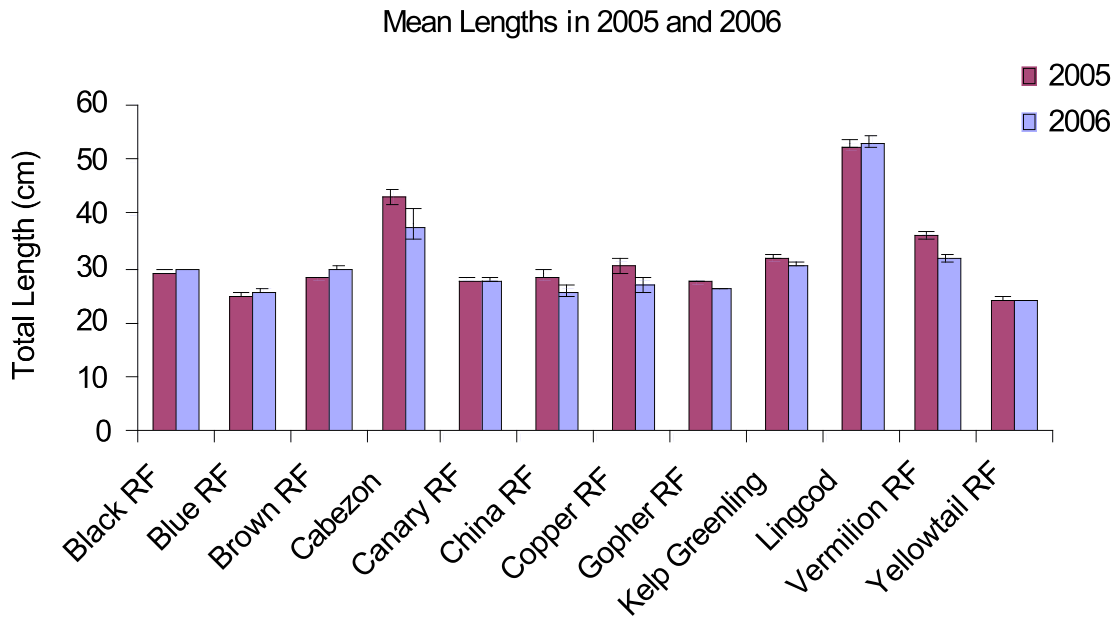

Figure 19. Mean lengths (and SE) of tagged fishes in 2005 and 2006.

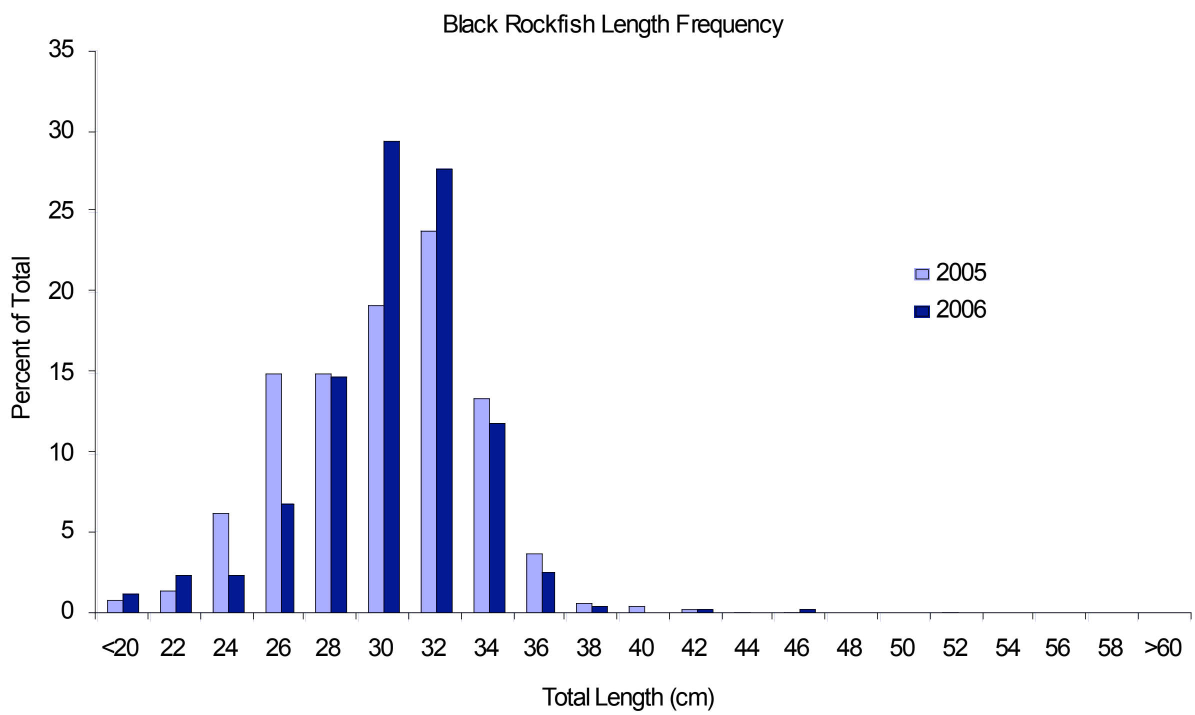

Figure 20. Length frequency histograms of black rockfish caught in 2005 (n = 3647, mean = 29.4 cm) and 2006 (n = 482, mean = 29.7 cm). Mean length at 50% maturity is 36 cm for males and 41 cm for females.

