# CHANGES IN SIZE COMPOSITION AND RELATIVE ABUNDANCE OF FISHES IN CENTRAL CALIFORNIA AFTER A DECADE OF SPATIAL FISHING CLOSURES

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## ABSTRACT

Rockfish Conservation Areas (RCAs) were implemented in 2000 to 2003 along the West Coast of the United States to reduce fishing mortality on rockfish (*Sebastes* spp.) and other groundfish species that had recently been declared overfished. In 2012, we initiated a study to compare recent catch rates, species compositions and length frequencies of fishes inside and outside the RCAs with data collected in central California between 1995 and 1998. At all sites surveyed, total catch rates from the new surveys (2012–14) were significantly higher than catch rates from before RCA implementation (1995–98). The majority of the differences were due to the increased relative abundance of yellowtail rockfish (*Sebastes flavidus*), although other species, including the overfished canary rockfish (*Sebastes pinniger*), also increased. Differences in the size composition of species between the two time periods reflected both the increased survival of older fishes and higher recruitment success in the past decade.

## INTRODUCTION

After receiving subsidies to develop domestic fishing capability in the 1970s, the US West Coast fishing fleet became overcapitalized in the 1980s, resulting in fishing mortality rates that were unsustainable (Ralston 2002; Melnychuk et al. 2013). As a consequence of the combined effects of overexploitation and poor recruitment conditions throughout the 1990s, seven species of rockfish (*Sebastes* spp.), as well as lingcod (*Ophiodon elongatus*) and Pacific hake (*Merluccius productus*) were declared overfished in West Coast waters during the late 1990s and early 2000s (Berkeley et al. 2004; PFMC 2003). In an effort to protect and rebuild overfished species, while allowing for some harvest of healthy stocks, a broad set of spatial area closures was implemented between 2000 and 2003 to minimize fishing mortality on rebuilding species. These areas are known as Rockfish Conservation Areas (RCAs), i.e., areas on the continental shelf and slope closed to specific recreational and commercial fishing activities. In US waters, the RCAs extend along the entire West Coast from the Mexican border to the Canadian border, and fishing prohibitions continue to date.

The regulatory boundaries of RCAs are lines that generally follow depth contours. The precise boundaries vary both over time (season and year), gear type used, and by latitude in different areas of the coast. Recreational fisheries have been constrained to waters shallower than the nearshore boundary of the recreational RCA, while both trawl and fixed gear commercial fisheries are allowed to fish deeper than the seaward boundary of the trawl and non-trawl RCAs (Mason et al. 2012). In California, the recreational RCA has been divided into a number of management areas, such that fishing for groundfish species has been prohibited deeper than 36–110 m (20–60 ftm) on the continental shelf.

Although RCAs are not intended to exclude fishing on a permanent basis, they are intended to provide the benefits of spatial closures often attributed to marine reserves, primarily the severe reduction of fishing effort to rebuild overfished species. Some of these benefits include general increases in population size and biomass, increases in the mean length of fish, and higher reproductive potential (Lester et al. 2009). The latter benefit can occur in situ through increased fish abundance as well as reduced mortality from fishing of larger, older fishes, which may contribute disproportionally to reproductive success (Hixon et al. 2014). In addition, enhanced reproductive potential within a closed area is expected to have "spillover" effects, seeding adjacent areas with both emigrating adults and dispersing progeny from the protected spawning population.

Recent studies have evaluated population trends before and after RCA closures using a combination of onboard observer data for recreational fisheries in areas open to recreational fishing (e.g., Cope et al. 2013) and data from bottom trawl surveys (e.g., Keller et al. 2014). While Keller et al. (2014) documented greater catch rates and larger fish within RCAs for a suite of demersal species, their data set did not include information from the time period prior to RCA establishment, contained minimal coverage of shallower regions targeted by recreational fisheries, and excluded high relief habitats that are inaccessible to trawling. Thus, there remains a need to better quantify changes in the relative abundance of rocky reef fishes in nearshore waters to understand the effects of area closures at fine spatial scales.

A temporally and spatially extensive pre-RCA data set made it possible to assess the effectiveness of the RCAs after a decade of spatial closures. From 1987 to 1998, in response to industry concerns of an apparent decline in the quality of fishing for rockfishes and lingcod in central and northern California waters, the California Department of Fish and Wildlife (CDFW) conducted at-sea sampling of the catch of commercial passenger fishing vessels (CPFVs) (Reilly and Wilson-Vandenberg 1999). During that period, observers accompanied charter-fishing vessels on over 2,200 fishing trips that targeted rockfishes and lingcod, collecting information on over 300,000 fishes. They recorded fishing effort (in units of angler hours spent fishing), species composition, lengths, and coarse fishing location information in every month of the year at sites from Morro Bay to Eureka, CA.

The goal of our research was to evaluate changes in species compositions, catch rates, and lengths of recreationally important species within three different regions of central California in pre-RCA and post-closure data sets. This research was a collaborative effort among the National Marine Fisheries Service (NMFS), CDFW, Moss Landing Marine Laboratories (MLML), California Sea Grant, the central coast CPFV fleet and volunteer anglers recruited through the California Collaborative Fisheries Research Program at MLML for the post-closure surveys. Here we compare fishery metrics calculated from the pre-RCA CDFW data set (1995–98) to a new post-closure data set (2012–14) that was generated by fishing in the same locations and using protocols and techniques similar to those used by Reilly and Wilson-Vandenberg (1999) during the CDFW surveys.

## METHODS

### Hook and Line Fishing Surveys

***1987–98 CDFW Data Set*** From 1987–98 CDFW selected trips to observe CPFV operations. On each trip, CPFV captains chose the fishing locations, determined drift length and the number of drifts. On selected trips, CDFW observers recorded a latitude and longitude for fishing drifts, the number of active anglers, fishing time, number of each species caught, and whether they were kept or released. This enabled calculations of catch per unit effort (CPUE) for discrete geographic areas. Observers recorded total length (mm) of a subset of retained fishes on the vessel while transiting to port. Thus, length data from 1987–98 do not have associated latitude and longitude coordinates on the fine geographic scale of a fishing drift. As a result, we only compared lengths of fishes from the 1987–98 data set from fishing trips that occurred exclusively at the locations that were sampled in 2012–14. Although the CDFW 1987–98 data have been used to support past stock assessments, information on catches at a greater spatial resolution were recovered as a component of this effort and recently uploaded in 2014 into a relational structured queried language (SQL) database.

***2012–14 Fishing Methods*** Field methods for the 2012–14 surveys followed fishing operations in the 1987–98 CDFW surveys with the exception that we released caught fishes, targeted specific locations where 1987–98 surveys took place, and recruited volunteer anglers. Although the end tackle used by fishers surveyed in the CDFW study was not precisely recorded, discussions with CPFV captains suggested that five-hook shrimp-fly gangions was the gear most commonly used at the time. Therefore, five-hook gangions with shrimp-fly lures were provided for each angler and no subtractions or additions of gear were allowed to enable the calculation of catch rates on a per-hook basis in future comparative studies. Half of the anglers used strips of squid bait on each hook and the other half did not use bait to represent different methods of fishing.

Captains were instructed to conduct fishing drifts as they would on a normal chartered day of fishing. GPS coordinates of CDFW fishing locations were provided to locate areas for fishing to occur. Once in those areas, captains searched for locations to fish, making use of depth sounders as well as their knowledge of the fishing grounds. Captains started and stopped fishing based on drift speed and catch rates, as they would on normal trips. Start and stop times for each drift were recorded to calculate CPUE. Beginning and ending coordinates were recorded and later plotted in GIS to track drift lines in relation to RCA boundaries as well as compare our fishing locations with the CDFW fishing data. Each day consisted of approximately three hours of fishing within the region.

