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An assessment of the response of rockfish populations to rockfish conservation area (RCA) closures in central California

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Introduction

Area closures are commonly employed by resource management agencies as essential components of fishery rebuilding plans. Closures are expected to allow fish populations to increase in number and restore demographic balance by allowing the return of larger and older individuals to the population. Amongst a wealth of academic papers written on the effects of MPAs is a large-scale review of 124 marine reserves in 29 countries which provided remarkably strong evidence of increases in abundance, mean size, biomass, and species diversity in protected areas (Lester et al. 2009).

In 2002, in response to precipitous declines in the stocks of specific rockfish species, the Pacific Fishery Management Council (PFMC) enacted area closures in the form of Rockfish Conservation Areas (RCAs). These areas were based on depth contours and prohibited take of rockfishes across vast stretches of the continental shelf along the West Coast of the United States. In 2012 the RCAs had been closed for 10 years and there existed a need to assess the effects that the RCAs had on rockfish populations.

A temporally and spatially extensive pre-closure data set makes the assessment of RCA effectiveness possible. From 1987 to 1998, in response to industry concerns of an apparent decline in the quality of fishing for rockfish and lingcod in Central and Northern California, the California Department of Fish and Wildlife (CDFW) conducted at-sea sampling of the catch of Commercial Passenger Fishing Vessels (CPFV) (Reilly and Wilson-Vandenberg 1999). During that period, observers accompanied charter-fishing vessels for a total of 2,267 sport fishing trips that targeted rockfishes and lingcod, collecting information on nearly 300,000 fishes. They recorded fishing effort, species composition, fish size, and reproductive state in every month of the year at specific sites from Morro Bay to Eureka. The data set was fully vetted by CDFW and National Marine Fisheries Service (NMFS) scientists and has been employed in stock assessments prepared for PFMC. In our project, we compared fishery metrics developed from this pre-RCA closure data set with a new post-closure data set that was developed by fishing in the same locations and using similar protocols and techniques as those used by Reilly and Wilson-Vandenberg (1999). The pre-closure data set will subsequently be referred to as the CDFW/CPFV data.

The goal of our collaborative fisheries research project was to evaluate changes in species compositions, densities, size compositions, biological characteristics, and bycatch of fishes since the implementation of the RCAs. To do so, we addressed the following questions:

1) How has relative abundance, as inferred by catch-per-unit-effort (CPUE), changed between RCA and associated reference (REF) sites since the late 1990s?

2) How has community composition of fished species changed in specific locations since the RCAs were enacted in 2002?

3) Has the size composition of fished species changed in specific locations since the RCAs were enacted?

4) Can we detect changes in life history traits (e.g., growth, maturity, fecundity) of fished species in central California, based on biological samples collected through this project?

Methods

Site selection

To ensure the reliability of our results, it was critical that RCA and REF sites were chosen to reflect reduced as well as continued fishing pressure over the last 10 years and that they were otherwise similar in depth and habitat structure as the CDFG/CPFV sites. Sites were also representative of the overall central coast rockfish community, with a focus on the Cordell Bank, Gulf of the Farallones, and Half Moon Bay regions, all of which are well sampled in the pre-closure CDFG/CPFV data set. Since the first designation of the RCAs, there have been slight changes to the boundaries over time, and the extent of actual fishing effort varied within areas that remained open to fishing. It was essential that we had input from those most knowledgeable about the region's resources and fishing history. Therefore, we met with local commercial and recreational fishermen during the months of July and August 2012 to select areas that would align with our sampling design and serve as appropriate sites. Reference sites were representative of the overall central California rockfish community from the fishermen's perspective. The areas selected and sampled as part of this project were Cordell Bank, South and Middle Farallon Islands, and waters off of Half Moon Bay (Figure 1). Each of the selected areas was sampled by Reilly and Wilson-Vandenberg from 1987 to 1998, providing site-specific pre-closure data available for comparison purposes. All three of these areas encompass sites that have prohibited fishing since 2002 (RCA) with Cordell Bank having two sites different only by depth (i.e. deep and shallow sites). The two other areas (Farallon Islands and Half Moon Bay) also contain two sites each, one where fishing has been prohibited (RCA) and a site that has been continuously open to fishing (REF). The study sites in these two areas represented different levels of fishing pressure (between RCA and REF), but were similar in habitat type so that we could evaluate the effects of the RCA.

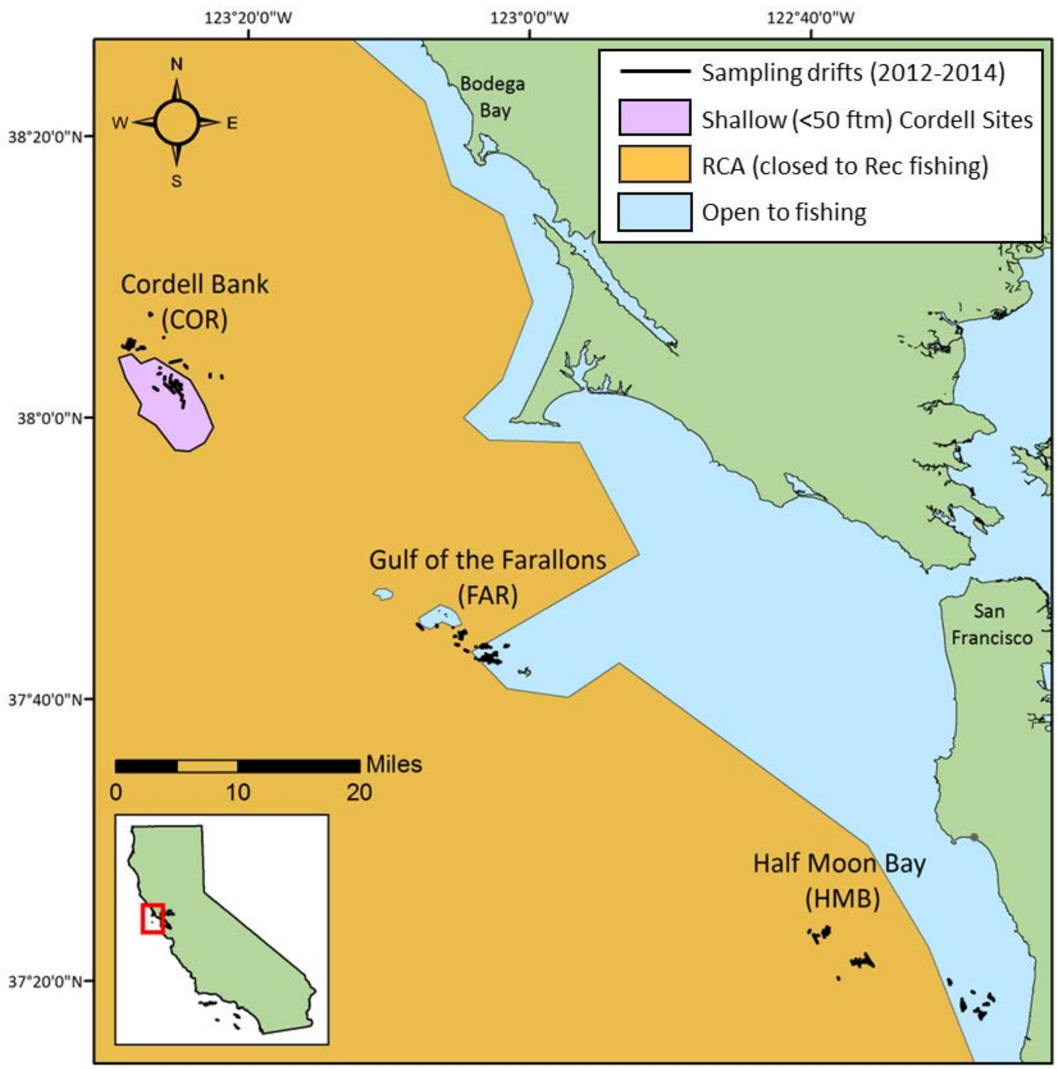


Figure 1: Location of collaborative fishing efforts to study the effects of the Recreational RCA on central California rockfish species. Drift locations are marked in black and are within three sampling areas (i.e. Cordell Bank, Farallon Islands, and Half Moon Bay). Cordell Bank sites include shallow and deep reefs within the RCA, whereas Farallon Islands and Half Moon Bay sites include drifts inside and outside of the RCA.

Field methods

Field methods followed those of the original CDFG/CPFV study protocols (Reilly and Vandenberg 1999) with the exception that we targeted specific areas and used volunteer anglers. We chartered three commercial passenger fishing vessels (CPFVs: *Huli Cat, Salty Lady,* and *New Sea Angler*) and their experienced deckhands. Volunteer anglers were recruited through online fishing websites, recommendations from CPFV captains, and through the existing and extensive California Collaborative Fisheries Research Program volunteer database at Moss Landing Marine Laboratories. Six volunteer anglers were recruited for each trip and were distributed evenly across three gear types utilized barbed hooks. All gear was standardized and provided for the anglers. Volunteer fishermen were assigned to stations 1 through 6, located on the bow, starboard and port sides of the fishing vessel. Fishermen at stations 1 and 2 on the bow fished a 10 oz lingbars with a single, unbaited shrimp-fly teaser; stations 3 and 4 on the starboard side fished 5-hook shrimp fly gangions with no bait; and stations 5 and 6 on the port side fished 5-hook shrimp fly gangions with strips of squid mantle as bait (Figure 2). These gear types are representative of the terminal tackle used by recreational fishers during the 1987-1998 CDFG/CPFV study. Fishers were not allowed to add or subtract to the gear provided to them.

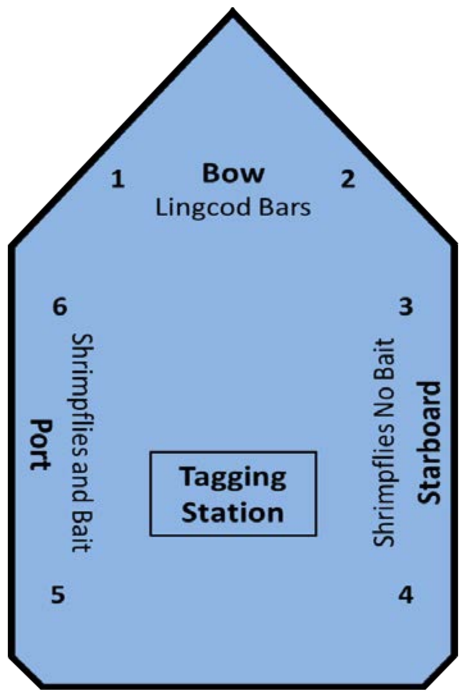


Figure 2: Placement of fishing stations and gear types onboard fishing vessels. Stations 1 and 2 were on the bow with 10 oz lingcod bars, a single shrimp fly teaser and no bait. Stations 3 and 4 were on the starboard side with 5-hook shrimp fly gangions with no bait. Stations 5 and 6 were on the port side with 5-hook shrimp fly gangions and bait (sliced squid mantle).

Captains were instructed to fish each survey trip as they would on a normal chartered day of fishing. GPS coordinates of CDFW/CPFV fishing sites were provided for general areas of RCA and REF sites at Half Moon Bay and the Farallon Islands, and deep and shallow sites at Cordell Bank. Captains were instructed to search for suitable places to start fishing, making use of depth sounders and previous knowledge of the fishing grounds. Captains started and stopped the volunteers fishing as they would for paying customers based on drift speed and catch rates. Start and stop times were recorded for each drift to later calculate catch rates of fishes per hook per hour for each drift. Beginning and ending latitude and longitude were recorded and later plotted in GIS to track our drift lines and compare our exact spatial coordinates with the CDFG/CPFV drift data. Each day consisted of 1.5 hours fishing in each of the two sites in the area being fished (RCA/deep and REF/shallow).