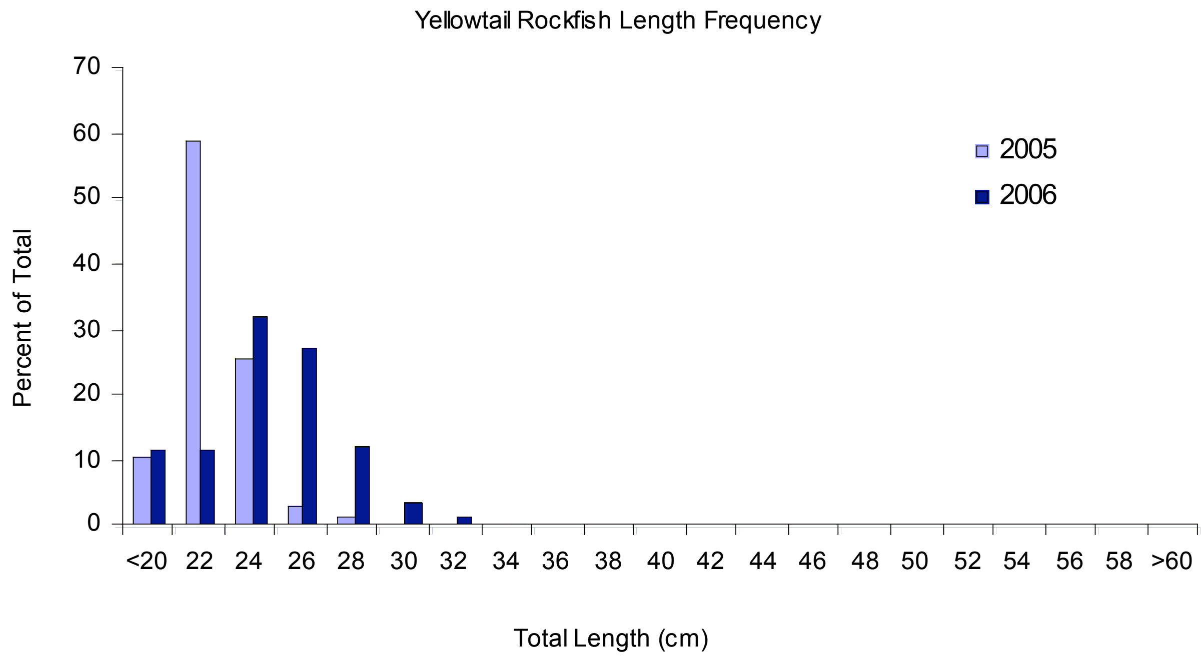

Figure 21. Length frequency histograms of yellowtail rockfish caught in 2005 (n = 159, mean = 24.4 cm) and 2006 (n = 294, mean = 24.1 cm). Length at 50% maturity is 35 cm for males and 36 cm for females.

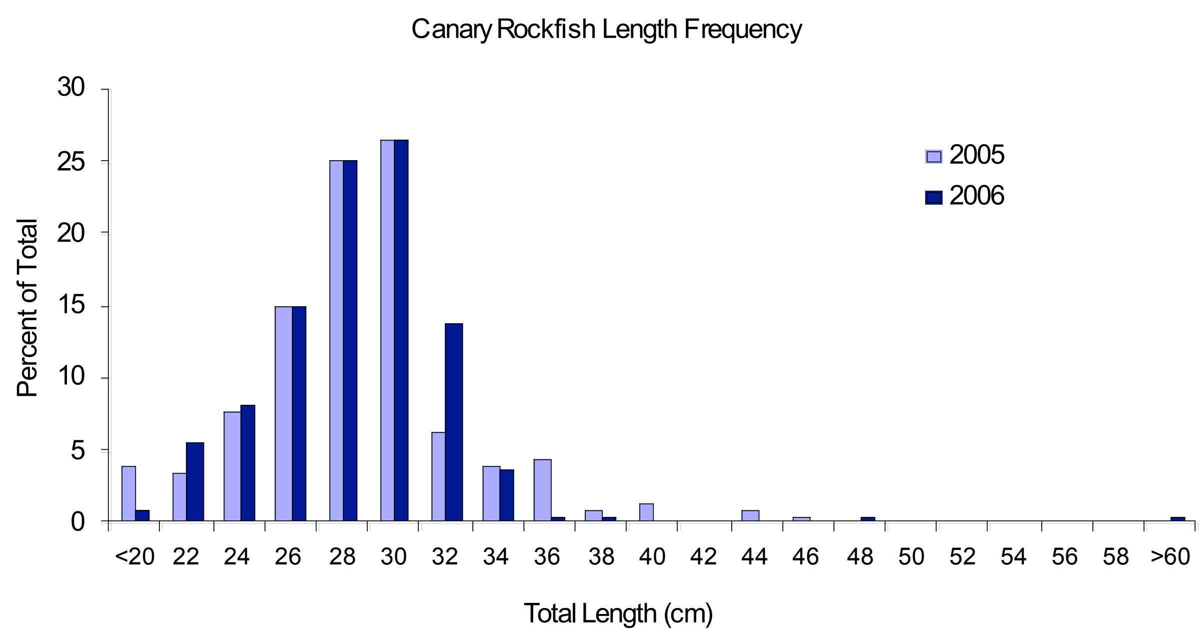

Figure 22. Length frequency histograms of canary rockfish caught in 2005 (n = 207, mean = 28.2 cm) and 2006 (n = 334, mean = 28.0 cm). Length at 50% maturity is 40 cm for males and 44 cm for females.