To ensure fish survival upon release, each fish caught was initially placed into an 18-gallon bin filled with fresh seawater. Care was taken to minimize damage to each fish while the hook was removed. Fish were identified to species and we measured fork length to the nearest half-

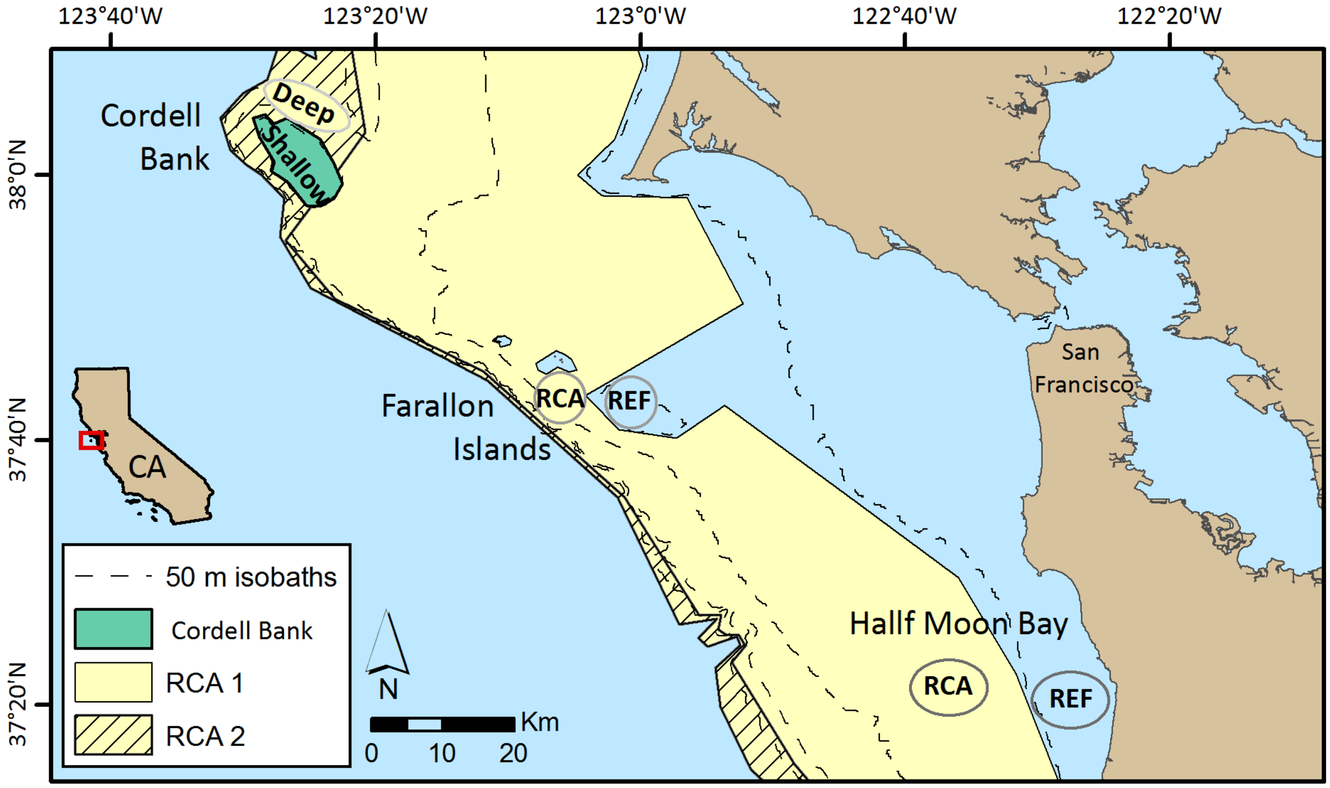


Figure 1. Rockfish Conservation Area boundaries and hook and line fishing sites (RCA, REF, Shallow, Deep) sampled in 1995–98 and 2012–14. Sampling was completed in the regions of Cordell Bank (COR), the Farallon Islands (FAR), and Half Moon Bay (HMB). RCA 1 is the area where recreational fishing and commercial bottom fixed-gear has been prohibited since 2002. RCA 2 is the area where commercial bottom trawling has been prohibited since 2002. These boundaries may change seasonally as well as annually.

centimeter. To enable future studies of fish movements, T-bar anchor tags were inserted into the dorsal muscle of a subset of fishes that displayed little or no signs of barotrauma. The majority of fishes were released back at depths of capture with the aid of descending devices. Subsets of selected species were retained for ongoing studies of reproductive ecology, (e.g., Beyer et al. 2015), age and growth, and isotope/diet analysis.

**Fishing Regions and Site Selection**

We selected three different regions of central California: Half Moon Bay (HMB), the Farallon Islands (FAR), and Cordell Bank (COR) for comparison of fish communities pre- and post-RCA implementation (fig. 1). All three regions contained popular fishing locations in the 1980s and 1990s, have areas that have been closed since 2002, and were sampled extensively by CDFW between 1987–98. From 2012–14, we fished within RCA sites (closed to recreational fishing) and reference sites (REF, open to fishing) (fig. 1). Sites within the RCA were selected based on their proximity to pre-RCA fishing drifts from the CDFW data set, whereas comparable REF sites were selected based on both their proximity to CDFW fishing drifts and on the fact that they had been fished seasonally since 2002. To select reference fishing sites where recreational fishing continued after 2002 we consulted with local commercial and recreational fishermen in July and August of 2012. The Half Moon Bay and the Farallon Islands regions have sites that have been fished since the implementation of RCAs. However, the surrounding areas of Cordell Bank had no comparable site open to fishing after 2002; therefore we compared "shallow" and "deep" sites to evaluate whether changes in the length and relative abundance of fishes over time varied by depth within this closed region.

As the RCAs are intended to closely approximate depth based spatial closures, the RCA fishing sites were generally deeper than the reference sites in Half Moon Bay and the Farallon Islands. The recreational RCA in the San Francisco Management Area (38°57.50'N to 37°11'N) restricted recreational fishing deeper than approximately 55 m (30 ftm) during the 2012–14 surveys. The Half Moon Bay fishing sites were between 4–20 km offshore and included low relief rocky reef habitats. Fishing drifts in the Half Moon Bay RCA site occurred at depths between 55–85 m and drifts within the REF site occurred at depths between 23–52 m. The Farallon Islands fishing sites were distributed between the North Farallon Island and Southeast Farallon Island, approximately 50 km west of San Francisco. Fishing drifts inside the RCA were at depths between 57–73 m and drifts within the REF site were in depths of 27–65 m. Fishing drifts in the REF sites were sometimes deeper than the stated shoreward depth of the RCA because published boundaries do not follow exact isobaths. Cordell Bank is located 40 km west of Point Reyes and is comprised of high relief pinnacles, none reaching closer to the surface than 35 m. The "shallow" fishing sites were all on top of the bank, on the northeast side, at depths between 55–135 m. The "deep" fishing sites were just north of the bank in water depths of 120–190 m.

### Analysis

***Selection of 1995–98 CDFW data*** To evaluate the effectiveness of RCA closures, only data from 1995–98 in the CDFW data set were used for comparison with the 2012–14 data set. These years were selected because they were the four years closest to the implementation of the RCAs, and had higher and more consistent number of drifts compared to the 1987–94 data. Individual drifts within the 1995–98 CDFW data set were selected for analyses based on three criteria: recorded amount of time fishing, location, and recorded depth. To minimize the bias caused by short drift times, which might over or underestimate catch rates, we excluded any drifts from catch rate analyses that were less than five minutes in duration for both the 1995–98 and 2012–14 data sets. Additionally, geographic filters were applied to the 1995–98 data set to ensure spatial congruence with the 2012–14 data set. Using ArcGIS, 1 km buffers around all 2012–14 drifts were created and drifts in the 1995–98 data set that did not overlap with the 1 km buffers were excluded from data analyses. Consequently, drifts with incomplete or no spatial information were also excluded. Finally, only 1995–98 drifts that were recorded within a depth of ±10 m of the minimum and maximum depth of 2012–14 drifts within a site were included to maintain similarity between the depths sampled in both time periods.

***Catch Rate Analyses*** We used CPUE, where effort was in units of angler hours, as a metric of relative abundance of fishes. As there was no documentation or records regarding the number of hooks each angler used in the CDFW data set, we measured catch on a per angler basis rather than catch on a per-hook basis. To calculate effort we multiplied the number of anglers observed by the total fishing time for each drift. CPUE was then calculated for each species by dividing the number of fish caught by fishing effort for each drift:

$$\text{CPUE} = \frac{\text{No. of fish caught per drift}}{[\text{No. of anglers}] \times [\text{No. hours fishing}]}$$

We compared species compositions at sites (RCA/REF, deep/shallow) within regions by examining the proportion of catch that each species comprised. The 1995–98 and 2012–14 data sets were compared by calculating the mean CPUE for each species and then determining the fraction of the sum of all mean species CPUE that each species comprised.