Between October 2012 and October 2014, 29 standardized hook-and-line survey days with a total of 239 drifts were completed across the three areas (Figure 5). A total of 440 drifts from the historical CDFW/CPFVdata set were comparable at the end of three years of sampling (Table 1). We conducted fishing during both late summer/fall and winter months to account for seasonal variability. Volunteer anglers (102) fished 449 hours and caught a total of 7785 fish from 31 species (Table 2). Each fish caught was initially placed into an 18-gallon bin filled with fresh seawater and labeled with the angler's station number. Care was taken to minimize damage to fishes while the hook was removed. Science crew identified fishes to species and measured fork length to the nearest half-centimeter using a wooden v-board (Figure 3). A subsample of fishes that displayed little or no signs of barotrauma were tagged externally in the dorsal muscle with a T-bar anchor tag using a handheld tagging gun to enable future studies of fish movements (Figure 4).

Figure 3: Tagging and measuring station onboard chartered fishing vessels. A wooden v-board was used to measure fishes to the nearest half centimeter.

Figure 3: Scientist, Andrea Launer, tags a Canary Rockfish in the dorsal musculature with a T-bar anchor tag.

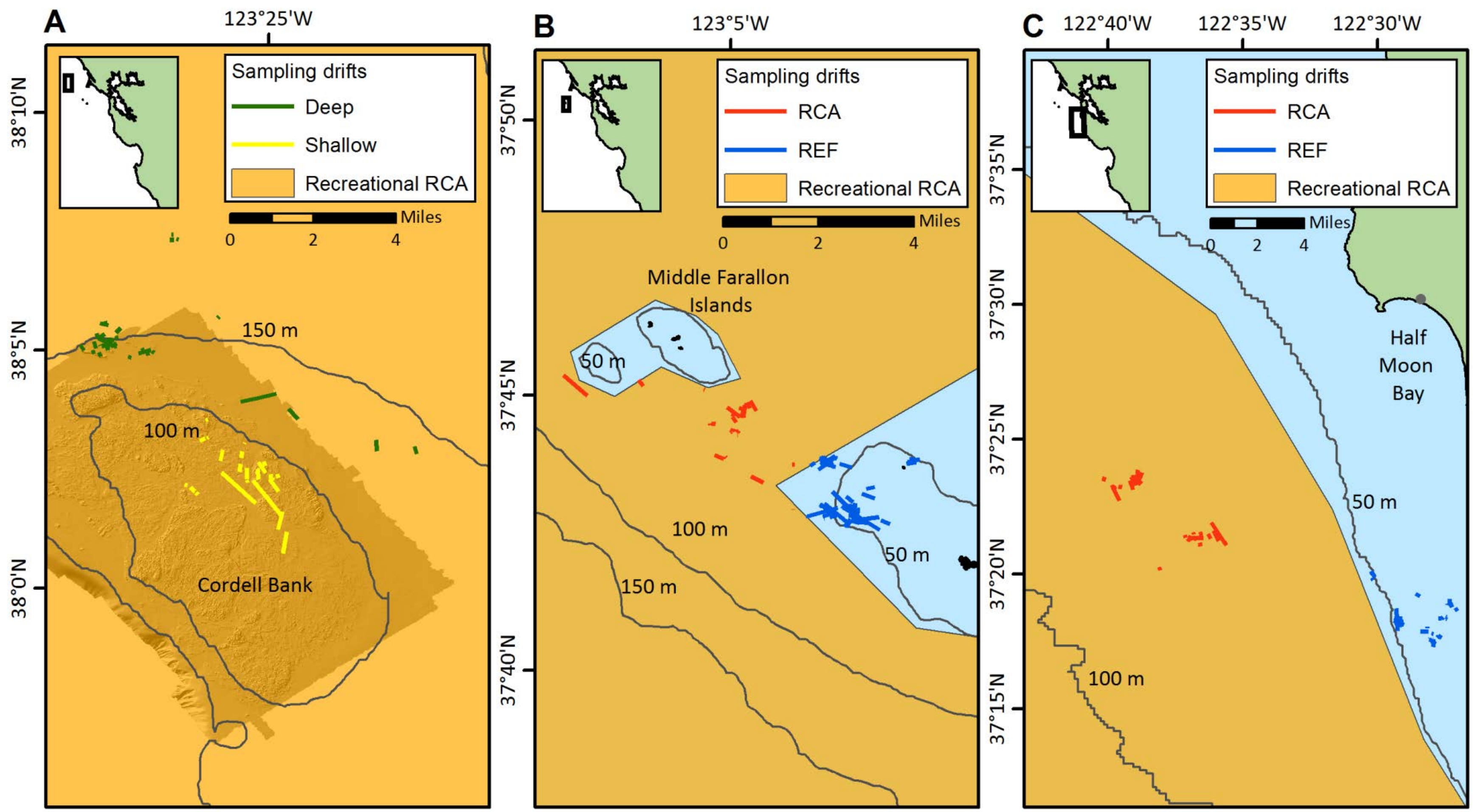


Figure 5: Areas shown with fishing drifts indicated by colored lines as follows: A) Cordell Bank with yellow drifts located in shallow site (<50 Fathoms) and green drifts in deep, B) Farallon Islands and C) Half Moon Bay areas with blue drifts located in waters open to fishing in light blue (REF) and red drifts are located in waters restricted from fishing (RCA).

Table 1: Number of individual drifts by site used for CPUE calculations for historical data (199
1998) and the current project (2012-2014).

Location	**1995-1998 Drifts**	**2012-2014 Drifts**
Cordell Deep	117	37
Cordell Shallow	78	24
Farallon Island: RCA	41	30
Farallon Island: REF	44	54
Half Moon Bay: RCA	100	35
Half Moon Bay: REF	60	59
Total	**440**	**239**

Table 2: Summary of fishing surveys conducted October 2012 through October 2014 including total angler hours
fishes caught, and number of unique species by areas and sites fished.

		No. Surveys		**Angler Hours Fished**		**Fishes Caught**		**No. of Spe**	
		Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Sh
Cordell Bank	Fall 2012	3	3	18.4	13.8	235	376	12	
	Winter 2013	1	1	4.2	3.9	103	118	7	
	Fall 2013	3	3	21.9	24.5	317	733	11	
	Winter 2014	1	1	11.6	9.0	198	197	10	
	Fall 2014	1	1	8.3	5.0	127	239	9	
	Total	**9**	**9**	**64.4**	**56.2**	**980**	**1663**	**12**	
		RCA	REF	RCA	REF	RCA	REF	RCA	
Farallon Islands	Fall 2012	3	3	1.7	38.6	9	572	3	
	Winter 2013	1	1	7.9	8.6	101	64	9	
	Fall 2013	4	4	35.1	31.5	500	303	20	
	Winter 2014	1	1	8.2	6.9	128	46	10	
	Fall 2014	1	1	9.1	9.1	313	183	11	
	Total	**10**	**10**	**62**	**94.7**	**1051**	**1168**	**20**	
Half Moon Bay	Fall 2012	3	3	22	23.8	443	364	17	
	Winter 2013	1	1	7.1	5.8	23	35	5	
	Fall 2013	4	4	36.4	38.6	583	729	18	
	Winter 2014	1	1	11.2	9.0	192	88	15	
	Fall 2014	1	1	8.7	9.0	225	241	13	
	Total	**10**	**10**	**85.4**	**86.2**	**1466**	**1457**	**20**	
	Grand Total	**29**	**29**	**211.8**	**237.1**	**3497**	**4288**	**27**	

GPS waypoints were taken during the release of tagged fishes to be used in the event of a later recapture. Many rockfish species exhibited external signs of barotrauma and it was our goal to increase survivorship of these fishes by minimizing deck time to less than five minutes. In many cases it was necessary vent the swim bladder with a sterilized hypodermic needle, and/or descend the fish using a weighted milk crate, Ace Calloway device, or a Seaqualizer® hydrostatic release. These release techniques have been used by the PIs for many years and have proven to be successful, based on high survival rates of tagged fishes. Fishes unable to be released do to severity of barotrauma or hook damage were euthanized and retained along with selected fish for biological and reproductive ecological studies.

Collections

Rockfish that were collected from the sampling trips were immediately placed on ice and processed the following day at the NOAA SWFSC laboratory. Females exhibiting extrusion of eggs or larvae due to barotrauma following capture were immediately placed into individual plastic bags to minimize loss of eggs or larvae. At the lab, we weighed (total weight, g) and measured (fork length, mm) fishes, and removed the liver of the fish to assess fish condition using the hepatosomatic index (HSI) (Equation 1):

$$\text{HSI} = \frac{\text{Liver weight (g)}}{\text{Somatic body weight (g)}} \tag{1}$$

To measure percent water content, a 2 - 10 g muscle tissue sample from each fish was dehydrated in an oven for 5 days at 65^0 C then re-weighed (Beyer et al. 2015). We dissected, weighed, and staged whole ovaries for developmental maturity on a scale of 1-6 (1=immature, 2=unfertilized vitellogenic eggs, 3=fertilized eggs, 4=eyed-larvae, 5=spent, 6=resting) (Gunderson et al. 1980, Wyllie-Echeverria 1987). For ovaries in stage 2, 3 or 4, two subsamples of eggs or larvae weighing between 0.5 - 1.0 g were collected and preserved in a 10% buffered formalin solution. A small cross-section of the gonads (both males and females) was preserved for later histological analysis of maturity and developmental stage. Sagittal otoliths were dissected, cleaned and stored dry for future age determination For genetic analysis, a small fin clip from the caudal fin of each fish (up to 1cm^2) was placed into a folded piece of blotter paper and stored in a hole-punched coin envelope (hole-punched to improve ventilation). Envelopes were placed in a desiccator for 5 days or until thoroughly dried, then archived and stored in a dry location. Stomach contents and additional muscle tissue samples from a subset of Rosy, Olive and Yellowtail Rockfish were collected, placed in Eppendorf tubes and stored at -20ºC for future stable isotope/diet analysis studies. Overall, we retained a total of 961 fish from 21 different rockfish (*Sebastes* spp.) species (Table 3).

Table 3: Total fish retained by type of rockfish (RF, *Sebastes* spp.) species and area of collection.