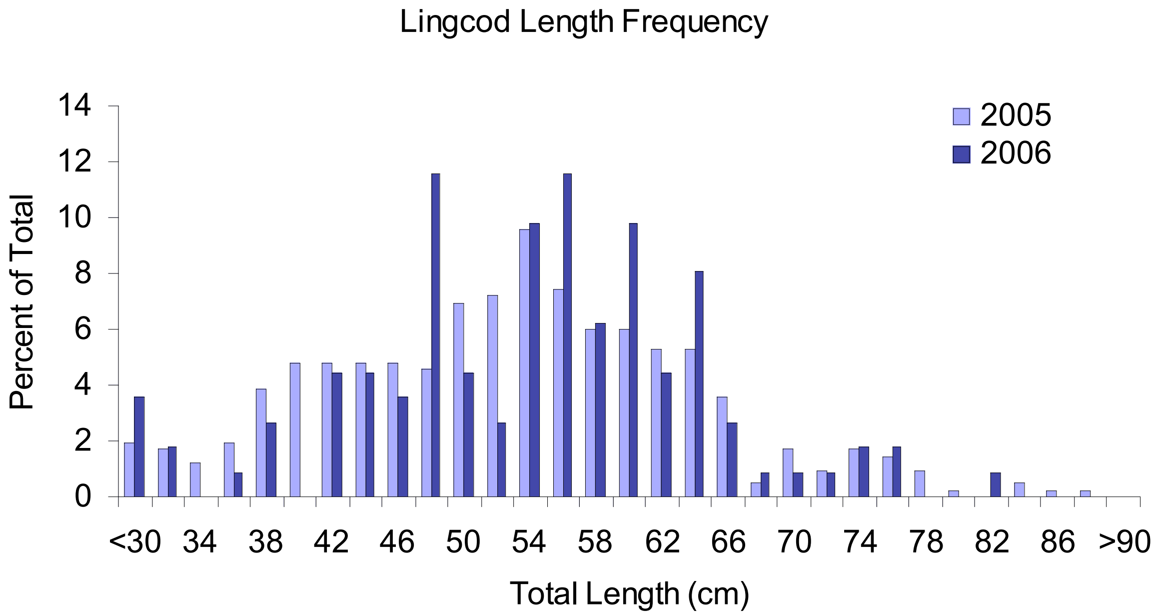

Figure 23. Length frequency histograms of lingcod caught in 2005 (n = 418, mean = 52.6 cm) and 2006 (n = 112, mean = 53.4 cm). Length at 50% maturity is 47 cm for males and 57 cm for females.

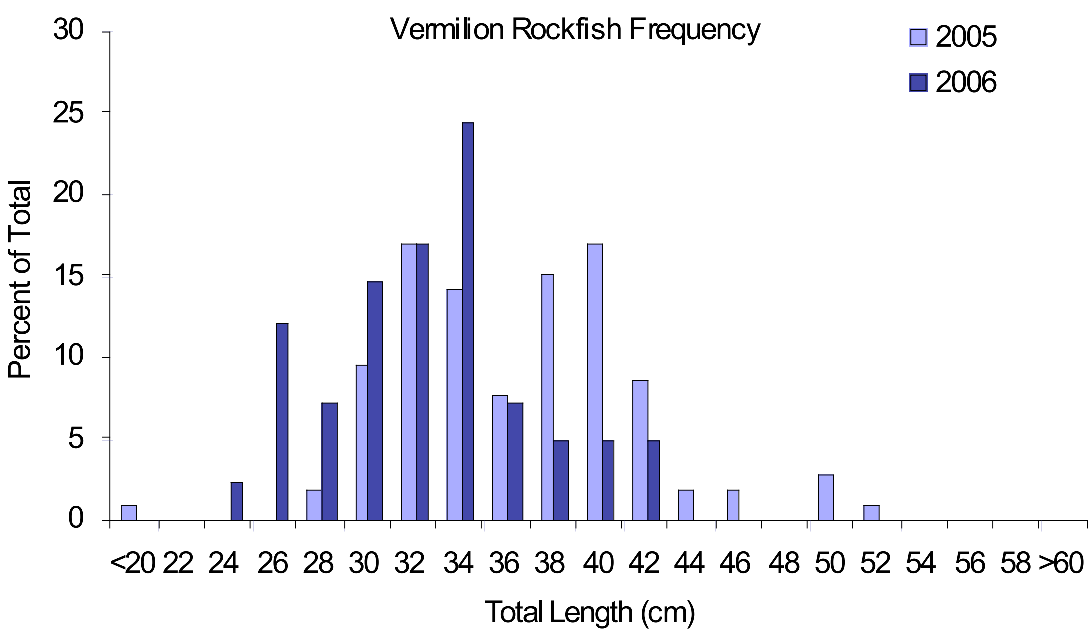

Figure 24. Length frequency histograms of vermilion rockfish caught in 2005 (n = 105, mean = 36.1) and 2006 (n=41, mean = 32.0). Length at 50% maturity is 38 cm for males and 37 cm for females.