To examine how total and species-specific catch rates have changed we used Welch's t-test ($\alpha = 0.05$) to compare CPUE in the 1995–98 and 2012–14 data sets. Welch's t-test was appropriate for these data because our samples were independent, had unequal variances, and sample sizes were high enough that we could assume normality (Ruxton 2006). We also used Welch's t-tests to compare the mean CPUE for each of the six most abundant species, inside and outside of the future RCAs in the 1995–98 data set, to determine if initial differences existed before the implementation of RCAs.

### Length Analyses

We compared species mean fork lengths (cm), length frequencies, and the percent of fish larger than the length of 50% maturity to assess overall changes in fish sizes between 1995–98 and 2012–14 data sets. We used Welch's t-test ($\alpha = 0.05$) to compare mean fork lengths of the six most abundant species in both of the time periods combined. Lengths from the 1995–98 data set were converted from total length to fork length using previously published methods (Echeverria and Lenarz 1984; Laidig et al. 1997). Data from Wyllie Echeverria (1987) and Silberberg et al. (2001) provided estimates for length of 50% maturity for species in the geographic region where we collected data. We used a Kolmogorov-Smirnov two-sample test to examine if the length frequency distributions were similar between the 1995–98 and 2012–14 data sets for yellowtail rockfish (*S. flavidus*), canary rockfish (*S. pinniger*), and widow rockfish (*S. entomelas*). Yellowtail rockfish lengths were analyzed because they were exceptionally abundant in field surveys. Canary and widow rockfish were analyzed because they were both federally listed as overfished species and are focal species for management. Statistical analyses were performed in JMP and R (JMP 2012, R Core Team 2014).

## RESULTS

The 1995–98 and 2012–14 data sets were comparable in both effort (fishing drifts) and measured fishes in all three regions (tables 1 and 2). For length analyses, we used 6,928 fishes from the 1995–98 data set and measured a total of 7,781 fishes between 2012–14 (table 2).

### Species Compositions

Yellowtail rockfish was the most abundant species (measured by mean CPUE) in both the 1995–98 and

TABLE 1
**Number of individual fishing drifts by region and site used for CPUE analyses comparing the historical fishing data set (1995–98) and the new data set (2012–14).**

| | | No. of Drifts | |
|---|---|---|---|
| Region | Site | 1995–98 | 2012–14 |
| Cordell Bank | Deep | 69 | 37 |
| | Shallow | 61 | 24 |
| Farallon Islands | RCA | 41 | 30 |
| | REF | 42 | 54 |
| Half Moon Bay | RCA | 62 | 35 |
| | REF | 43 | 59 |

TABLE 2
**Number of fishing trips and counts of fish lengths used in analyses of the historical fishing data set (1995–98) and the new data set (2012–14).**

| | | Fishing Trips | | Count of Fish Lengths | |
|---|---|---|---|---|---|
| Region | Site | 1995–98 | 2012–14 | 1995–98 | 2012–14 |
| Cordell Bank | Deep | 8 | 9 | 1584 | 978 |
| | Shallow | 6 | 9 | 1160 | 1661 |
| Farallon Islands | RCA | 3 | 8 | 793 | 1051 |
| | REF | 4 | 10 | 985 | 1169 |
| Half Moon Bay | RCA | 11 | 10 | 1854 | 1465 |
| | REF | 3 | 10 | 552 | 1457 |

the 2012–14 data sets (fig. 2). Yellowtail rockfish comprised the largest percentage of CPUE at all sites except the Farallon Islands and Half Moon Bay reference sites in 1995–98, where blue rockfish (*S. mystinus*) were more abundant (fig. 2). The six most abundant species across all regions in the 1995–98 data set were: yellowtail rockfish, blue rockfish, canary rockfish, rosy rockfish (*S. rosaceus*), chilipepper (*S. goodei*), and widow rockfish. Five of these species were also the most abundant in the 2012–14 sampling, although the order of abundance shifted to yellowtail rockfish, blue rockfish, canary rockfish, widow rockfish, rosy rockfish, and lingcod. Species compositions between the 1995–98 and 2012–14 data sets at each site appeared to be more similar than comparisons of paired RCA and reference sites within a region, or deep and shallow sites at Cordell Bank (fig. 2).

## Changes in Catch Rates

***Farallon Islands and Half Moon Bay*** Relative to the pre-closure 1995–98 period, total catch rates inside and outside the RCA were significantly higher ($p \leq 0.05$) in the 2012–14 period (fig. 3). This difference was in part attributable to a twofold to threefold increase in the catch

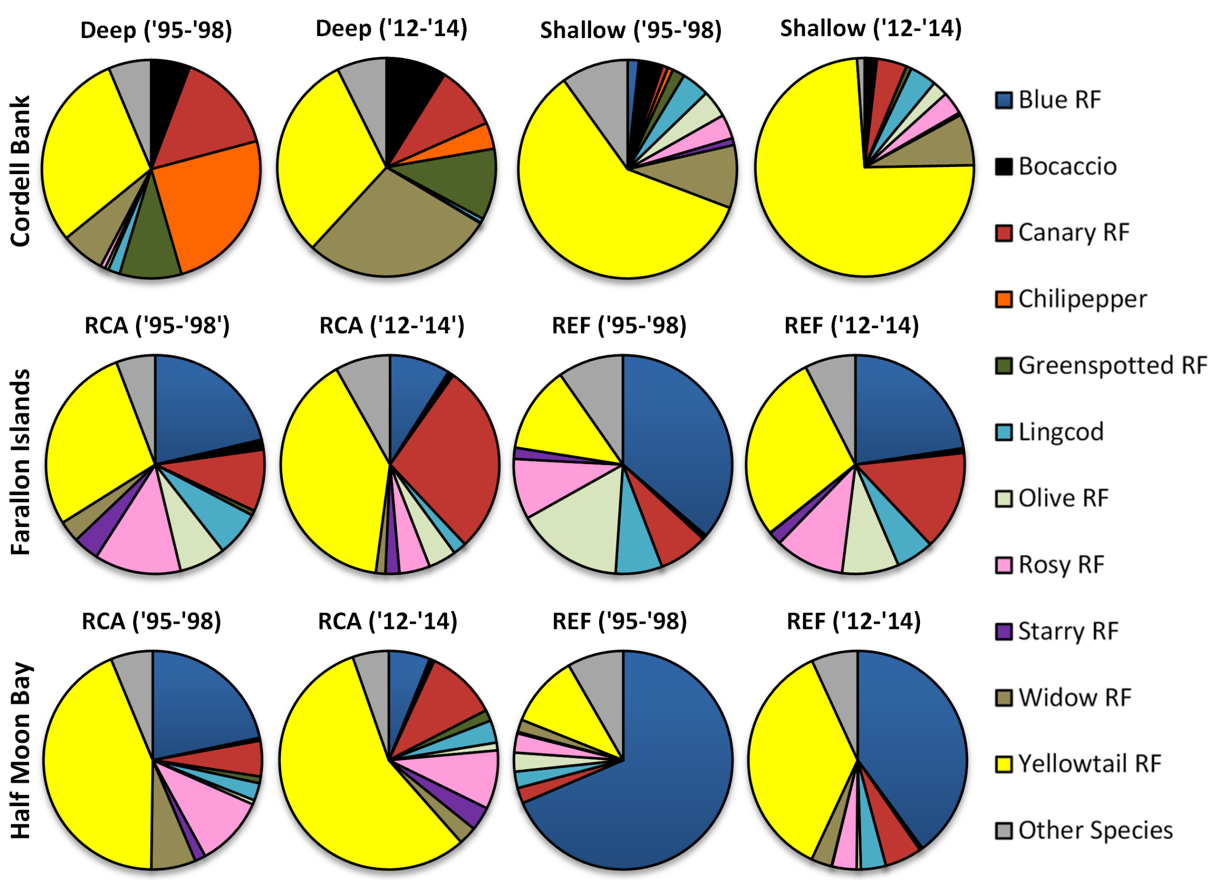


Figure 2. Species compositions calculated as fraction of total CPUE (catch per angler per hour) by site for the historical data set (1995–98) and our recent data set (2012–14) for the 11 most abundant species.