Species		Sampling Location		
Common name	Scientific name	Cordell Bank	Farallon Islands	Half Moon Bay
Black RF	*S. melanops*			8
Blue RF (undifferentiated)	*S. mystinus*			10
"True" Blue RF	*S. mystinus*		12	15
"Northern" Blue RF	*S. mystinus*		29	31
Bocaccio	*S. paucispinis*	8	2	4
Canary RF	*S. pinniger*	28	17	10
Chilipepper RF	*S. goodei*	90		
China RF	*S. nebulosus*		3	2
Copper RF	*S. caurinus*			4
Flag RF	*S. rubrivinctus*			1
Greenspotted RF	*S. chlorostictus*			2
Olive RF	*S. serranoides*	10	14	22
Redstripe RF	*S. proriger*	1	1	
Rosy RF	*S. rosaceus*	31	91	137
Speckled RF	*S. ovalis*	6		
Squarespot RF	*S. hopkinsi*		1	
Starry RF	*S. constellatus*			7
Vermilion RF	*S. miniatus*	4		1
Widow RF	*S. entomelas*	40	1	5
Yelloweye RF	*S. ruberrimus*	5		
Yellowtail Rf	*S. flavidus*	153	49	106
	TOTAL	**340**	**160**	**287**

Historical CPFV dataset

Historical rockfish data were obtained from the CDFW Onboard Sampling Program (Reilly et al., 1999). From 1987-1998 CDFW observers randomly selected at-sea trips aboard Commercial Passenger Fisheries Vessels (CPFV). CDFW observers were instructed to record the fishing location ("drift"), number of anglers, fishing time, and number of fish caught by species. Observers recorded total fork length (to nearest mm) while transiting from the final drift to port, thus lengths from this study cannot be attributed to individual drifts and are comparable at the trip level. In addition, not all observed angler's fish were measured as a subset of all fish caught were measured at the end of the fishing trip The 1987-1998 CPFV dataset was recently keypunched, uploaded into Structured Query Language (SQL) and ArcGIS environments, and is housed at the NMFS with permission from CDFW. In this report, the CPUE and length analysis are separated because CPUE is calculated for each "drift" and the length data for each "trip." For the purpose of studying the effects of the RCAs, data from the three years closest to the area closures were selected (1995-1998) for comparison with the three current years of sampling (2012-2014).

2012-2014 Dataset

Data from each fishing trip were entered into a master database at Moss Landing Marine Laboratories following the data entering protocol developed for the California Collaborative Fisheries Research Program (Yochum et al., 2011). For data quality control, all drift data including start/stop time, latitude, longitude, and environmental data were checked for errors. Fish lengths were checked, making sure fish were not incorrectly entered above or below the minimum and maximum size by species.

Drift Selection

In order to minimize the bias of short drift times in over or underestimating catch-rates, we excluded from analyses any drifts that were less than five minutes in duration. In addition, we excluded any 2012-2014 drifts that crossed RCA boundary. Filters were applied to the historic CDFG/CPFV dataset in order to assure close spatial agreement among the 2012-2014 and 1995-1998 drift data. Using ArcGIS, 1 km buffers were drawn around all 2012-2014 drifts and overlaid on maps of our study areas. CDFG/CPFV drifts that did not start within these buffers were excluded from the data analyses (Figure 6). Finally, only historical drifts that were within a depth of +/- 10 m of the 2012-2014 sites were included to maintain similarity of depths of capture.

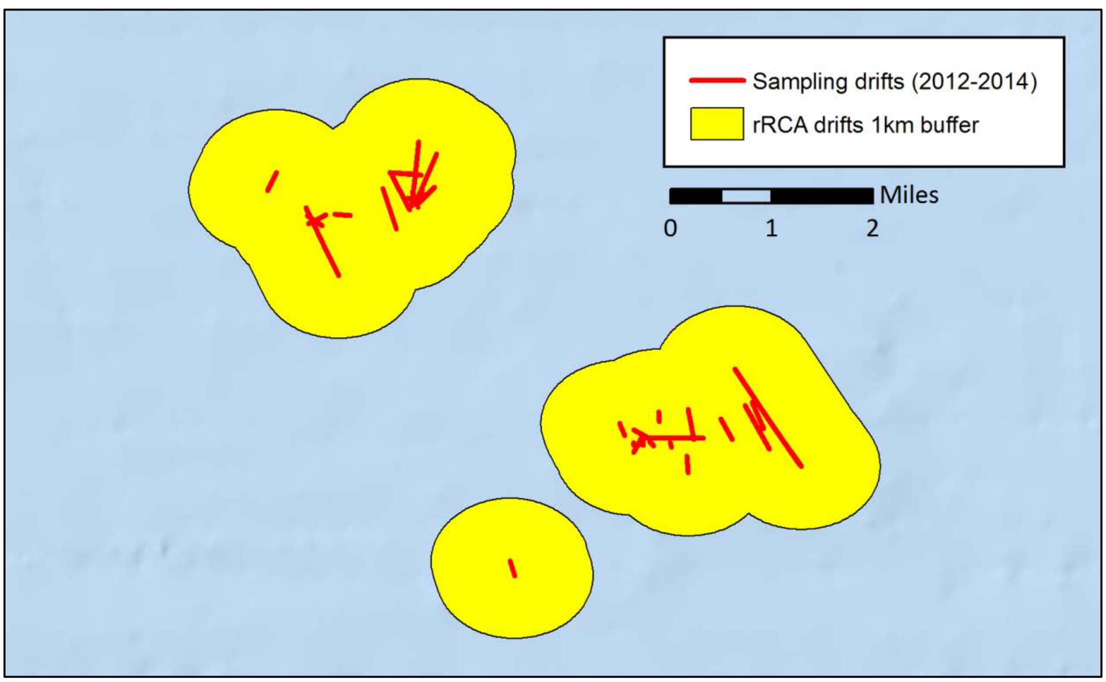


Figure 6: Examples of buffers [1km ellipses placed around current (2012-2014) drift lines] used to select historical CDFW data by site to compare to new data set. All CDFW data used were within or started within these buffers and within a water depth +/- 10 m of the current fishing drifts.

CPUE Calculations and Analyses

For the historical CPFV data, catch-per-hook-hour (CPUE) by species was calculated by dividing the number of fish caught per drift by fishing effort. To calculate effort we multiplied the number anglers observed by five hooks (the allowable maximum at the time) and then multiplied that by the total fishing time for each drift (Equation 2).

$$\text{Drift CPUE} = \frac{\text{No. of fish caught}}{[\text{No. of Anglers}] * [\text{5 hooks}] * [\text{No. hours fishing}]} \qquad (2)$$

For the newer data set CPUE was calculated with the same method except that fishing effort included values for angler off time and the number of hooks per drift as standardized gear types were different than the historical date gear (See methods; Equation 3).

$$\text{Drift CPUE} = \frac{\text{No. of fish caught}}{\begin{gathered}[(\text{\# Bar anglers})*(\text{No. hours fishing})+(\text{Off time})*\text{2 hooks})] \\ +[(\text{Baited anglers})*(\text{No. hours fishing})+ (\text{Off time})*\text{5 hooks})] \\ +[(\text{Unbaited anglers})*(\text{No. hours fishing})+ (\text{Off time})*\text{5 hooks})]\end{gathered}} \qquad (3)$$

We plotted CPUE for the top 6 species caught by year and sample site (RCA/deep, REF/shallow). Species-composition charts based on species' mean CPUE were plotted to compare fish communities. In order to determine how catch rates of fishes have changed in our study areas since the 2002 closure, we performed Welch's t-tests ($\alpha = 0.01$) between year-groups in the statistical program R to compare the top 6 species' mean CPUE in 1995-1998 with the mean CPUE measured during 2012-2014. The Welsh t-test assumes that samples are independent and have an unequal variance. We also used Welch's t-tests to compare the mean CPUE for the top 6 species inside and outside of the RCA for each year-group to test if there were initial and later differences. Additionally, total CPUE (all species combined) by site and year-group was plotted in Microsoft Excel. Welch's t-test was used to determine differences in mean total CPUE between year-groups. Finally, Welch's t-tests were used to determine mean differences of mean total CPUE inside and outside of the RCA for each year-group.

Length Analyses

We compared rockfish lengths from before the RCA closures (CPFV/CDFW) and 10 years after closures (current data) to assess any shifts in length frequencies. Historical data for length calculations were selected using the same criteria as those chosen for CPUE (see above). Historical lengths were converted from total length to fork length using previously published methods (Echeverria, T. and W.H. Lenarz, 1984; Laidig et al., 2003).

Length frequency distributions for the top 6 species caught in the CDFW data (1990s) and this study (2010s) were compared using histograms. The length frequencies were normalized (percentage) to all lengths observed, where length bins were set to 2 cm. We performed a Welsh t-test ($\alpha = 0.01$) using R comparing the fork lengths in 1990s with 2010s for each area. We also used a Welsh t-test to compare fork lengths by site (i.e. Deep/Shallow and REF/RCA).

Fecundity Analyses

We estimated fecundity using the gravimetric method. Weighed subsamples of preserved eggs or larvae were counted under a dissecting scope using a small painters brush to separate eggs or larvae. Next we multiplied the count by the total weight of the ovary and averaged the estimates from the two subsamples (Equation 4).

$$\text{Fecundity} = \frac{\text{Subsample count}}{\text{Subsample weight (g)}} * \text{Whole ovary weight (g)} \qquad (4)$$

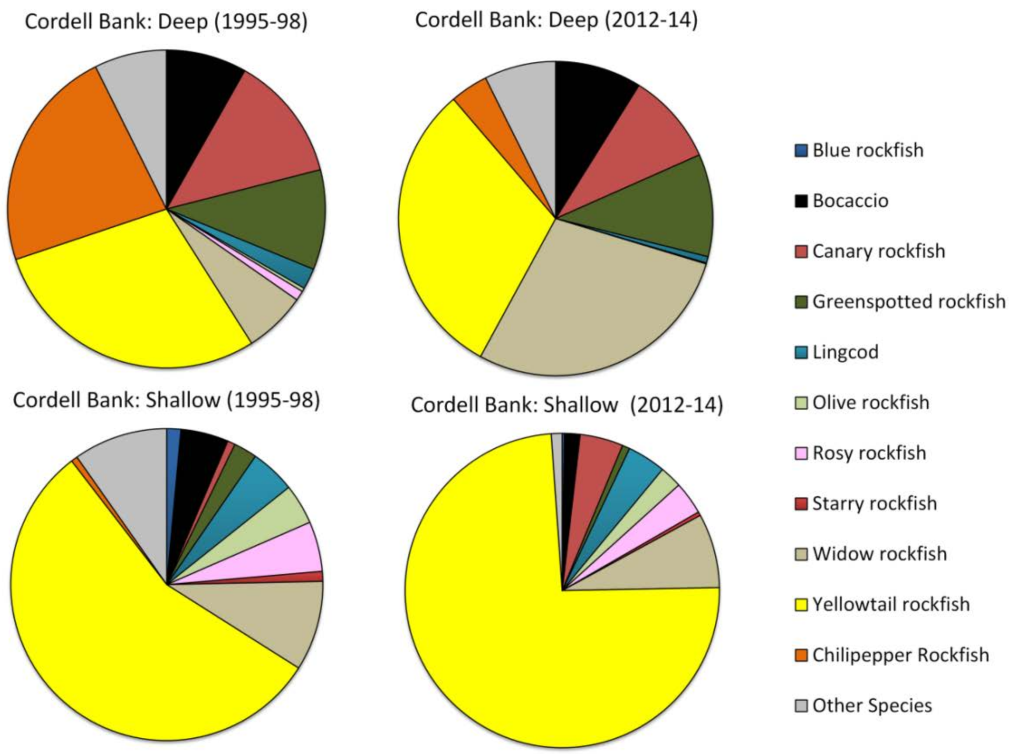
Fecundity estimates from this project were combined with data collected by the NOAA Southwest Fisheries Science Center (Stafford et al. 2014, Beyer et al. 2015) and a historic dataset of Yellowtail Rockfish fecundities collected from 1985 to 1990 (Eldridge and Jarvis 1995). All studies used similar methods to collect fish by hook-and-line, weigh and measure specimens, dissect tissue samples, and to estimate fecundity (gravimetric method).