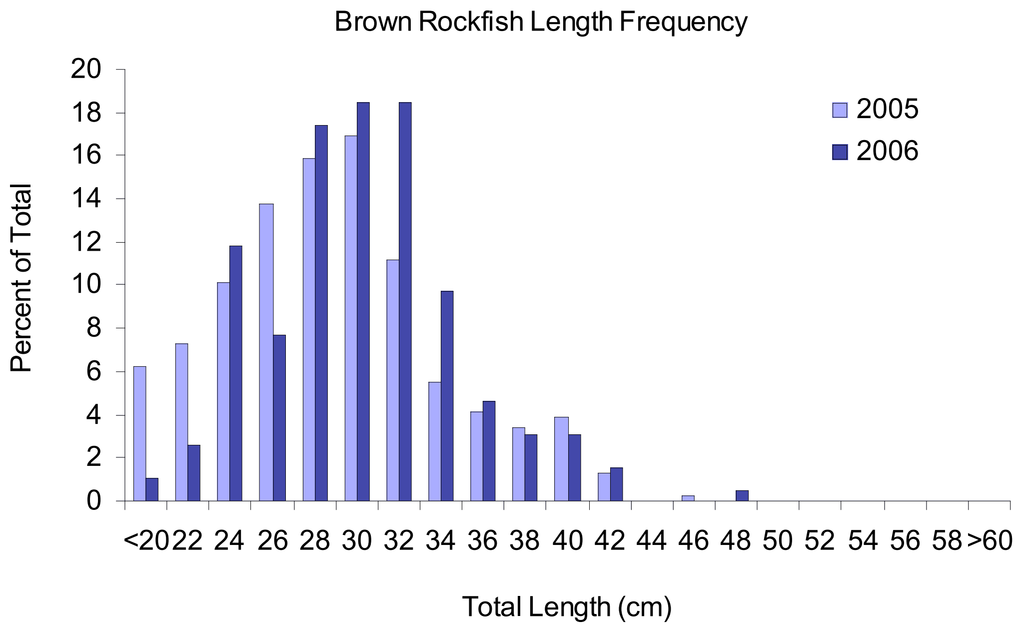

Figure 25. Length frequency histograms of brown rockfish caught in 2005 (n = 384, mean = 28.3 cm) and 2006 (n = 195, mean = 29.7 cm). Length at 50% maturity is 31 cm for both males and females.

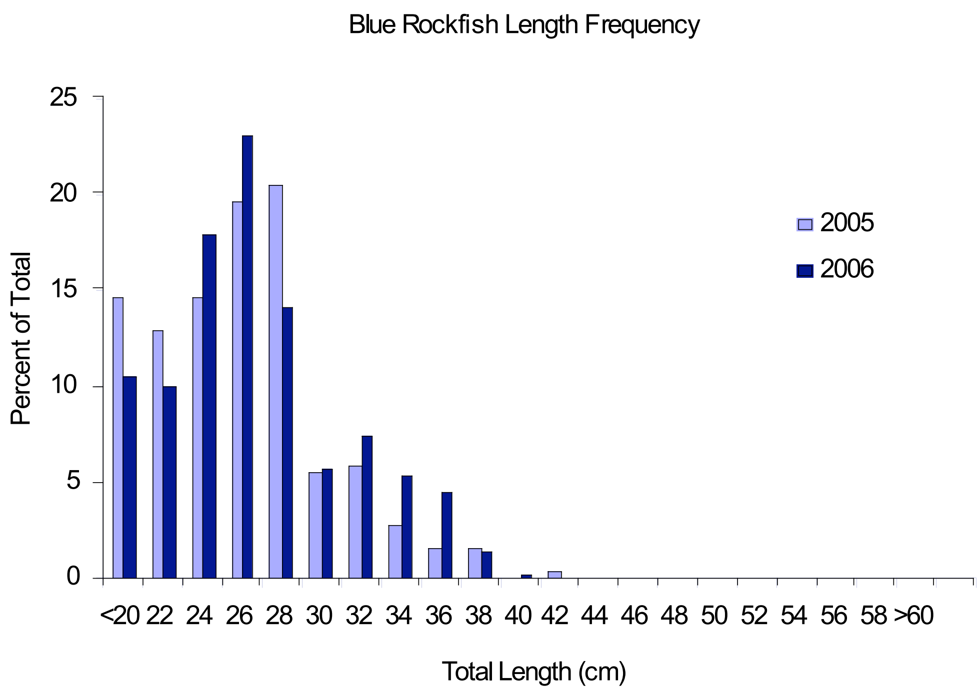

Figure 26. Length frequency histograms of blue rockfish caught in 2005 (n = 254, mean = 25.3 cm) and 2006 (n = 640, mean = 26.0 cm). Length at 50% maturity is 27 cm for males and 29 cm for females.

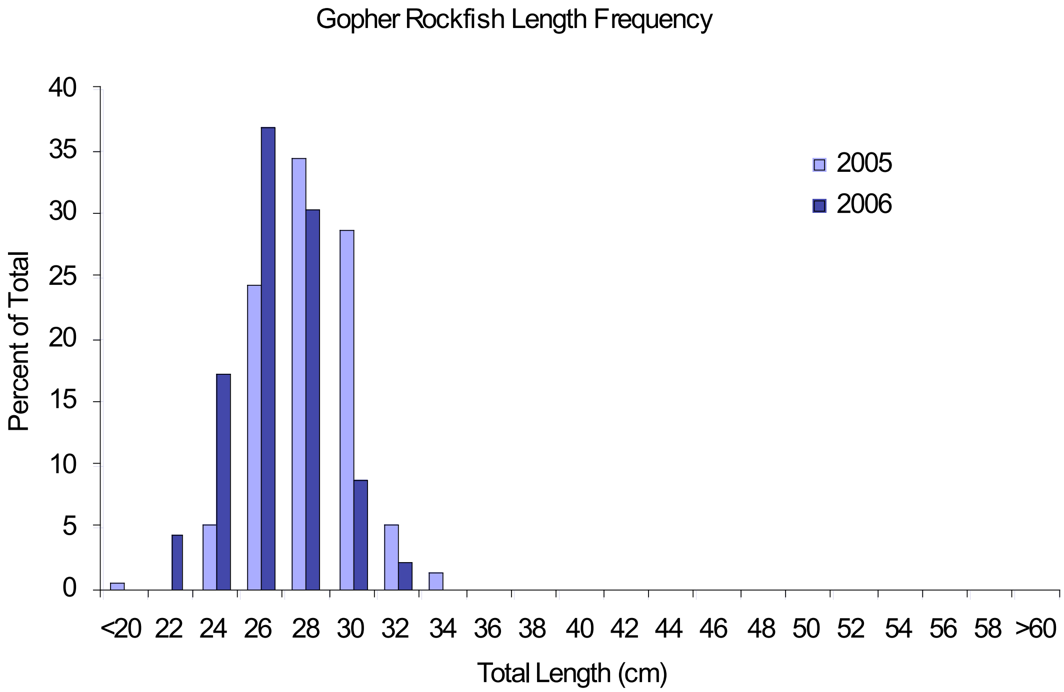

Figure 27. Length frequency histograms of gopher rockfish caught in 2005 (n = 136, mean = 27.6 cm) and 2006 (n = 46, mean = 26.2 cm). Length at 50% maturity is 17 cm for both males females.