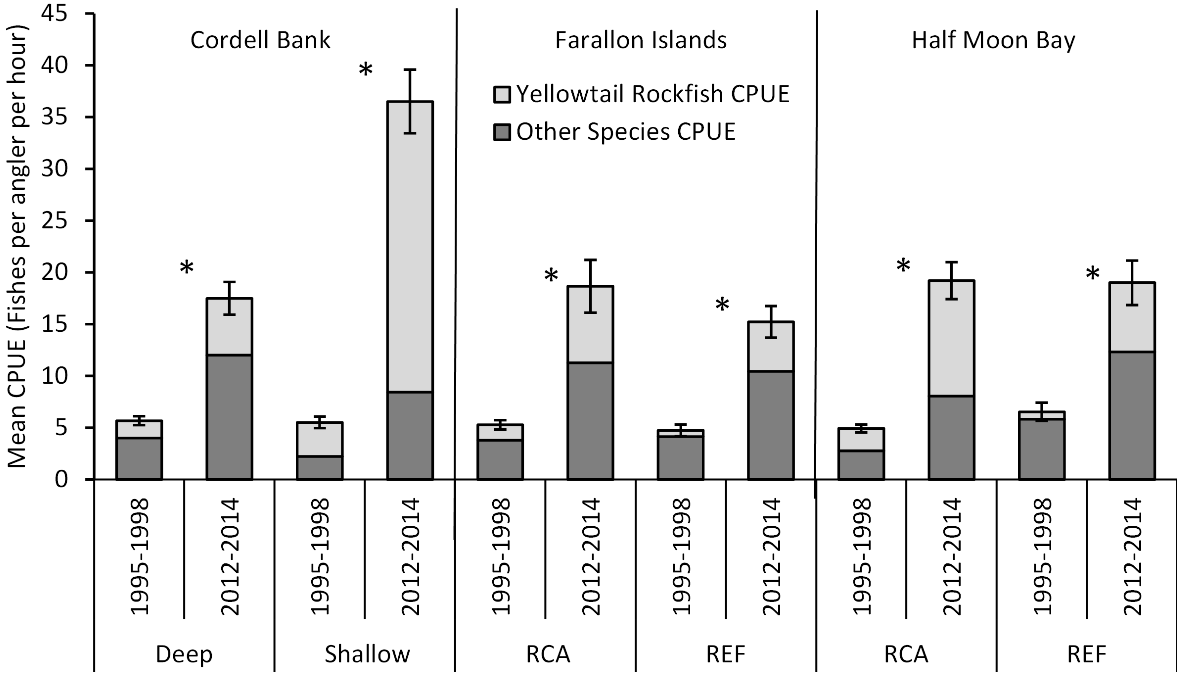


Figure 3. Mean total CPUE (all species caught per angler per hour) shown by site and period of data collection. Yellowtail rockfish CPUE is displayed separately as it represented the single largest proportion of any species caught. Error bars show the standard error of total CPUE. Asterisks indicate a significant mean difference between CPUE for all species combined as well as CPUE without yellowtail rockfish at each site between the 1995–98 and 2012–12 data sets ($\alpha = 0.05$).

of yellowtail rockfish. However, CPUE was still significantly higher (at some sites doubled) in recent years even when discounting yellowtail rockfish catch (fig. 3). We found significant increases and no significant decreases in CPUE at various sites for all six species (yellowtail rockfish, blue rockfish, canary rockfish, widow rockfish, rosy rockfish, and lingcod) between the 1995–98 and 2012–14 data sets (fig. 4). Canary and yellowtail rockfish CPUE were greater in the 2012–14 data set in all sites at the Farallon Islands and Half Moon Bay (fig. 4).

When comparing total CPUE within each time period we found no significant differences between RCA and reference sites in the Farallon Islands or Half Moon Bay regions (table 3). However, relative differences in CPUE between the RCA and reference sites for individual species changed over time. For example, there was no significant difference in canary rockfish CPUE between the RCA and reference sites in the 1995–98 data set, but the 2012–14 data set showed higher CPUE of canary rockfish in the RCA at both the Farallon Islands and Half Moon Bay regions (fig.4, table 4). Conversely, some trends remained the same in the 1995–98 and 2012–14 data sets. In the Half Moon Bay region, rosy rockfish were more abundant in the RCA and blue rockfish were more abundant in the reference site in both time periods (fig. 4, table 4).

***Cordell Bank*** Similar to the Farallon Islands and Half Moon Bay, total CPUE increased dramatically ($p \leq 0.05$) in both the deep and shallow sites in the 2012–14 data set compared to the 1995–98 data set at Cordell Bank (fig. 3). The shallow site exhibited the greatest increase of all sites in mean CPUE (by approximately six-fold) between the two time periods. Yellowtail rockfish CPUE comprised the majority of this difference (fig. 3). Additionally, compared to the 1995–98 data set, the mean CPUE of lingcod and rosy rockfish at the shallow site and canary rockfish and widow rockfish at the deep site significantly increased in the 2012–14 period (fig. 4). As at the Farallon Islands and Half Moon Bay sites, no significant decreases in CPUE occurred over time at either Cordell Bank site.

For the comparisons between the deep and shallow sites at Cordell Bank, no difference was observed within

TABLE 3
**Mean total CPUE differences (Diff.) at sites within each data set, with p-values and degrees of freedom (df). Positive values indicate greater CPUE at deep sites (Cordell Bank) or inside the RCA (Farallon Islands and Half Moon Bay), while negative values denote greater CPUE in shallow/REF sites. Significant differences are shown in bold (p ≤ 0.05).**

| | 1995–98 | | | 2012–14 | | |
|---|---|---|---|---|---|---|
| Region | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df |
| Cordell Bank | 0.16 | 0.82 | 116 | **–19.00** | **0.00** | 34 |
| Farallon Islands | 0.55 | 0.46 | 77 | 3.43 | 0.25 | 49 |
| Half Moon Bay | –1.60 | 0.10 | 59 | 0.20 | 0.94 | 86 |