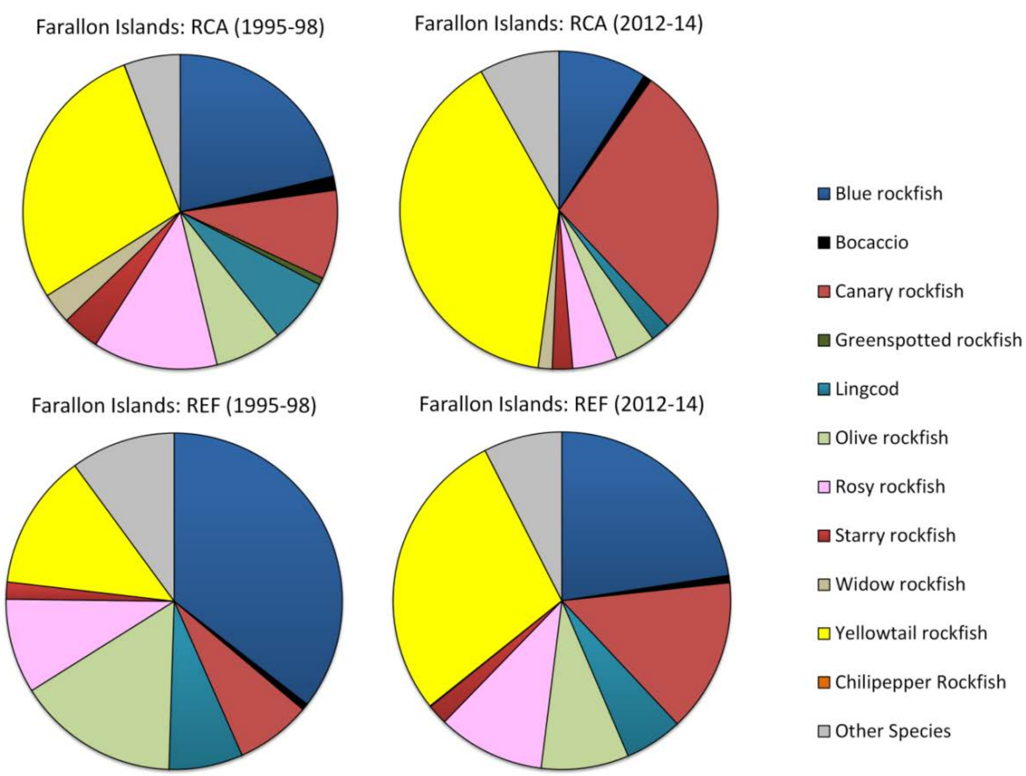
The majority of rockfish in Central California release live young over the winter months from December through June (Love et al. 2002). All January through June collections were assigned to the previous calendar year to pool results into a common parturition season. We used an ANCOVA, with female length as a covariate, to determine means and assess interannual variability in fecundity (SYSTAT 13 version 13.00.05).

Results

Species Composition

The six most abundant species in the CDFG/CPFV data base, as measured by mean CPUE (fishes/hook/hour) were: Yellowtail Rockfish (*Sebastes flavidus*), Blue Rockfish (*S. mystinus*), Canary Rockfish (*S. pinniger*), Rosy Rockfish (*S. rosaceus*), Widow Rockfish (*S. entomelas*) and Lingcod (*Ophiodon elongates*). These six species were also the top six most abundant during the 2012-2014 sampling, though the order of abundance shifted to Yellowtail Rockfish, Canary Rockfish, Blue Rockfish, Widow Rockfish, Rosy Rockfish; and Lingcod (Figure 7).


Cordell Bank: Deep (1995-98)
Cordell Bank: Deep (2012-14)
Cordell Bank: Shallow (1995-98)
Cordell Bank: Shallow (2012-14)
Blue rockfish
Bocaccio
Canary rockfish
Greenspotted rockfish
Lingcod
Olive rockfish
Rosy rockfish
Starry rockfish
Widow rockfish
Yellowtail rockfish
Chilipepper Rockfish
Other Species


Farallon Islands: RCA (1995-98)
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Farallon Islands: REF (2012-14)
Blue rockfish
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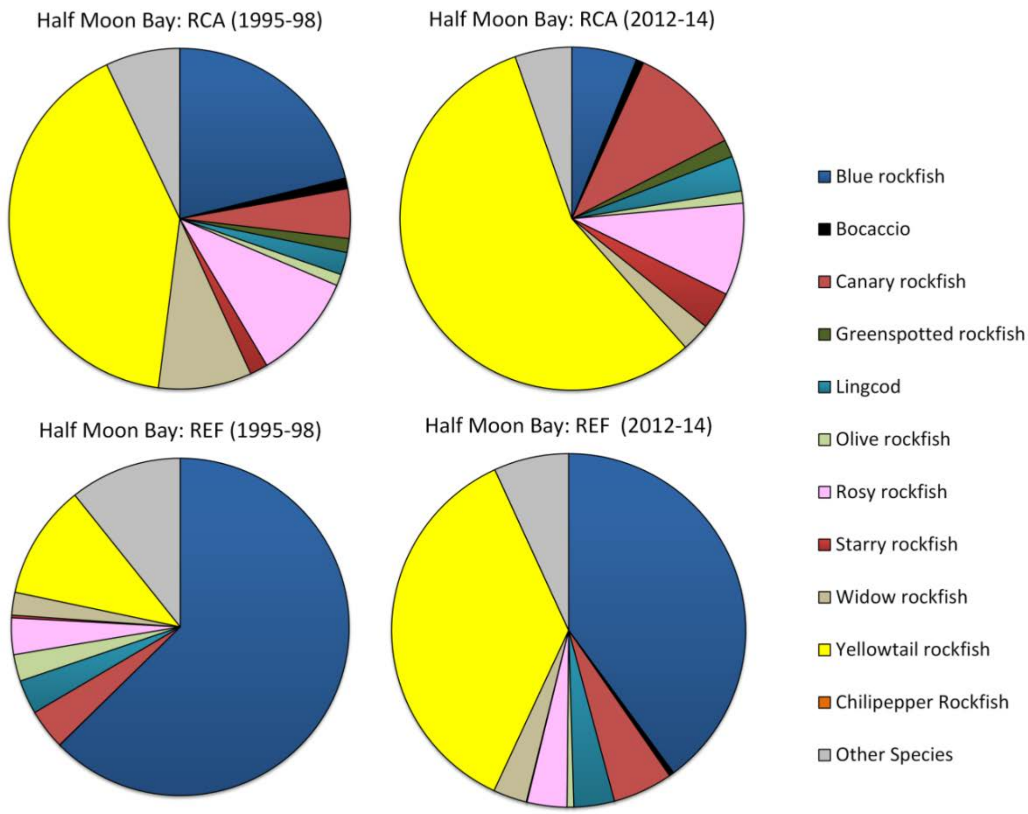

Figure 7: Species compositions calculated as fraction of total CPUE (Fishes/Hook/Hour) by site and by time of data collection with top 11 species listed.

There was a high degree of inter-site variability in species composition. Yellowtail Rockfish were the most abundant species caught during the recent sampling, especially at the sites: Cordell Bank Shallow, Farallon Islands RCA and Half Moon Bay RCA. Canary Rockfish were relatively abundant at the Farallon Islands and showed relative increases in percent of total fishes caught when compared with the 1995-1998 data (Figure 7). Blue Rockfish showed an opposite trend and made up a smaller portion of the total catch across sites sampled in the recent years.

Changes in Relative Abundance (CPUE)

Mean CPUE (fishes/hook/hour) generally increased from the late1990s to 2010s across all sites for the top six species caught (Table 4 (A-C), Figures 8-12). Yellowtail rockfish were significantly more abundant ($p \leq 0.01$) at all sites sampled in the 2010s compared with the CDFG/CPFV data; with the largest increase in CPUE being at Cordell Bank Shallow (Table 4A, Figure 8A). Similarly, Canary Rockfish increased in abundance at all sites, with the greatest increase being at Farallon Islands RCA (Table 4A, Figure 8B). Blue Rockfish were not encountered at Cordell Bank Deep, and minimally at Cordell Bank Shallow (Table 4B, Figure 8C). Significant increases in mean catch rates of Blue Rockfish occurred at Half Moon Bay REF ($p \leq 0.01$) in the 2012's compared with 1990s (Table 4B, Figure 8C). Widow Rockfish mean CPUE increased in 2010s, though only Cordell Bank Deep and Half Moon Bay REF were significant increases at $\alpha = 0.01$ (Table 4B, Figure 8D). CPUE of Rosy Rockfish showed significant increases in the 2010 data at Cordell Bank Shallow, Farallon Island REF, and both Half Moon Bay RCA and Half Moon Bay REF (Table 4C, Figure 8E). Similarly, CPUE of Lingcod also significantly increased at Cordell Bank Shallow, Farallon Islands REF, Half Moon Bay RCA and Half Moon Bay REF (Table 4C, Figure 8F). Differences between mean CPUE at each area, regardless of inside and outside the RCA, varied for the top six species caught during the 2010s as well as the 1990s (Table 5).

Table 4: Mean difference in CPUE (Fishes/Hook/Hour) from 1990s to 2010s of top 6 species caught and associated p-values and degrees of freedom (df) where positive mean difference value is an increase in mean CPUE in 2010. Negative values are a decrease in mean CPUE in 2010. Significant p-values (≤ 0.01) are shown in bold.

A	Yellowtail mean difference (CPUE)	p-value	df	Canary mean difference (CPUE)	p-value	df
Cordell Deep	**0.9**	**0.00**	38	**0.24**	**0.00**	41
Cordell Shallow	**5.19**	**0.00**	24	0.34	0.03	23
Farallon Islands RCA	**1.22**	**0.00**	30	**0.98**	**0.00**	31
Farallon Islands REF	**0.81**	**0.00**	55	**0.42**	**0.00**	59
Half Moon Bay RCA	**1.88**	**0.00**	35	**0.39**	**0.00**	35
Half Moon Bay REF	**1.28**	**0.00**	61	**0.17**	**0.00**	75

B	Blue mean difference (CPUE)	p-value	df	Widow mean difference (CPUE)	p-value	df
Cordell Deep	0	N/A	N/A	**1.02**	**0.00**	36
Cordell Shallow	0	0.86	40	0.50	0.11	23
Farallon Islands RCA	0.12	0.42	38	0.02	0.59	35
Farallon Islands REF	0.41	0.02	90	0.00	0.32	53
Half Moon Bay RCA	0.03	0.60	46	0.02	0.65	48
Half Moon Bay REF	**0.82**	**0.01**	82	**0.09**	**0.00**	70

C	Rosy mean difference (CPUE)	p-value	df	Lingcod mean difference (CPUE)	p-value	df
Cordell Deep	-0.01	0.19	85	0.01	0.71	46
Cordell Shallow	**0.21**	**0.01**	24	**0.26**	**0.00**	27
Farallon Islands RCA	0.04	0.45	37	0.00	0.88	56
Farallon Islands REF	**0.25**	**0.00**	77	**0.12**	**0.01**	62
Half Moon Bay RCA	**0.25**	**0.00**	36	**0.11**	**0.00**	35
Half Moon Bay REF	**0.1**	**0.01**	72	**0.11**	**0.00**	72