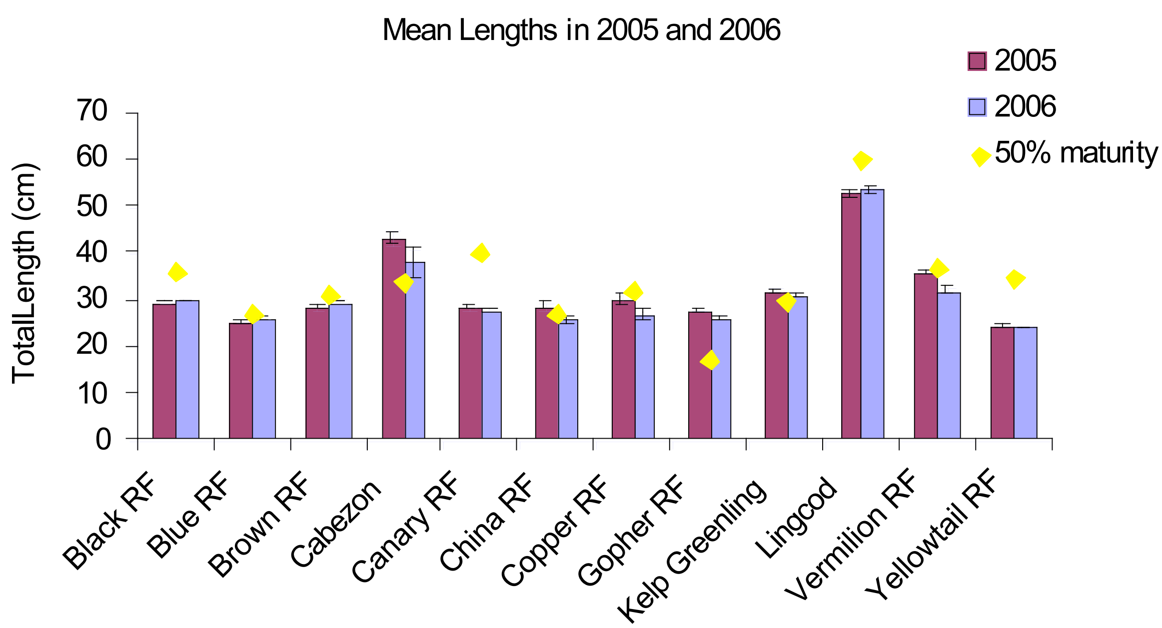

Figure 28. Mean lengths (cm) of fishes caught in 2005 and 2006 compared with length at 50% maturity for each species.

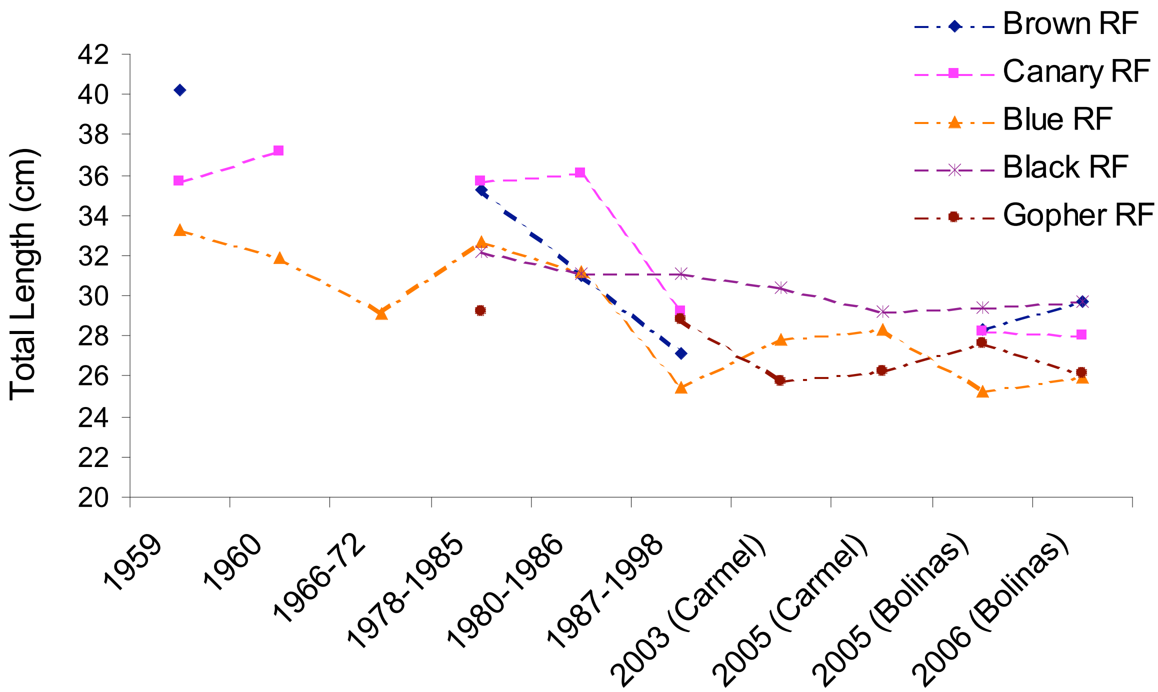

Figure 29. Reported mean lengths of selected rockfishes caught in the central California (Santa Cruz, Monterey, and San Luis Obispo counties) Commercial Passenger Fishery Vessel fishery compared with data from this study and from a research project in Carmel in 2003 and 2005. Data compiled from Karpov et al. 1995 (years 1959, 1960, 1966-72, 1980-1986), Lea et al. 1999 (years 1978-1985), unpublished DFG onboard observer data (years 1987-1998), courtesy of Deb Wilson-Vandenberg, Carmel test fishing data (years 2003, 2005, Starr et al. unpublished data) and 2005, 2006 data from this study. Points are connected at times with dashed lines for visual reference only.