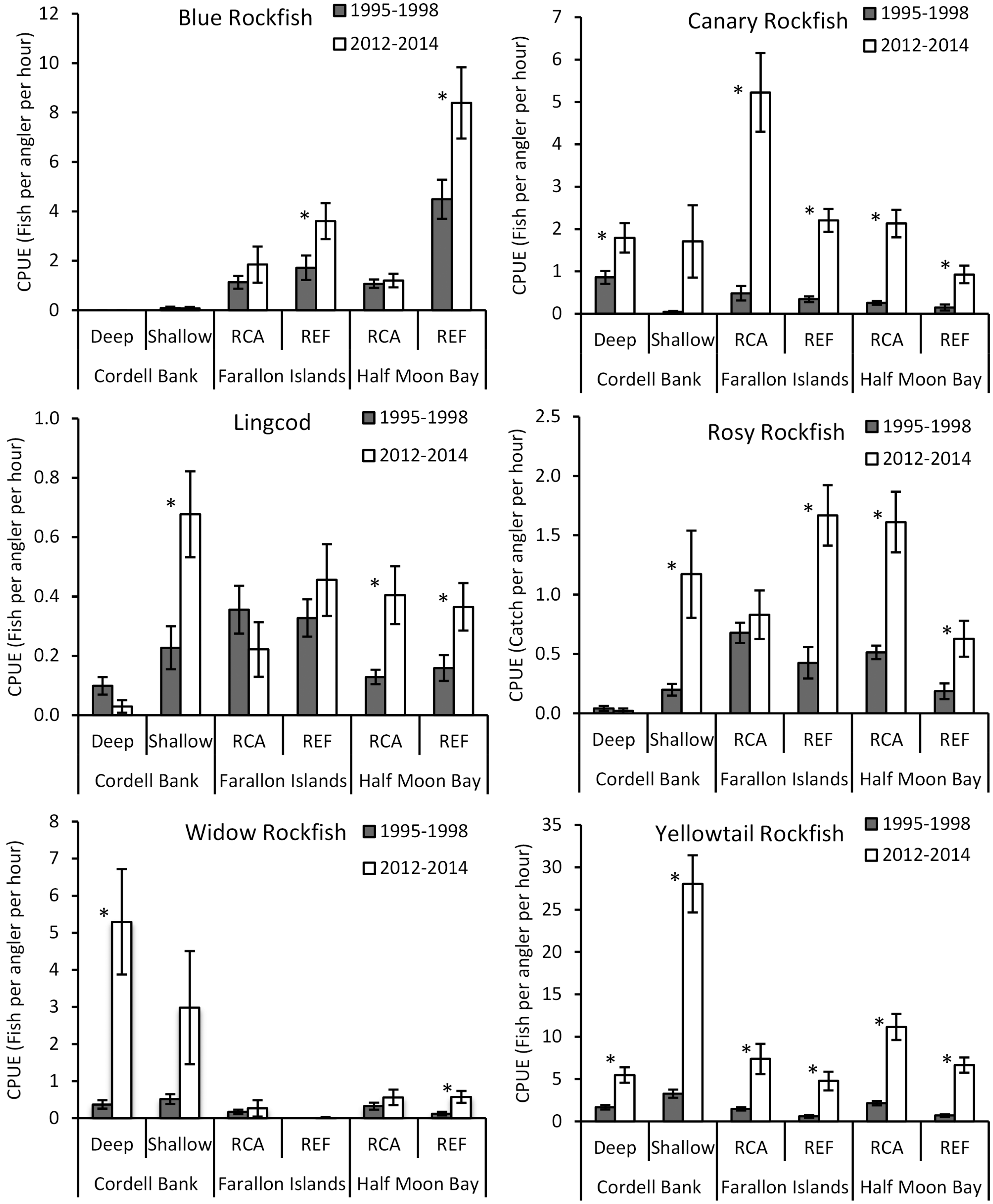


Figure 4. Changes in CPUE of the six most abundant species caught in both the old data set (1995–98) and new data set (2012–14). Error bars represent one standard error from the mean. Asterisks denote significant differences between old and new mean CPUE at each site (α = 0.05).

the 1995–98 data set, whereas total CPUE was higher in the shallow site in 2012–14 (fig. 3, table 3). For individual species, canary rockfish were more abundant in the deep site in the 1995–98 data set but did not differ between deep and shallow sites in the 2012–14 data set (fig. 4, table 4). Yellowtail and rosy rockfish remained more abundant in the shallow site in both the 1995–98 and 2012–14 data sets (fig. 4, table 4).

## Changes in Size of Fishes

***Farallon Islands and Half Moon Bay*** Mean fork lengths and sample sizes for the top six species at each

TABLE 4
**Comparisons of CPUE between RCA and reference sites within the old 1995–98 data set (A) and 2012–14 data set (B) for the six most abundant species across both data sets. Comparisons at Cordell Bank are between "shallow" and "deep" sites. Positive differences in mean CPUE indicate more fish in the RCA/deep site whereas negative values indicate more fish in the REF/shallow site. All significant results are shown in bold (p ≤ 0.05).**

(A)

| | Blue Rockfish | | | Canary Rockfish | | | Lingcod | | |
|---|---|---|---|---|---|---|---|---|---|
| 1995–98 | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df |
| Cordell Bank | –0.09 | 0.06 | 60 | **0.81** | **0.00** | 70 | –0.13 | 0.10 | 79 |
| Farallon Islands | –0.59 | 0.30 | 62 | 0.14 | 0.46 | 52 | 0.03 | 0.79 | 76 |
| Half Moon Bay | **–3.42** | **0.00** | 46 | 0.11 | 0.20 | 74 | –0.03 | 0.54 | 67 |

| | Rosy Rockfish | | | Widow Rockfish | | | Yellowtail Rockfish | | |
|---|---|---|---|---|---|---|---|---|---|
| | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df |
| Cordell Bank | **–0.16** | **0.00** | 81 | –0.15 | 0.41 | 123 | **–1.60** | **0.00** | 94 |
| Farallon Islands | 0.25 | 0.11 | 70 | **0.17** | **0.01** | 40 | **0.88** | **0.00** | 73 |
| Half Moon Bay | **0.33** | **0.00** | 92 | 0.21 | 0.06 | 89 | **1.46** | **0.00** | 95 |

(B)

| | Blue Rockfish | | | Canary Rockfish | | | Lingcod | | |
|---|---|---|---|---|---|---|---|---|---|
| 2012–14 | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df |
| Cordell Bank | –0.08 | 0.16 | 22 | 0.08 | 0.93 | 29 | **–0.65** | **0.00** | 23 |
| Farallon Islands | –1.75 | 0.09 | 73 | **3.02** | **0.00** | 33 | –0.23 | 0.13 | 81 |
| Half Moon Bay | **–7.19** | **0.00** | 59 | **1.20** | **0.00** | 58 | 0.04 | 0.75 | 71 |

| | Rosy Rockfish | | | Widow Rockfish | | | Yellowtail Rockfish | | |
|---|---|---|---|---|---|---|---|---|---|
| | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df | Diff. in mean CPUE | p-value | df |
| Cordell Bank | **–1.15** | **0.00** | 22 | 2.32 | 0.27 | 51 | **–22.57** | **0.00** | 25 |
| Farallon Islands | **–0.84** | **0.01** | 80 | 0.25 | 0.26 | 28 | 2.59 | 0.22 | 50 |
| Half Moon Bay | **0.98** | **0.00** | 54 | –0.01 | 0.96 | 68 | **4.48** | **0.02** | 54 |

site in each period are reported in table 5. In contrast to the clear increase in CPUE over time, patterns in fish size were more variable between regions. For example, compared to the 1995–98 data set in Half Moon Bay, mean lengths of yellowtail rockfish were larger during the 2012–14 period both inside and outside the RCA. However, the opposite trend was observed at the Farallon Islands, where mean yellowtail rockfish lengths were significantly larger (p ≤ 0.05) in the 1995–98 period both inside and outside the RCA (table 6). Results from Kolmogrov-Smirnov two-sample test showed that length distributions of yellowtail rockfish were different at all sites between the 1995–98 period and the 2012–14 period (p ≤ 0.05). Almost all of the yellowtail rockfish caught both inside and outside the RCA at the Farallon Island and Half Moon Bay regions in the 2012–14 data set were below the length at 50% maturity (fig. 5A and fig. 6). Similarly, most canary rockfish caught in both the Farallon Islands and Half Moon Bay regions were smaller than the length at 50% maturity and were distributed similarly across size classes between the two time periods (fig. 5B and fig. 6). Mean lengths of widow rockfish were significantly larger (p ≤ 0.05) in the Half Moon Bay RCA in the 2012–14 period (3.8 cm larger mean size), but the majority of the widow rockfish caught from 2012–14 at Half Moon Bay and the Farallon Islands were smaller than the size at 50% maturity (fig. 5C and fig. 6). The mean length of lingcod was greater in the 1995–98 data set than the 2012–14 data set both inside and outside the RCA at the Farallon Islands as well as outside the RCA in Half Moon Bay (table 6).

In general, the mean lengths of species in both the 1995–98 and the 2012–14 data sets were larger in the RCA than in the reference sites at the Farallon Islands and Half Moon Bay (table 7). In both data sets, the mean lengths of blue, canary, and yellowtail rockfish were greater in the RCA than in the reference site (table 7). Additionally, in the 2012–14 data set, mean length of

Figure 5 (on following page). Yellowtail (A), Canary (B), and Widow (C) rockfish length frequencies by region and site. Lengths (x-axis) are classified by two cm bins of fork length. Length frequencies are normalized and displayed as the proportion of fish in each length bin (y-axis). Vertical dashed lines indicate fork length at 50% maturity; 35 cm, 42 cm, 35 cm respectively, converted from total lengths in Wyllie Echeverria (1987) using methods from Echeverria and Lenarz (1984). Asterisks indicate results from Kolmogorov-Smirnov two-sample test of differences in distributions between the old data set (1995–98) and new data set (2012–14). ** p ≤ 0.001, *p ≤ 0.05. See Table 5 for sample sizes.