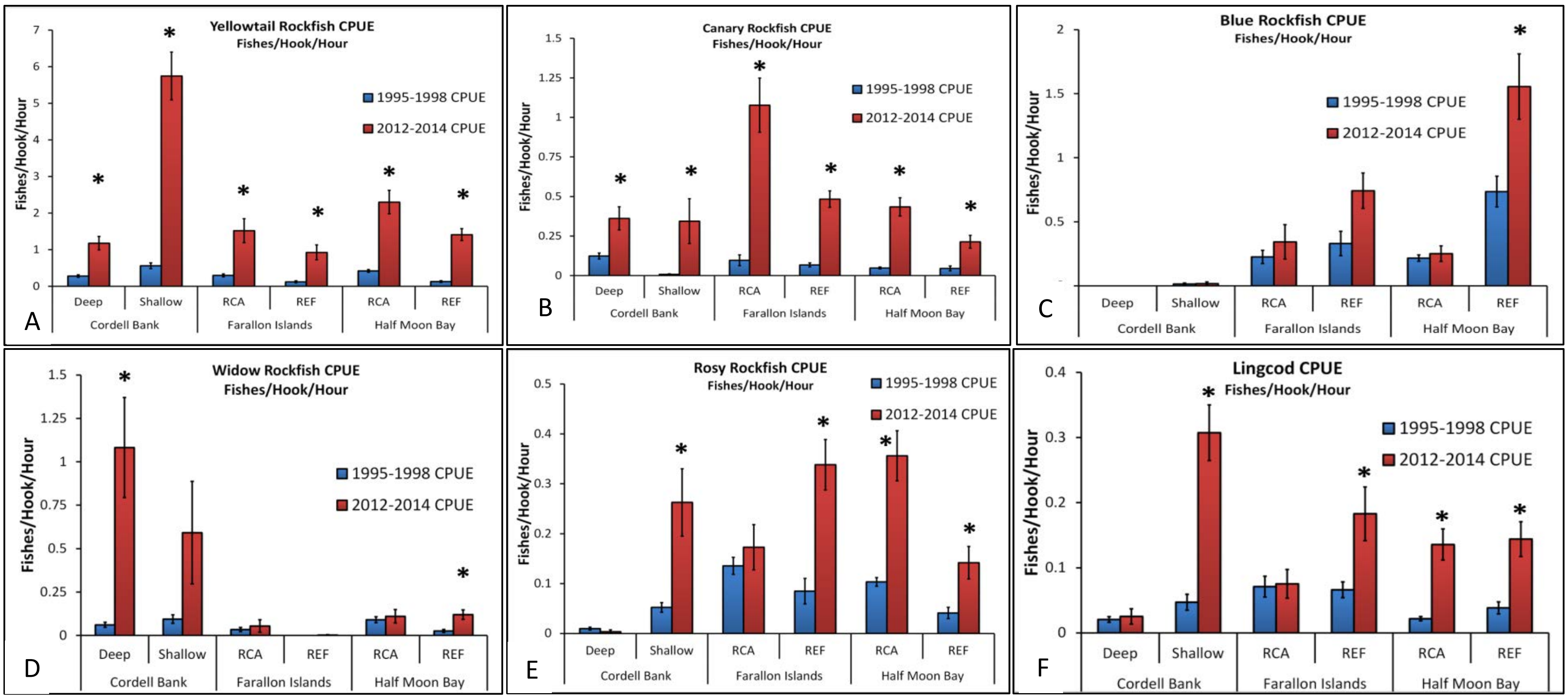

Figure 8: Mean rockfish [A. Yellowtail Rockfish (*Sebastes flavidus*), B. Canary Rockfish (*S. pinniger*), C. Blue Rockfish (*S. mystinus*), D. Widow Rockfish (*S. entomelas*), E. Rosy Rockfish (*S. rosaceus*) and F. Lingcod (*Ophiodon elongates*)] CPUE (Fishes/Hook/Hour) by site and year-group. Star indicates significant difference between 1990s and 2010s, where α = 0.01.

1990s	Yellowtail mean difference (CPUE)	p-value	df	Canary mean difference (CPUE)	p-value	df	Blue mean difference (CPUE)	p-value	df	Widow mean difference (CPUE)	p-value	df	Rosy mean difference (CPUE)	p-value	df	Lingcod mean difference (CPUE)	p-value	df
Cordell Bank	-0.28	0.00	106	**0.12**	**0.00**	122	-0.02	0.06	77	-0.03	0.25	131	**-0.04**	**0.00**	91	-0.03	0.04	97
Farallon Islands	**0.18**	**0.00**	72	0.03	0.43	51	-0.10	0.34	66	**0.03**	**0.01**	40	0.05	0.10	74	0.01	0.81	76
Half Moon Bay	**0.29**	**0.00**	154	0.00	0.87	77	**-0.52**	**0.00**	64	**0.07**	**0.00**	142	**0.06**	**0.00**	123	-0.02	0.10	74

2010s	Yellowtail mean difference (CPUE)	p-value	df	Canary mean difference (CPUE)	p-value	df	Blue mean difference (CPUE)	p-value	df	Widow mean difference (CPUE)	p-value	df	Rosy mean difference (CPUE)	p-value	df	Lingcod mean difference (CPUE)	p-value	df
Cordell Bank	**-4.57**	**0.00**	27	0.02	0.91	35	-0.02	0.19	23	0.49	0.24	56	**-0.26**	**0.00**	23	**-0.28**	**0.00**	26
Farallon Islands	0.59	0.13	52	**0.59**	**0.00**	34	-0.40	0.04	76	0.05	0.16	29	-0.17	0.02	79	-0.11	0.02	76
Half Moon Bay	0.89	0.02	51	**0.22**	**0.00**	67	**-1.30**	**0.00**	64	-0.01	0.84	66	**0.21**	**0.00**	62	-0.01	0.82	90

Table 5: Mean difference in CPUE (Fishes/hook/hour) of the top 6 species caught in the 1990s (top) and 2010s (bottom) comparing sites within each area sampled (for Cordell Bank, Deep/Shallow and for Farallon Islands and Half Moon Bay, RCA/REF). Positive differences in mean CPUE indicate more fish in the RCA/deep site whereas negative values indicate more fish in the REF/Shallow site. Significant differences are indicated in bold ($p \leq 0.01$).

Total mean CPUE (all species combined) was significantly greater in the mo recent sampling years when compared with pre-closure data (Table 6, Figure 9). Cord Bank Shallow had the greatest increase in mean CPUE. Much of this increase in me CPUE was due to the increase in Yellowtail Rockfish abundance over time (Figure 9 No statistical difference between mean CPUE inside and outside of the RCA existed f the locations sampled in 1990s (Table 7). However, the recent sampling showed th mean CPUE was significantly in the Cordell Shallow site than the Cordell Deep s (Table 7).

Table 6: Mean differences in total CPUE (all species combined: Fishes/Hook/Hour) fro 1990s to 2010s. Where positive mean difference value is an increase in mean CPUE in 2010s (shown in italics). All significant p-values (≤ 0.01) are indicated in bold.

Area and site	Mean difference (Fishes/Hook/Hour)	p-value	df
Cordell Deep	***2.86***	**0.00**	39
Cordell Shallow	***6.74***	**0.00**	24
Farallon Islands RCA	***2.76***	**0.00**	31
Farallon Islands REF	***2.36***	**0.00**	67
Half Moon Bay RCA	***3.07***	**0.00**	36
Half Moon Bay REF	***2.72***	**0.00**	73

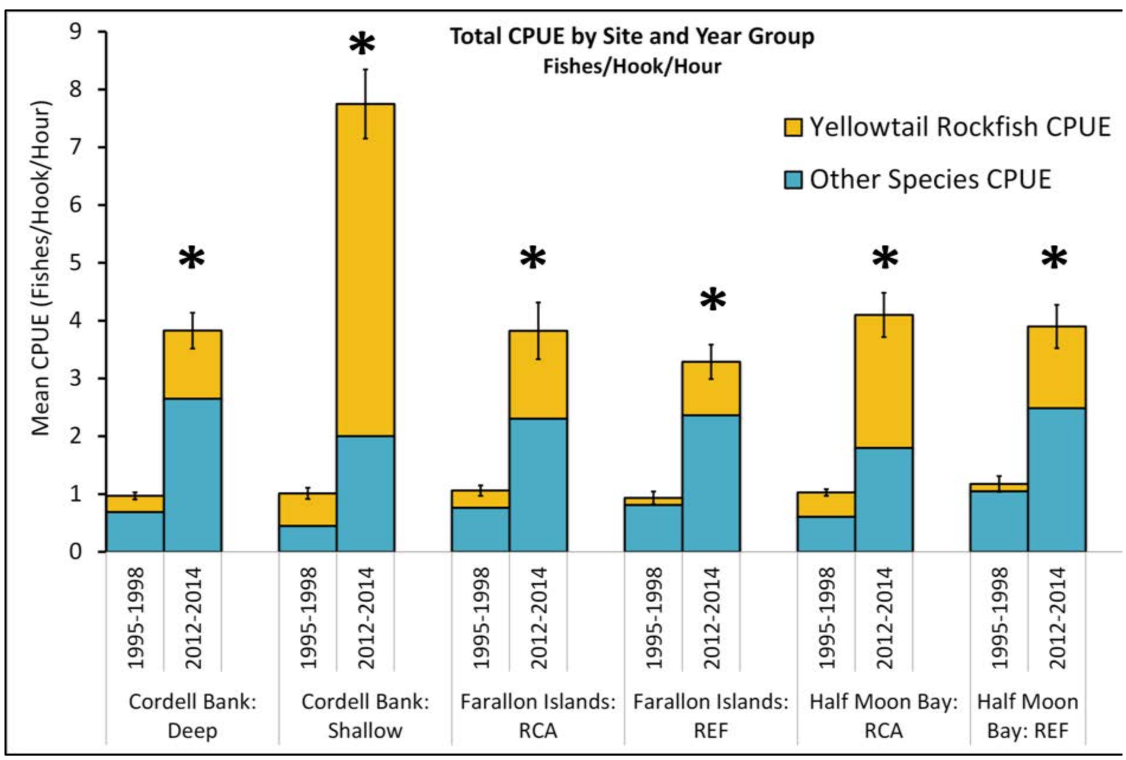

Figure 9: Mean total CPUE (all species combined by fishes/hook/hour) by site and year of da collection. Yellowtail Rockfish are represented in yellow while all other species are combin in the blue bars. Star indicates significant difference between 1990s and 2010s, where α = 0.01.

Table 7: Mean total CPUE differences for both year groups for the deep and shallow sites in Cordell Bank and inside and outside of the RCA for both the Farallon Islands and Half Moon Bay areas. Positive values denote greater CPUE for deep sites and inside the RCA, while negative values denote greater CPUE in shallow/REF areas.

	1995-1998 mean difference (CPUE)	p-value	df	2012-2014 mean difference (CPUE)	p-value	df
Cordell Bank	-0.04	0.71	134	**-3.92**	**0.00**	35
Farallon Islands	0.13	0.38	81	0.54	0.35	51
Half Moon Bay	-0.15	0.31	81	0.20	0.71	85

Lengths

The number of fishing trips in the 2010s was similar to the number of 1990s trips selected by GIS and year criteria (Table 8, although there were slightly fewer trips in the Half Moon Bay sites in the 1990s. The top 6 species caught in 2010s and their associated frequency of occurrence are found in Table 9. When comparing length frequencies from 1990s to 2010s, results were mixed with respect to whether or not mean lengths by species were larger in 2010s. For the six species evaluated here, there was an even split between species: location pairs that were larger in the 1990s relative to those from the 2010s (10 larger, 10 smaller, 12 with no significant difference, 4 not enough data for comparison). Thus, there was no overarching, coherent signal in mean length data across species for which length data were reasonably robust.