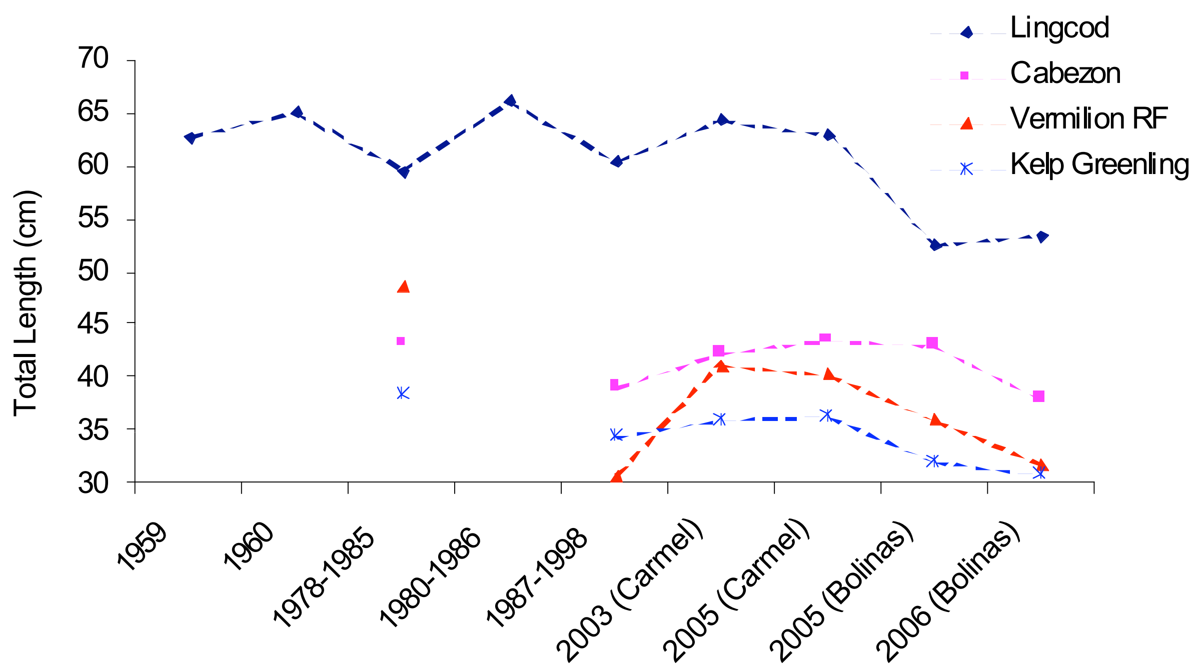

Figure 30. Reported mean lengths of selected rockfishes caught in the central California (Santa Cruz, Monterey, and San Luis Obispo counties) Commercial Passenger Fishery Vessel fishery compared with data from this study and from a research project in Carmel in 2003 and 2005. Data compiled from Karpov et al. 1995 (years 1959, 1960, 1966-72, 1980-1986), Lea et al. 1999 (years 1978-1985), unpublished DFG onboard observer data (years 1987-1998), courtesy of Deb Wilson-Vandenberg, Carmel test fishing data (years 2003, 2005, Starr et al. unpublished data) and 2005, 2006 data from this study. Points are connected at times with dashed lines for visual reference only.