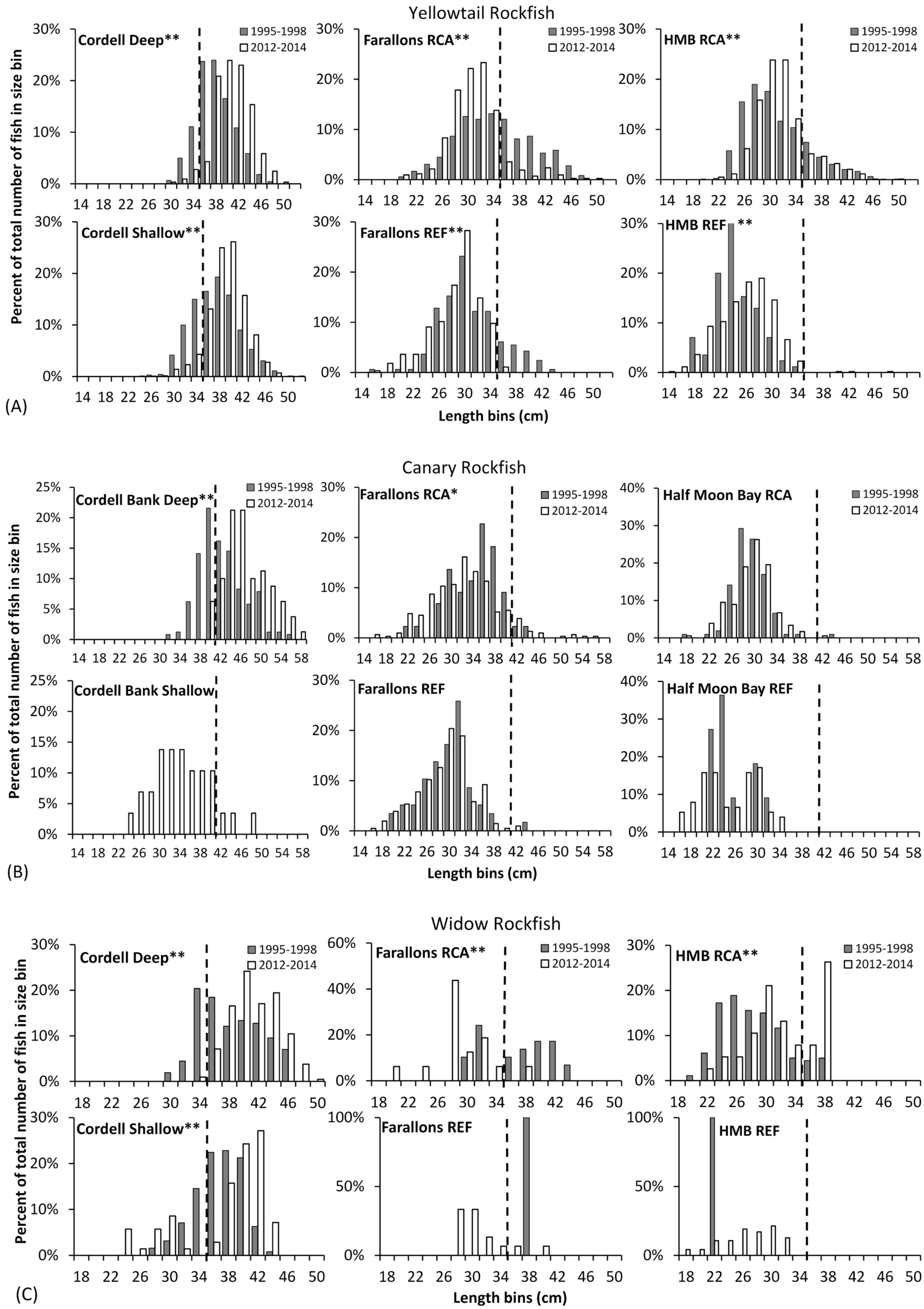
Yellowtail Rockfish
Cordell Deep**
Farallons RCA**
HMB RCA**
Cordell Shallow**
Farallons REF**
HMB REF **
1995-1998
2012-2014
Percent of total number of fish in size bin
Length bins (cm)
(A)
Canary Rockfish
Cordell Bank Deep**
Farallons RCA*
Half Moon Bay RCA
Cordell Bank Shallow
Farallons REF
Half Moon Bay REF
(B)
Widow Rockfish
Cordell Deep**
Farallons RCA**
HMB RCA**
Cordell Shallow**
Farallons REF
HMB REF
(C)

TABLE 5
**Number (n) of fish measured and mean fork length (cm) by site and years of data collection. Species shown are the six most abundant species caught in both old and new data sets.**

| | | | Blue Rockfish | | | Canary Rockfish | | | Lingcod | | | Rosy Rockfish | | | Widow Rockfish | | | Yellowtail Rockfish | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Site | Data set | mean size (cm) | SE | n | mean size (cm) | SE | n | mean size (cm) | SE | n | mean size (cm) | SE | n | mean size (cm) | SE | n | mean size (cm) | SE | n |
| Cordell Bank | Deep | 1995–98 | — | — | — | 43.5 | 0.3 | 241 | 70.8 | 1.5 | 16 | 23.9 | 1.6 | 7 | 39.4 | 0.3 | 157 | 39.0 | 0.2 | 442 |
| | | 2012–14 | — | — | — | 47.7 | 0.5 | 80 | 77.0 | 3.9 | 8 | 22.5 | 0.7 | 3 | 42.1 | 0.2 | 211 | 41.6 | 0.2 | 326 |
| | Shallow | 1995–98 | 33.7 | 0.4 | 79 | | | — | 70.2 | 0.8 | 7 | 22.2 | 0.9 | 7 | 37.9 | 0.2 | 254 | 38.4 | 0.2 | 720 |
| | | 2012–14 | 35.0 | 1.0 | 11 | 35.0 | 0.7 | 58 | 59.6 | 1.1 | 69 | 20.9 | 0.4 | 54 | 38.3 | 0.7 | 70 | 40.0 | 0.1 | 1297 |
| Farallon Island | RCA | 1995–98 | 32.6 | 0.3 | 224 | 35.6 | 0.7 | 44 | 68.5 | 2.2 | 17 | 21.3 | 0.4 | 48 | 37.9 | 0.9 | 29 | 35.4 | 0.3 | 357 |
| | | 2012–14 | 31.0 | 0.5 | 95 | 33.0 | 0.4 | 310 | 47.7 | 2.6 | 23 | 21.6 | 0.4 | 46 | 29.8 | 1.0 | 16 | 31.7 | 0.2 | 420 |
| | REF | 1995–98 | 29.1 | 0.2 | 454 | 33.0 | 0.6 | 58 | 66.3 | 1.4 | 32 | 23.2 | 0.3 | 56 | 40.0 | — | 1 | 32.1 | 0.4 | 164 |
| | | 2012–14 | 29.5 | 0.2 | 276 | 31.9 | 0.3 | 206 | 49.8 | 1.0 | 82 | 23.0 | 0.2 | 114 | 29.5 | — | 1 | 29.4 | 0.2 | 276 |
| Half Moon Bay | RCA | 1995–98 | 29.2 | 0.2 | 526 | 32.6 | 0.3 | 106 | 70.6 | 2.0 | 23 | 20.5 | 0.3 | 54 | 29.3 | 0.3 | 180 | 32.0 | 0.2 | 779 |
| | | 2012–14 | 33.8 | 0.3 | 103 | 32.1 | 0.3 | 179 | 56.3 | 1.3 | 45 | 20.5 | 0.2 | 111 | 33.1 | 0.8 | 38 | 32.5 | 0.1 | 776 |
| | REF | 1995–98 | 27.0 | 0.2 | 412 | 28.3 | 1.1 | 11 | 57.1 | 0.5 | 2 | 21.5 | 0.1 | 2 | 22.6 | — | 1 | 25.6 | 0.4 | 85 |
| | | 2012–14 | 27.0 | 0.2 | 573 | 27.5 | 0.6 | 76 | 54.2 | 1.5 | 52 | 19.6 | 0.3 | 57 | 27.6 | 0.6 | 47 | 26.8 | 0.2 | 527 |

widow rockfish was greater in the RCA than in the reference site in Half Moon Bay.