For example, Yellowtail Rockfish were significantly larger in the 2010s at Cordell Bank and Half Moon Bay, but significantly smaller at the Farallon Islands (Figure 10). Blue Rockfish were significantly larger in 2010s at the Half Moon Bay RCA (Figure 11). Canary Rockfish were significantly larger in 2010s only at the Cordell Bank Deep site, where fish were an average of 4.2 cm larger in the 2010s (Figure 12). For Rosy Rockfish there were no significant length differences between 1990s and 2010s at any sites (Figure 13). Widow rockfish mean lengths were significantly larger at Half Moon Bay RCA in 2010s (3.8 cm larger in 2010), but the majority of the Widow rockfish caught in 2010s at Half Moon Bay and Farallon Islands were smaller than the size at 50% maturity (Figure 14). Lingcod were larger in the 1990s than in 2010s at 5 of 6 sites (Figure 15). For all species, Cordell Bank tended to have larger rockfish in both 1990s and 2010s when compared to Farallon Islands and Half Moon Bay sites. The mean differences between 1990s and 2010s in length for all rockfish species by site can be found on Table 10. In general, in both 1990s and 2010s rockfish lengths were larger in the RCA sites than the Reference sites (Table 10 and 11).

Table 8: Number of Fishing Trips and count of fish lengths in 1990s and 2010s.

Area	Site	Fishing Trips 1995-1998	Fishing Trips 2012-2014	Count of Fish Lengths 1995-1998	Count of Fish Lengths 2012-2014
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	Deep	8	9	1584	978
	Shallow	6	9	1160	1661

Table 9. Number (n) of rockfish used in mean length analysis by site and years collected. Species shown are the top 6 species caught in 2010s.

			Yellowtail	Blue	Canary	Rosy	Widow	Lingcod
Cordell Bank	Deep	1995-1998	442	-	241	7	157	16
		2012-1014	326	-	80	3	211	8
	Shallow	1995-1998	720	79	-	7	254	7
		2012-1014	1297	11	58	54	70	69
Farallon Island	RCA	1995-1998	357	224	44	48	29	17
		2012-1014	420	95	310	46	16	23
	REF	1995-1998	164	454	58	56	1	32
		2012-1014	276	276	206	114	1	82
Half Moon Bay	RCA	1995-1998	779	526	106	54	180	23
		2012-1014	776	103	179	111	38	45
	REF	1995-1998	85	412	11	2	1	2
		2012-1014	527	573	76	57	47	52

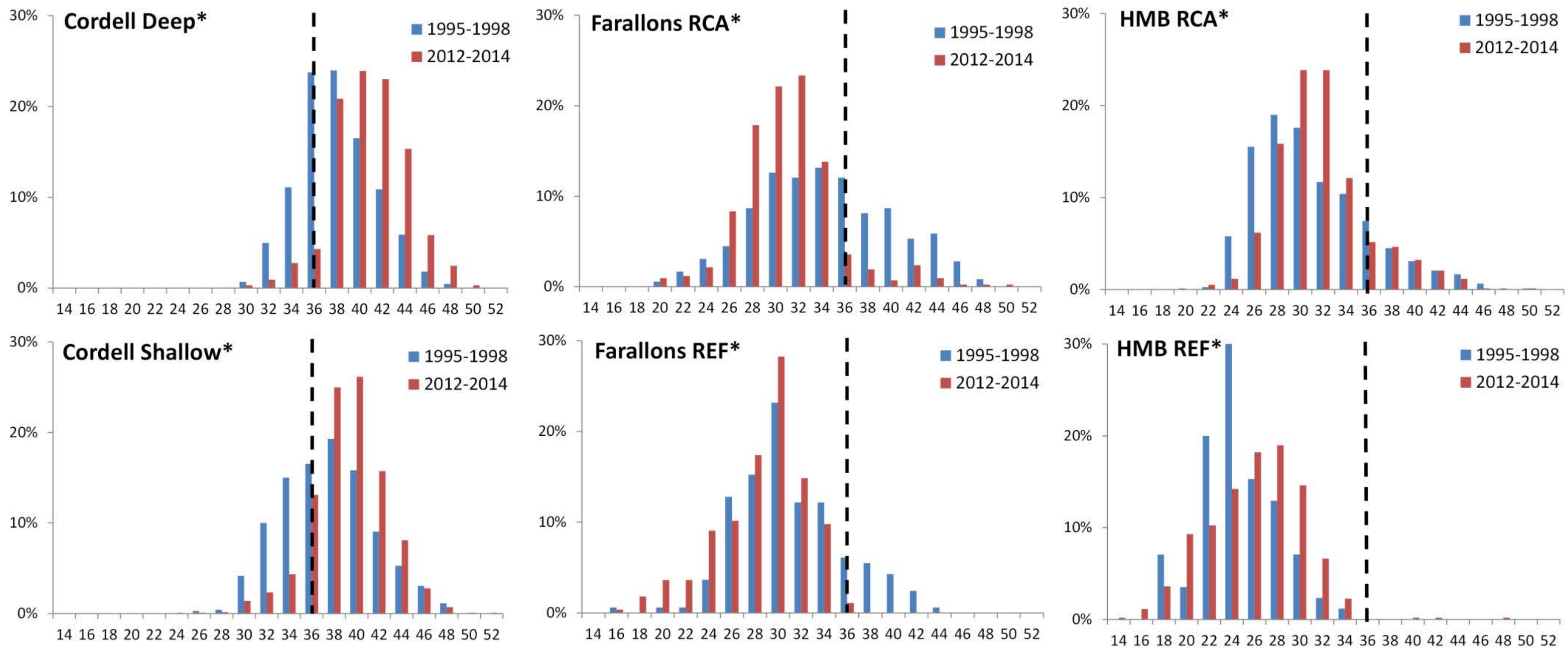

Figure 10: Yellowtail Rockfish normalized length frequencies by location, where x axis is fork length (cm) and y-axis normalized (proportion of sample size) of rockfish. Vertical dashed line indicates length at 50% maturity for females (Echeverria 1987). Star indicates significant difference in mean size between 1990s and 2010s, where α = 0.01.

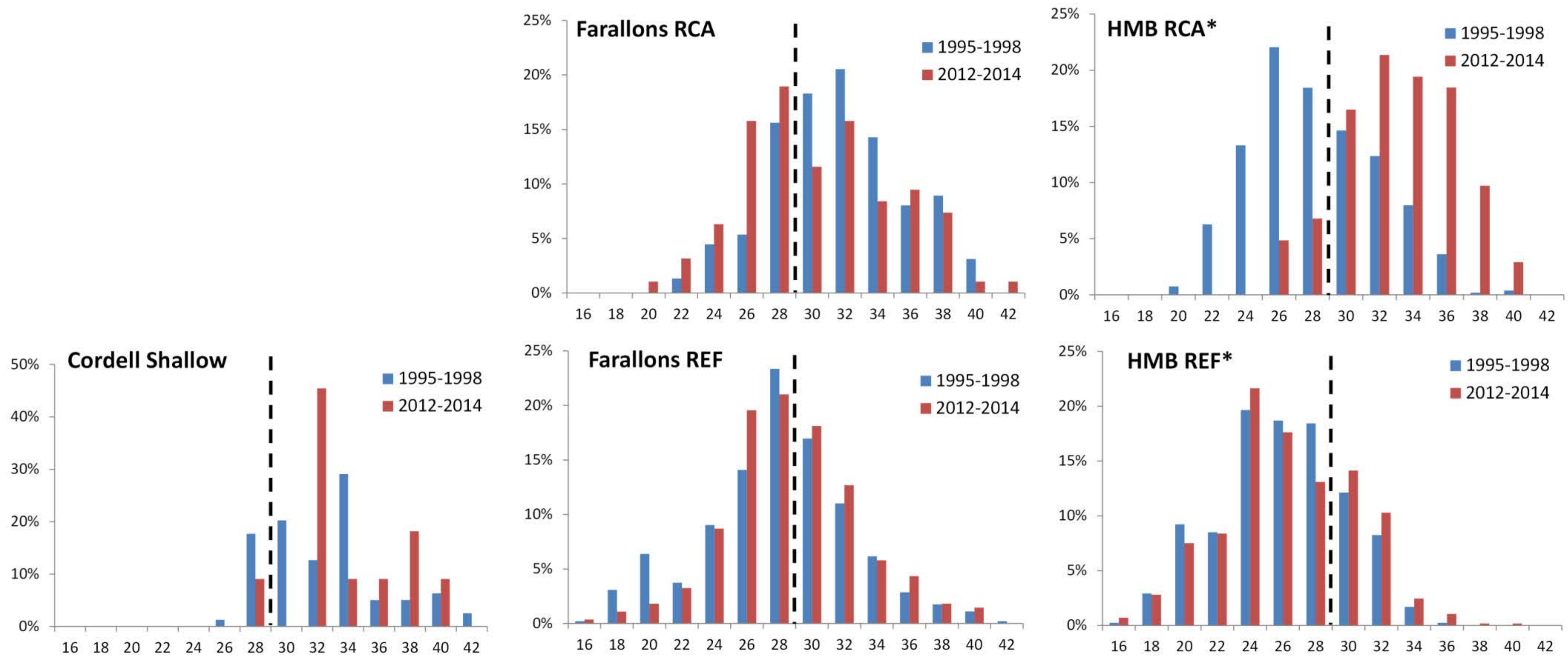

Figure 11: Blue Rockfish normalized length frequencies by location, where x axis is fork length (cm) and y-axis normalized (percentage) of rockfish. Vertical dashed line indicates length at 50% maturity for females (Echeverria 1987). Star indicates significant difference in mean size between 1990s and 2010s, where α = 0.01. No Blue Rockfish were caught in Cordell Bank Deep.

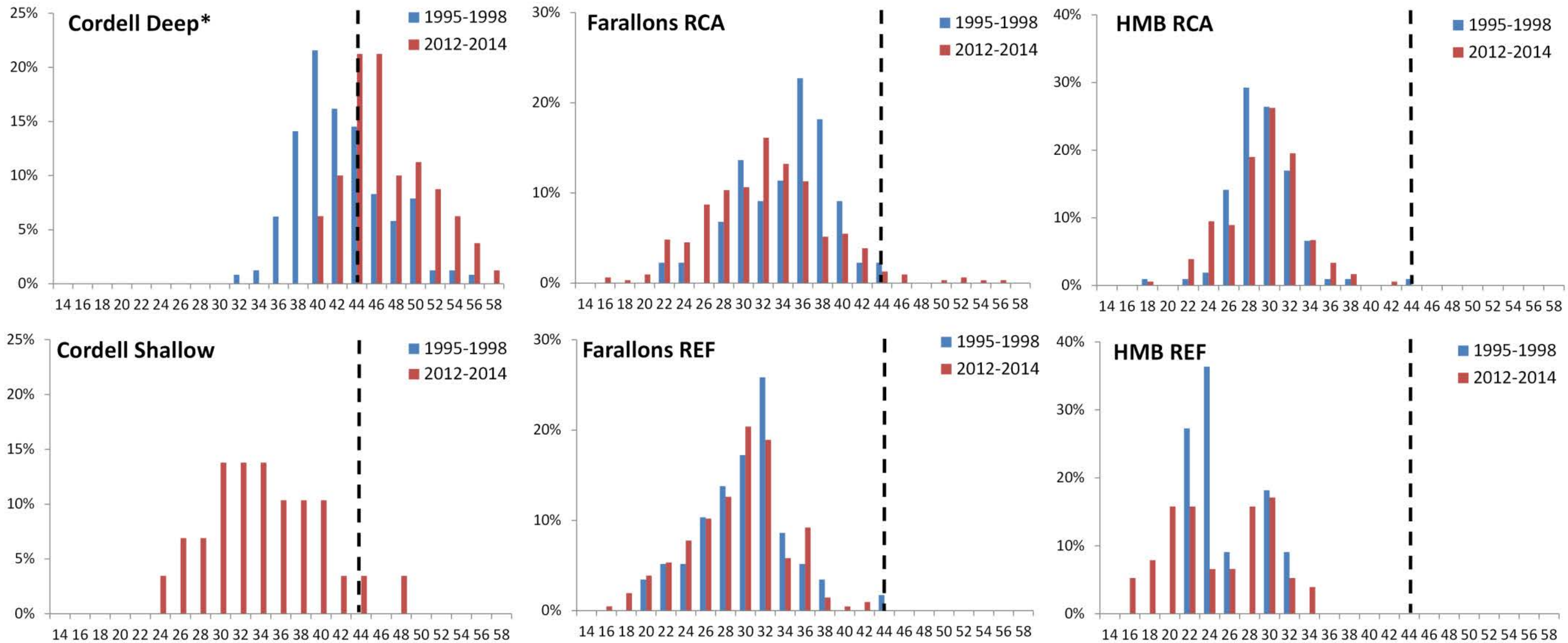

Figure 12: Canary Rockfish normalized length frequencies by location, where x axis is fork length (cm) and y-axis normalized (percentage) of rockfish. Vertical dashed line indicates length at 50% maturity for females (Echeverria 1987). Star indicates significant difference in mean size between 1990s and 2010s, where α = 0.01.