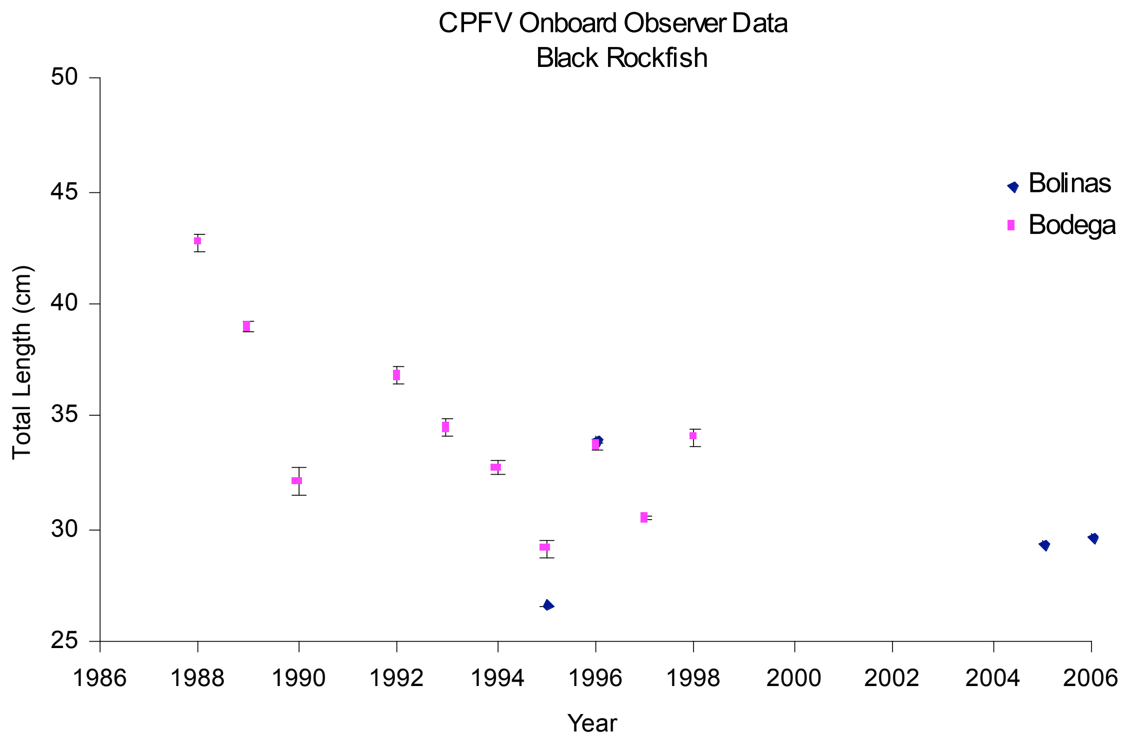

Figure 31. Mean lengths (± SE) of black rockfish measured by onboard observers and caught in the Commercial Passenger Fishing Vessel Fishery from 1988-1998 in areas north of Pt. Reyes (Bodega, CA) and south of Pt. Reyes (Bolinas, CA). Data complied from Pacific States Marine Fisheries Commission RecFin data (years 1988-1998). Also shown are mean lengths of black rockfish caught in this study in 2005 (n = 3647) and 2006 (n = 482).

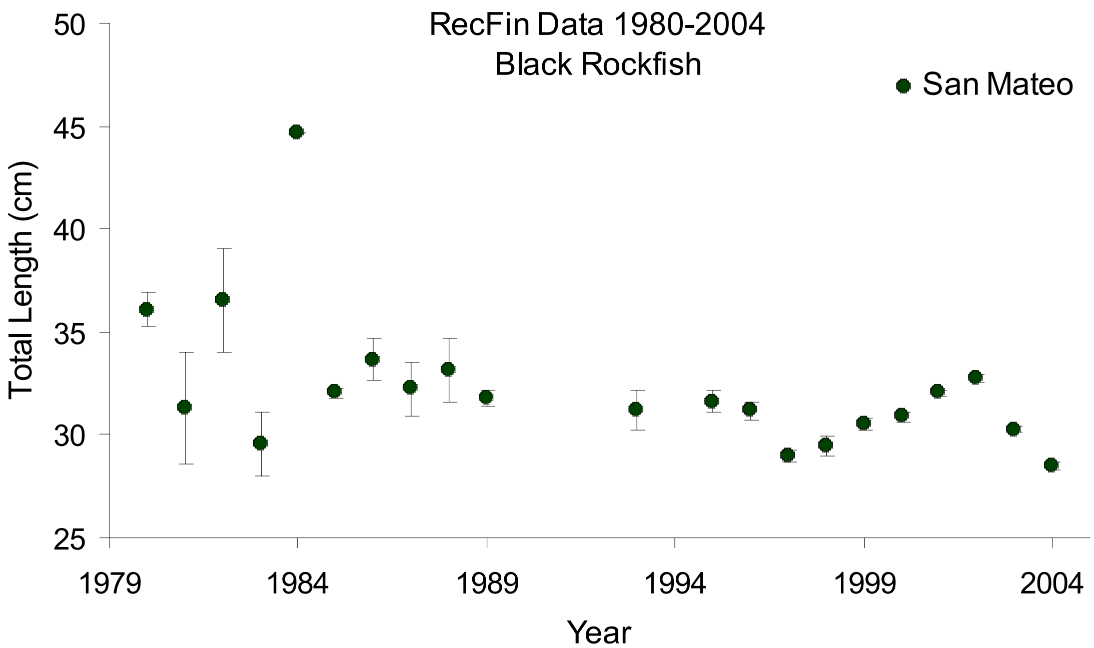

Figure 32. Mean lengths (± SE) of black rockfish caught on Commercial Passenger Fishing Vessels in San Mateo County from 1988-1998 and reported in Pacific States Marine Fisheries Commission RecFin database.

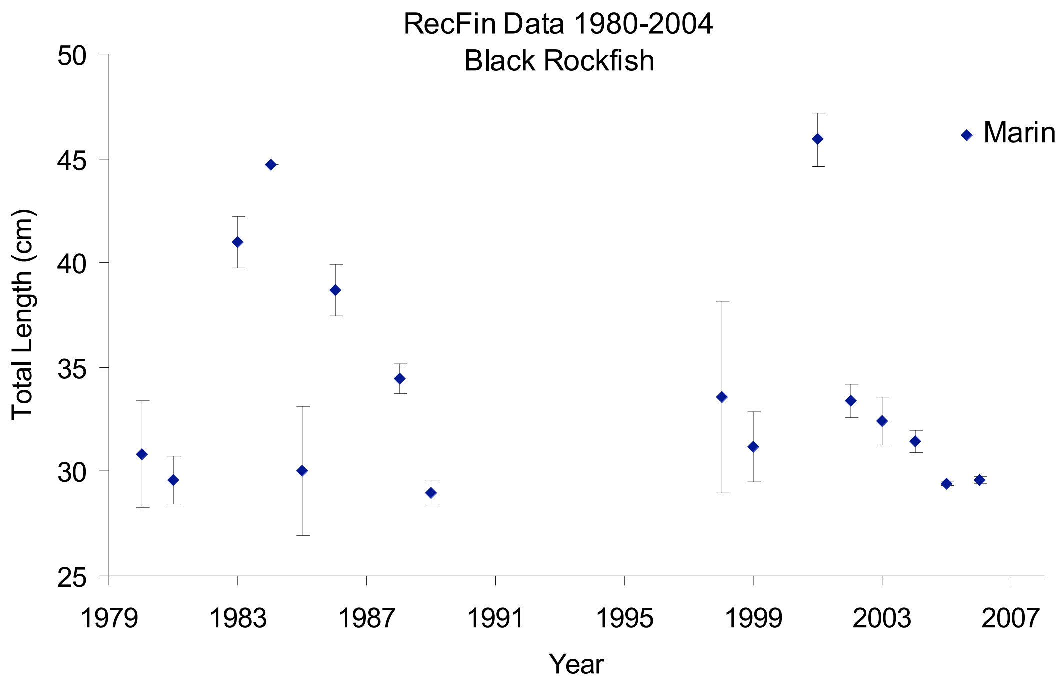

Figure 33. Mean lengths (± SE) of black rockfish caught on Commercial Passenger Fishing Vessels in Marin County from 1988-1998 and reported in Pacific States Marine Fisheries Commission RecFin database. Also shown are data from this study in 2005 and 2006.