***Cordell Bank*** The highest percent of mature yellowtail rockfish in both data sets were observed at Cordell Bank (fig. 5A and fig. 6). Additionally, compared to 1995–98, the mean lengths of yellowtail rockfish were significantly larger ($p \leq 0.05$) in 2012–14 in both the deep and shallow sites (table 6). The Cordell Bank deep site was the only site with more than 10% of canary rockfish that were greater than the length at 50% maturity (fig. 5B and fig. 6). Canary rockfish were an average of 12.8 cm larger in the deep site than the shallow site in the 2012–14 data set (table 7). Compared to the 1995–98 data set, the six most abundant species had a higher percentage of fishes over the length at 50% maturity at Cordell Bank in the 2012–14 data set; however, this trend was not seen in the Farallon Islands and Half Moon Bay regions (fig. 6).

## DISCUSSION

Overall, catch rates in the 2012–14 period were two to six times higher (depending on the site) than those observed in the 1995–98 period, suggesting striking increases in total abundance of demersal species in central California shelf habitats. Significant increases, at least at some of the sites, were observed for three of the species designated as overfished prior to establishment of the RCAs; canary rockfish, widow rockfish, and lingcod (other overfished species are typically uncommon at the depths included in our study). Our sampling in 2012–14 was designed to mimic the CDFW 1990s effort as closely as possible to allow direct comparison of CPUE. Although the gear used in the earlier study was not explicitly recorded by observers, we believe our assumption of five-hook gangions is reasonable and possibly conservative since there was no hook limit in effect at that time. If a high proportion of anglers were using more than five-hook gangions then our results would underestimate the extent of the increase in CPUE.

The marked increase in rockfish and other demersal species in the last decade is consistent with many other sources of fishery dependent data sets, fishery independent data sets, and stock assessment results (e.g., Wallace and Cope 2011; Field 2013; Cope et al. 2013). For example, the abundance of lingcod in California waters was estimated to be at less than 10% of the unfished level in 1998 (the last year of the CDFW study), but above 70% by 2009 (Hamel et al. 2009). In this study, catch rates of Lingcod were greater in the recent period, although their magnitude varied spatially. However, the specific causes of the increased abundance for any given species or region are difficult to conclusively identify, as even with stock assessment models there are no analyses of the relative abundance or contribution to new recruitment

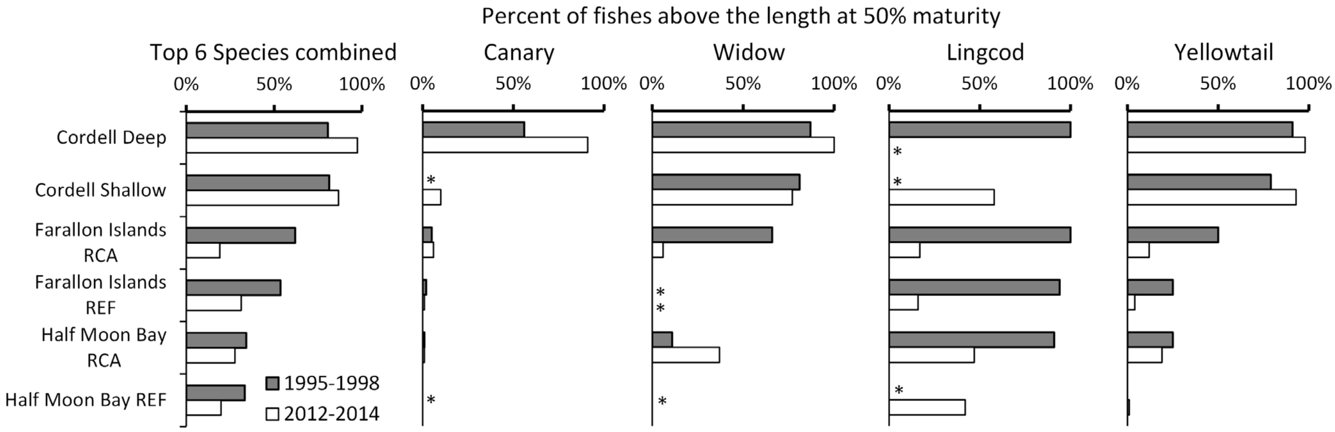


Figure 6. Summary of the percent of fishes caught at each site that were above the length of 50% maturity (Wyllie Echeverria 1987). The combined six species reported here are: canary, widow, yellowtail, blue, and rosy rockfish and lingcod. Asterisks indicate sites at which species counts were less than 15 individual fish.

TABLE 6
**Differences in mean fork length between the 1995–98 and 2012–14 data sets and associated p-values for all areas and sites sampled. Positive differences indicate an increase in mean length in the 2012–14 data set, and negative values indicate a decrease in mean length in the 2012–14 data set. All significant results are shown in bold (p ≤ 0.05). Species shown are the top six most abundant species across both data sets.**

| | | Blue Rockfish | | | Canary Rockfish | | | Lingcod | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Region | Site | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df |
| Cordell Bank | Deep | N/A | — | — | **4.2** | **0.00** | 142 | 6.2 | 0.17 | 9 |
| | Shallow | 1.2 | 0.29 | 13 | N/A | — | — | **–10.6** | **0.00** | 36 |
| Farallon Islands | RCA | **–1.6** | **0.00** | 155 | **–2.7** | **0.00** | 69 | **–20.9** | **0.00** | 37 |
| | REF | **0.4** | **0.00** | 293 | –1.12 | 0.11 | 100 | **–16.5** | **0.00** | 63 |
| Half Moon Bay | RCA | **4.6** | **0.00** | 156 | –0.5 | 0.25 | 240 | **–14.3** | **0.00** | 39 |
| | REF | 0 | 0.97 | 926 | –0.8 | 0.54 | 16 | N/A | — | — |

| | | Rosy Rockfish | | | Widow Rockfish | | | Yellowtail Rockfish | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Region | Site | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df |
| Cordell Bank | Deep | N/A | — | — | **2.7** | **0.00** | 288 | **2.6** | **0.00** | 716 |
| | Shallow | N/A | — | — | 0.4 | 0.59 | 80 | **1.6** | **0.00** | 1249 |
| Farallon Islands | RCA | 0.3 | 0.60 | 92 | **–8.1** | **0.00** | 35 | **–3.6** | **0.00** | 628 |
| | REF | –0.2 | 0.60 | 112 | N/A | — | — | **–2.8** | **0.00** | 293 |
| Half Moon Bay | RCA | –0.1 | 0.85 | 103 | **3.8** | **0.00** | 50 | **0.5** | **0.03** | 1498 |
| | REF | N/A | — | — | N/A | — | — | **1.2** | **0.00** | 130 |

from fish inside versus outside of closed areas. Consequently, the observation that catch rates have increased both inside and outside of the RCAs could be an indication that either spillover and larval export effects are more than compensating for continued fishing removals in the outside sites, or could simply represent improved recruitment throughout the broader region occupied by lingcod and rockfish. The continuity of the RCA along the entire West Coast and the overall areal extent of the closure provided a high potential for reproductive contributions from inside and outside sites, but overall reductions in fishing mortality rates have clearly contributed to direct population increases of the shelf species whose habitats are closed to fishing. In addition to the additive benefits of these management actions that closed habitats and reduced fishing mortality, ocean conditions through the late 1990s tended to be associated with poor recruitment, whereas a greater fraction of years from 1999 through the period of this study (particularly the 2008–14) have been associated with strong recruitment and reproductive success, with strong year classes often occurring synchronously among species (Ralston et al. 2013; Stachura et al. 2014; Leising et al. 2014). While our results clearly document and quantify the improved status of demersal species in the surveyed regions, the subsequent link to specific management actions or ocean-driven changes in recruitment success is beyond the scope of our analysis.