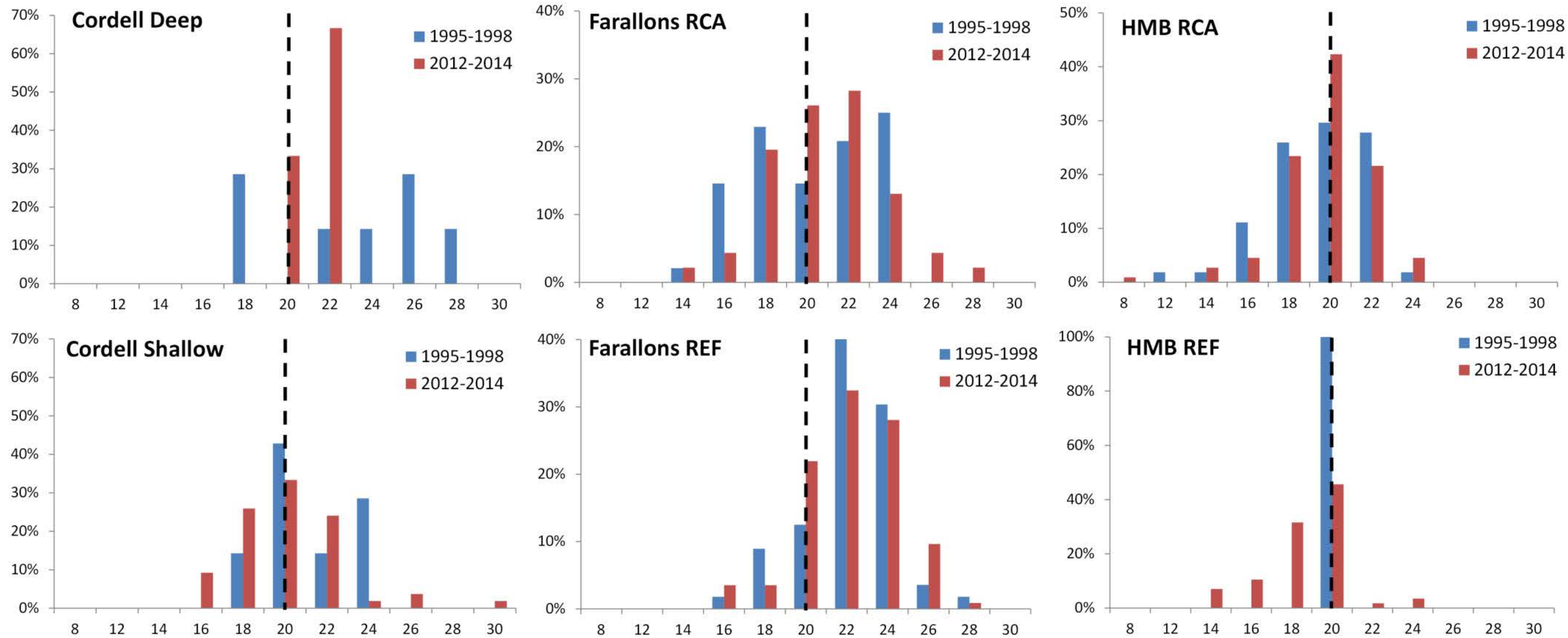

Figure 13: Rosy Rockfish normalized length frequencies by location, where x axis is fork length (cm) and y-axis normalized (percentage) of rockfish. Vertical dashed line indicates length at 50% maturity for females (Echeverria 1987). Star indicates significant difference in mean size between 1990s and 2010s, where α = 0.01. Notice difference in y-axis units for Half Moon Bay (HMB).

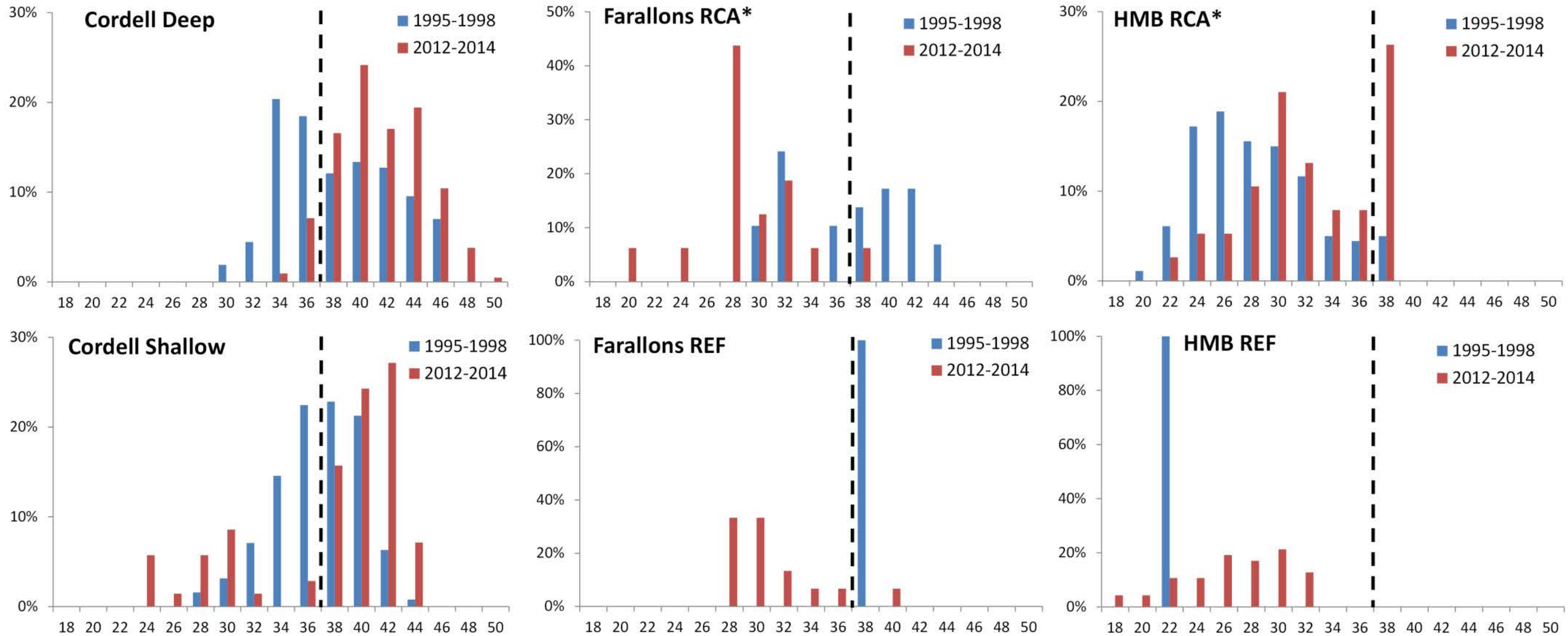

Figure 14: Widow Rockfish normalized length frequencies by location, where x axis is fork length (cm) and y-axis normalized (percentage) of rockfish. Vertical dashed line indicates length at 50% maturity for females (Echeverria 1987). Star indicates significant difference in mean size between 1990s and 2010s, where α = 0.01. Notice the difference in range of y-axis units.

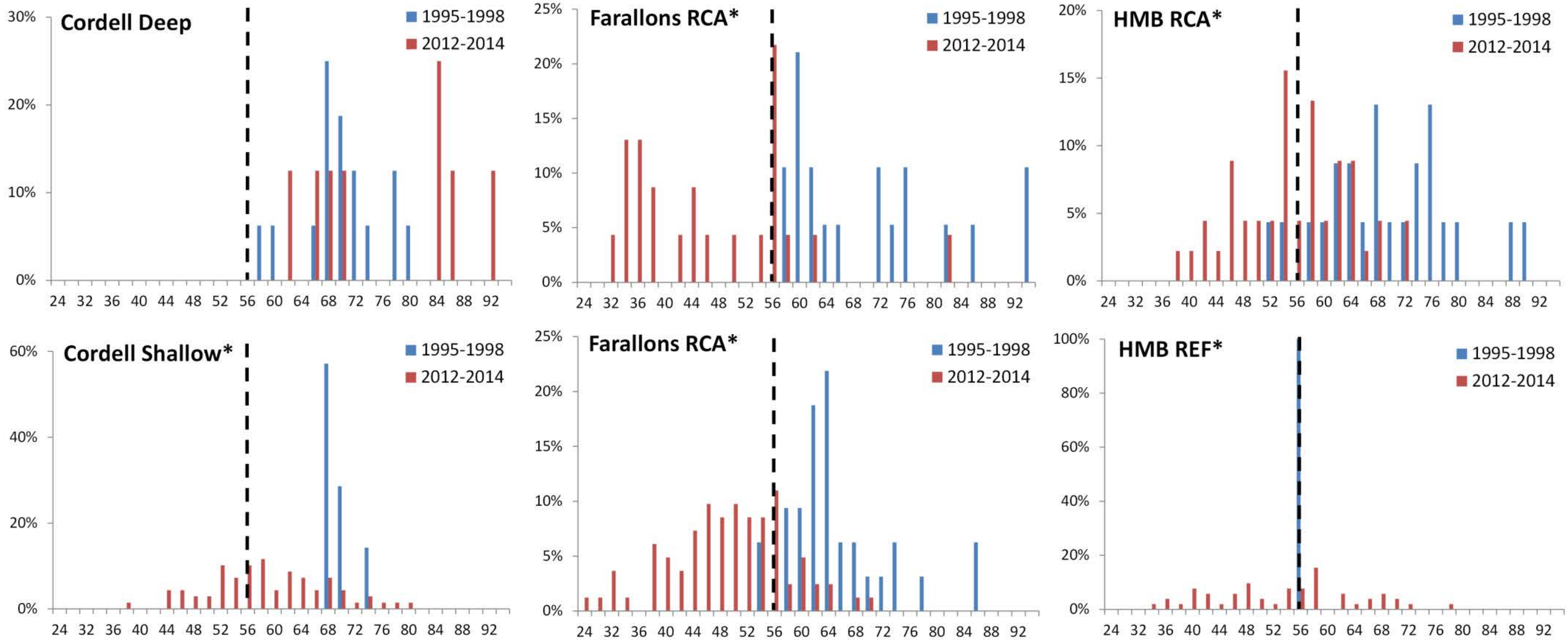

Figure 15: Lingcod normalized length frequencies by location, where x-axis is fork length (cm) and y-axis normalized (percentage) of rockfish. Vertical dashed line indicates length at 50% maturity for females (Silberberg et al., 2001). Star indicates significant difference in mean size between 1990s and 2010s, where α = 0.01. Notice differences in ranges of y-axis units.