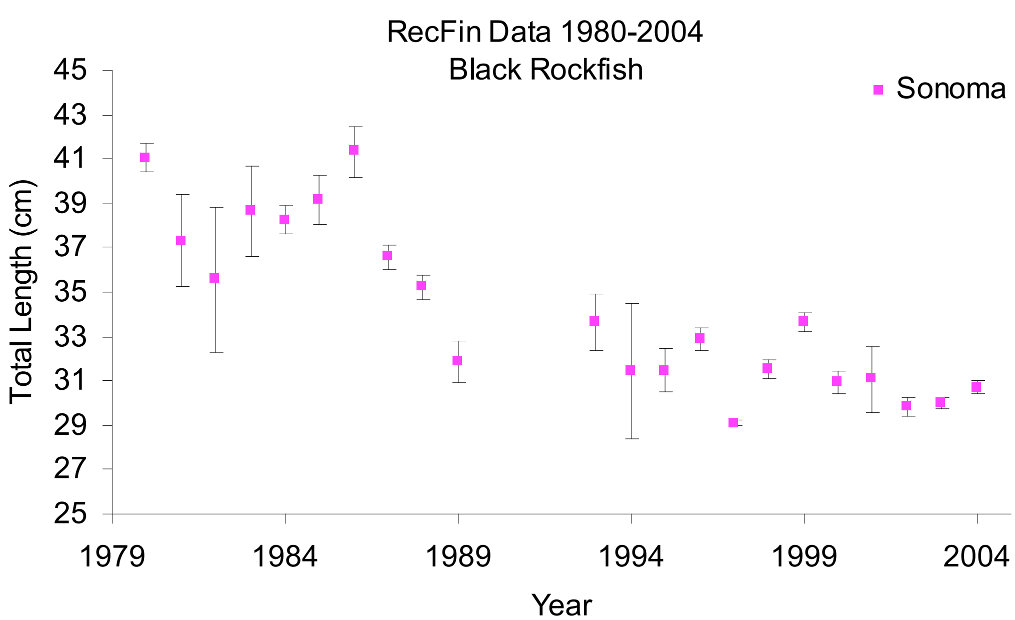

Figure 34. Mean lengths (± SE) of black rockfish caught on Commercial Passenger Fishing Vessels in Sonoma County from 1988-1998 and reported in Pacific States Marine Fisheries Commission RecFin database.

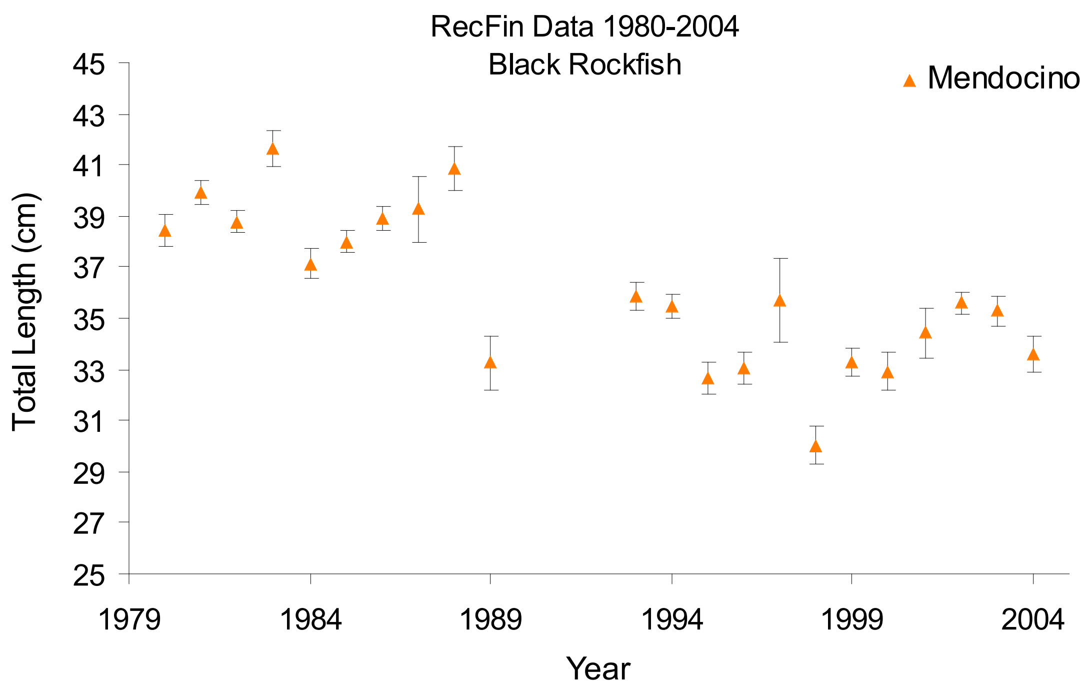

Figure 35. Mean lengths (±SE) of black rockfish caught on Commercial Passenger Fishing Vessels in Mendocino County 1988-1998 and reported in Pacific States Marine Fisheries Commission RecFin database.