Although all of our sites were within a relatively small section of the US West Coast, there were clear spatial

TABLE 7
**Differences in mean fork length inside and outside the RCA within the 1995–98 data set (A) and the 2012–14 data set (B) for the six most abundant species across both data sets. Comparisons at Cordell Bank are between "shallow" and "deep" sites. Positive differences indicate greater mean fork lengths in deep/RCA sites, whereas negative values indicate smaller fork lengths in RCA/deep sites. All significant results are shown in bold (p ≤ 0.05).**

(A)

| | Blue Rockfish | | | Canary Rockfish | | | Lingcod | | |
|---|---|---|---|---|---|---|---|---|---|
| 1995–98 | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df |
| Cordell Bank | N/A | — | — | N/A | — | — | 0.6 | 0.69 | 21 |
| Farallon Islands | **3.6** | **0.00** | 511 | **2.6** | **0.00** | 93 | 2.2 | 0.39 | 29 |
| Half Moon Bay | **2.2** | **0.00** | 873 | **4.3** | **0.00** | 11 | N/A | — | — |
| | Rosy Rockfish | | | Widow Rockfish | | | Yellowtail Rockfish | | |
| | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df |
| Cordell Bank | N/A | — | — | 1.5 | 0.05 | 267 | **0.6** | **0.00** | 1077 |
| Farallon Islands | **–1.9** | **0.00** | 89 | N/A | — | — | **0.1** | **0.00** | 389 |
| Half Moon Bay | N/A | — | — | N/A | — | — | **6.5** | **0.00** | 126 |

(B)

| | Blue Rockfish | | | Canary Rockfish | | | Lingcod | | |
|---|---|---|---|---|---|---|---|---|---|
| 2012–14 | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df |
| Cordell Bank | N/A | — | — | **12.8** | **0.00** | 103 | **17.4** | **0.00** | 8 |
| Farallon Islands | **1.5** | **0.00** | 163 | **1.1** | **0.02** | 495 | –2.2 | 0.44 | 28 |
| Half Moon Bay | **6.8** | **0.00** | 150 | **4.6** | **0.00** | 108 | 2.1 | 0.28 | 94 |
| | Rosy Rockfish | | | Widow Rockfish | | | Yellowtail Rockfish | | |
| | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df | Diff. in mean (cm) | p-value | df |
| Cordell Bank | N/A | — | — | **1.6** | **0.00** | 84 | **1.6** | **0.00** | 521 |
| Farallon Islands | **–1.4** | **0.00** | 75 | N/A | — | — | **2.4** | **0.00** | 618 |
| Half Moon Bay | **0.8** | **0.00** | 123 | **0.8** | **0.00** | 71 | **5.7** | **0.00** | 1094 |

differences in species compositions and catch rates. After accounting for the differences in relative abundance over the two time periods (1995–98, 2012–14), differences in catch rates were the largest among regions, likely reflecting differences in ocean and/or habitat conditions, with more modest differences in catch rates inside and outside of the recreational RCA boundary. This is consistent with work presented by Starr et al. (2015), who used comparable hook and line fishing inside and outside of the newly created State Marine Protected Areas (MPAs), and showed that area-specific and temporal trends in catch rates tended to be greater than the differences in catch rates inside and outside of MPAs. Over longer time scales differences between closed and open fishing areas are expected to increase, as Starr et al. (2015) found greater differences between exploited areas and adjacent habitats that had been protected for over 20 years as compared to seven years.

The very dramatic increase in catch rates of yellowtail rockfish, which accounted for the overwhelming majority of fishes encountered in this study, is particularly interesting. Although this stock is more abundant and more important to commercial fisheries north of Cape Mendocino, this species was historically a key component of recreational fisheries in central and northern California. Following the implementation of the RCAs, which closed most of the yellowtail rockfish habitat to fishing, catches have been very modest (the average central California catches in 2003–12 period were 12% of the 1993–2002 average, based on catch data reported in Cope et al. 2013). Due to a paucity of fishery-independent data, a stock assessment for yellowtail rockfish has never been conducted south of Cape Mendocino, yet the stock is assumed to be healthy (well above target levels) north of Cape Mendocino (Cope et al. 2013) and the data-poor methods applied to the central California stock have indicated that the stock is above target levels and that both historical and recent catches are far below sustainable levels (Dick and MacCall 2010). Similar to yellowtail rockfish, catch rates of canary rockfish at both the Farallon Islands and Half Moon Bay regions have also increased considerably between the 1995–98 and 2012–14 time period. Our study showed that most canary rockfish tended to be less than the 50% maturity length, which is consistent with earlier stock assessment results that indicated patchiness in the distribution of small canary rockfish relative to larger individuals, with the central California region including a greater fraction of smaller and immature individuals (Wallace and Cope 2011). Given this pattern, the increase in catch rates of canary rockfish indicates strong recruitment in recent years, which is also consistent with results from trawl surveys, stock assessments and pre-recruit surveys (Wallace and Cope 2011; Ralston et al. 2013; Thorson and Wetzel 2015). As it has been shown that catch rates for some rockfish species in recreational fisheries increase substantially following strong recruitment events (Field et al. 2010). More detailed investigations into the interaction between strong recruitment events and catch rates in the recreational fishery should be explored; particularly canary rockfish is a key constraining species for the recreational fishery in this region.

A primary objective of spatial closures is to allow enhanced survival and aging of long-lived species, with the expected result of increased fish sizes. However, recovery of overfished species will be reflected by decreases in mean size as high abundances of juveniles recruit to the population. The conflicting shifts in fish size over time for the most abundant species in this study may reflect the occurrence of both processes. At the Cordell deep site, shifts to larger sizes over time were significant for canary rockfish, widow rockfish, and yellowtail rockfish, and there was a trend toward larger sizes for lingcod. In both data sets the majority of fish at this site were mature adults, potentially suggesting that higher recruitment in recent years would not be evident as young fish have not yet migrated to deeper habitats (Lea et al. 1999; Love et al. 2002). Likewise, at the deeper shelf and slope habitats examined by Keller et al. (2014), fish sizes tended to be larger within the RCAs compared to areas open to trawling. At our other, shallower sites, lingcod sizes decreased markedly over time, presumably indicating successful recruitment. In particular, the 1999 year class was exceptionally strong for Lingcod and likely contributed to our recent catches. In contrast, the dominance of mature lingcod in the late 1990s likely reflected the poor recruitment observed for that stock during that period (Hamel et al. 2009). Canary rockfish likewise were generally smaller in size in the 2012–14 data set and mostly composed of immature fish at all sites other than the Cordell deep site, suggesting successful recruitment and a shift to predominantly younger fish in recent years. Other species had inconsistent shifts in fish size over time at the shallower sites, potentially reflecting a mix of increased survival of older fish and increased recruitment of juveniles.

Because RCAs are depth-based closures, comparisons between the RCA and reference sites at the Farallon Islands and Half Moon Bay for both catch rate and length data may be confounded by depth and habitat differences that influence the distribution of fishes, as many rockfish (as well as lingcod and many other groundfishes), exhibit ontogenetic migrations to deeper water as they increase in size and age (Lea et al. 1999; Love et al. 2002; Love et al. 2009). For that reason, the mean fish length of a given population within a more shallow depth range is likely to decline and their abundance increase in response to strong recruitment events, as those individuals initially recruit to shallower habitats (Love el al. 2009; Jaworski et al. 2010). Our selection of reference sites was somewhat constrained to slightly shallower water since RCA boundaries are generally based on depth. Some efforts to mitigate for these depth differences were taken by attempting to select reference sites closer to RCA boundaries and in more comparable depths where possible, but even slight differences in depth may be influential to our results. For example, blue rockfish typically reside in shallower depths than the other species sampled in our study. At both Half Moon Bay and the Farallon Islands, Blue Rockfish were more abundant at the reference sites than the RCA sites both before and after the RCAs were implemented, and increases in CPUE over time were only evident at the reference sites. The slightly deeper depths of the RCA sites may have reduced the habitat suitability for blue rockfish in contrast to the other species. Similarly, our results showed that both before RCA implementation and ten years after, mean lengths of yellowtail, canary, and blue rockfish were greater inside the RCA, suggesting an ontogenetic pattern unrelated to the fishing closure. Given that the deeper waters were open to fishing historically and are closed now, it is not possible to fully decouple possible reserve effects from the effects of ontogenetic migration and strong recruitment pulses, thus complicating the hypothesis that fish lengths will increase in closed areas as fish are allowed to age and grow.

Regardless of whether or not the trends observed are due to management protection, our results are consistent with stock assessments and others studies demonstrating a strong and sustained recovery of rockfish and other groundfish, and indicate that the existing RCAs tend to be populated by larger individuals, which may have a higher reproductive capacity (Sogard et al. 2008: Hixon et al. 2014). As such, these data will be useful for future stock assessments, as well as for finer-scale evaluations of changes in species composition and spatial variability in both abundance and recruitment. Future analyses are anticipated in combination with analysis of ongoing observer program data, which, combined with these results, should help to address questions relating to stock structure and distribution and lead to improvements and refinements to ongoing spatially explicit management decisions.

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