Table 10. Mean difference of fork lengths from 1990s and 2010s and associated p- values for all areas and si sampled. Positive mean difference value indicates an increase in mean length in 2010s, and a negative value i decrease in mean length in 2010s. All significant results are shown in bold (P≤0.01). Species shown are the to species caught in the 2010s.

Area	Site	Yellowtail mean difference (cm)	p-value	df	Blue mean difference (cm)	p-value	df	Canary mean difference (cm)	p-value	df
Cordell Bank	Deep	**2.6**	**0.00**	716	N/A	-	**-**	**4.2**	**0.00**	14
	Shallow	**1.6**	**0.00**	1249	1.2	0.29	**13**	N/A	-	-
Farallon Islands	RCA	**-3.6**	**0.00**	628	**-1.6**	**0.00**	**155**	**-2.7**	**0.00**	6
	REF	**-2.8**	**0.00**	293	**0.4**	**0.00**	**293**	-1.12	0.11	10
Half Moon Bay	RCA	**0.5**	**0.03**	1498	**4.6**	**0.00**	**156**	-0.5	0.25	24
	REF	**1.2**	**0.00**	130	0.0	0.97	**926**	-0.8	0.54	1

Area	Site	Rosy mean difference (CPUE)	p-value	df	Widow mean difference (CPUE)	p-value	df	Lingcod mean difference (CPUE)	p-value	d
Cordell Bank	Deep	-1.4	0.45	**8**	**2.7**	**0.00**	288	6.2	0.17	9
	Shallow	-1.3	0.22	**8**	0.4	0.59	80	**-10.6**	**0.00**	3
Farallon Islands	RCA	0.3	0.60	**92**	**-8.1**	**0.00**	35.0	**-20.9**	**0.00**	3
	REF	-0.2	0.60	**112**	-	N/A	-	**-16.5**	**0.00**	6
Half Moon Bay	RCA	-0.1	0.85	**103**	**3.8**	**0.00**	50	**-14.3**	**0.00**	3
	REF	**-1.9**	**0.00**	**36**	-	N/A	-	-2.9	0.07	4

Table 11: Mean difference in length for the top 6 species caught in the 1990s (top) and 2010s (bottom) comparing sites within each area sampled (for Cordell Bank, Deep/Shallow and for Farallon Islands and Half Moon Bay, RCA/REF). Positive mean differences are greater fork length values in Deep/RCA, whereas negative values are smaller fork lengths. Significant differences ($p \leq 0.01$) are indicated in bold.

1990s	Yellowtail mean difference (cm)	p-value	df	Canary mean difference (cm)	p-value	df	Blue mean difference (cm)	p-value	df	Widow mean difference (cm)	p-value	df	Rosy mean difference (cm)	p-value	df	Lingcod mean difference (cm)	p-value	df
Cordell Bank	**0.6**	**0.00**	1077	N/A			N/A			1.7	0.37	9	1.5	0.05	267	0.6	0.69	21
Farallon Islands	**0.1**	**0.00**	389	**3.6**	**0.00**	511	**2.6**	**0.00**	93	**-1.9**	**0.00**	89	N/A			2.2	0.39	29
Half Moon Bay	**6.5**	**0.00**	126	**2.2**	**0.00**	873	**4.3**	**0.00**	11	**-1.0**	**0.00**	41	N/A			**13.5**	**0.00**	**23**

2010s	Yellowtail mean difference (cm)	p-value	df	Canary mean difference (cm)	p-value	df	Blue mean difference (cm)	p-value	df	Widow mean difference (cm)	p-value	df	Rosy mean difference (cm)	p-value	df	Lingcod mean difference (cm)	p-value	df
Cordell Bank	**1.6**	**0.00**	521	N/A			**12.8**	**0.00**	103	1.6	0.13	3	**1.6**	**0.00**	84	**17.4**	**0.00**	8
Farallon Islands	**2.4**	**0.00**	618	**1.5**	**0.00**	163	1.1	0.02	495	**-1.4**	**0.00**	75	N/A			-2.2	0.44	28
Half Moon Bay	**5.7**	**0.00**	1094	**6.8**	**0.00**	150	**4.6**	**0.00**	108	0.8	0.02	123	**0.8**	**0.00**	**71**	2.1	0.28	94

Fecundity

A total of 20 rockfish species were collected including Black, Blue (two species yet to be named), Bocaccio, Canary, Chilipepper, China, Copper, Flag, Greenspotted, Olive, Redstripe, Rosy, Speckled, Squarespot, Starry, Vermilion, Widow, Yelloweye and Yellowtail Rockfish. Fecundity samples were collected from all females with developing eggs or larvae (Table 12).

Table 12. Collections of species for fecundity studies by species and area collected.

Species		Sampling Location		
Common name	Scientific name	Cordell Bank	Farallon Islands	Half Moon Bay
Black	*Sebastes melanops*			
Blue (undifferentiated)	*Sebastes mystinus*			5
"True" Blue	*Sebastes mystinus*		1	3
"Northern" Blue	*Sebastes mystinus*		1	10
Bocaccio	*Sebastes paucispinis*	5		
Canary	*Sebastes pinniger*	16		
Chilipepper	*Sebastes goodei*	57		
China	*Sebastes nebulosus*		3	1
Copper	*Sebastes caurinus*			
Flag	*Sebastes rubrivinctus*			1
Greenspotted	*Sebastes chlorostictus*			1
Olive	*Sebastes serranoides*	2		4
Redstripe	*Sebastes proriger*			
Rosy	*Sebastes rosaceus*	6	6	9
Speckled	*Sebastes ovalis*	2		
Squarespot	*Sebastes hopkinsi*			
Starry	*Sebastes constellatus*			5
Vermilion	*Sebastes miniatus*	1		1
Widow	*Sebastes entomelas*	36		
Yelloweye	*Sebastes ruberrimus*	1		
Yellowtail	*Sebastes flavidus*	75		6

Condition

Female condition, measured by the hepatosomatic index, varied by collection year and sampling location. For the female condition of one schooling species (Yellowtail Rockfish) and one benthic species (Rosy Rockfish) collected at all three sampling locations over the months of August through October prior to the winter reproductive season we observed similar hepatosomatic index for both species as they varied by year (Figure 16). Females had higher proportional liver weights in the late summer/fall of 2013 compared with the other two years. Higher energy reserves are likely the result of more favorable oceanographic conditions and increased food availability during the spring and summer upwelling period in the California Current.

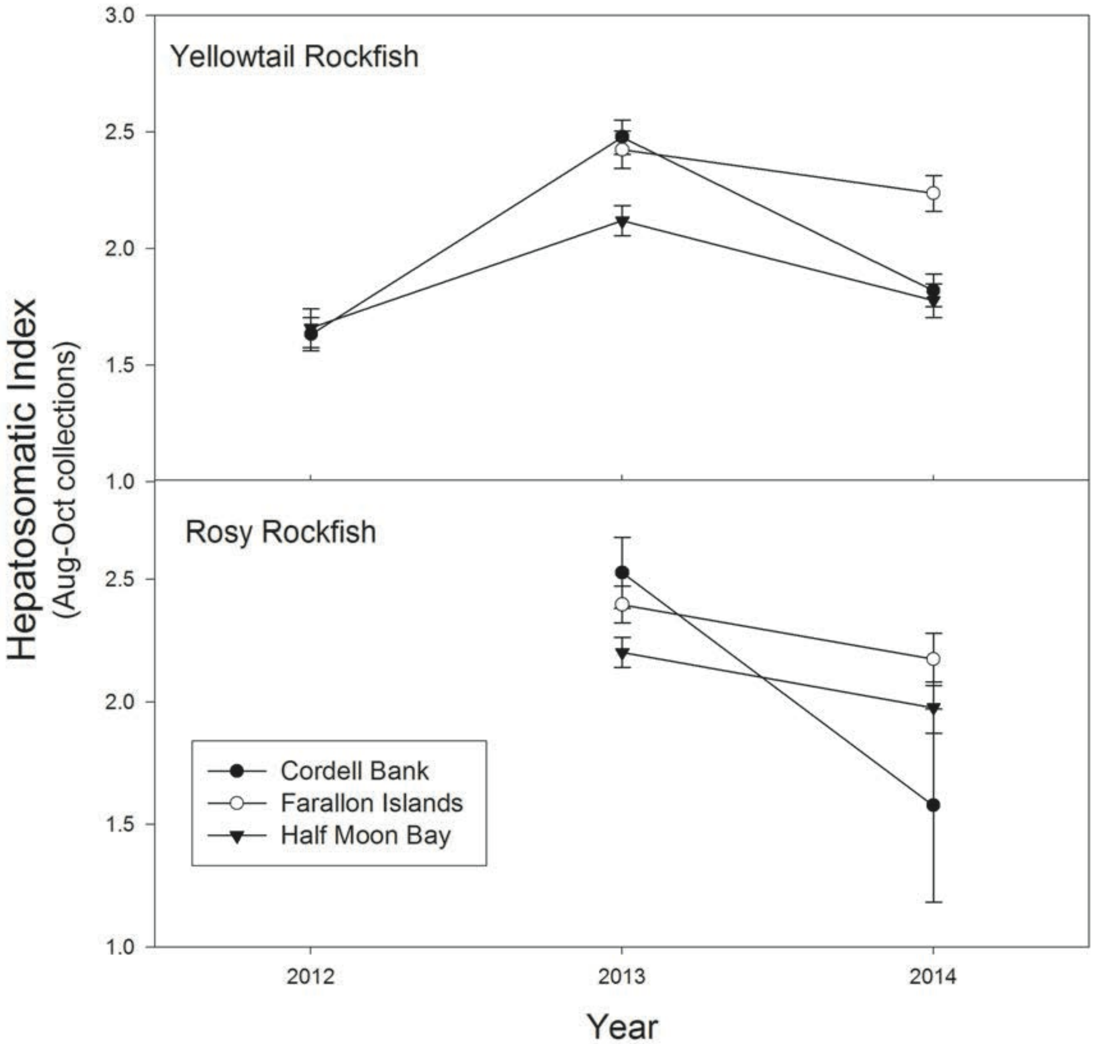

Figure 16: Female condition (HSI, liver weight *somatic body weight^{-1}) prior to the reproductive season (August-October collections) for one schooling species (Yellowtail Rockfish) and one benthic species (Rosy Rockfish) collected at all three sampling locations. (±SE).

Size dependent relative fecundity relationships

Fecundity was calculated on both an absolute (total number of offspring) and relative (number of offspring per gram somatic weight) basis for each female. Fecundity estimates from the RCA project were combined with data collected since 2009 by the NOAA Southwest Fisheries Science Center. Size dependent relative fecundity relationships were established for many rockfish species, with the most information garnered for six species, the Yellowtail (*Sebastes flavidus*), Blackgill (*S. melanostomus*) , Northern and True Blue Rockfish (*S. mystinus*), Chilipepper (*S. goodei*) and Rosy Rockfish (*S.rosaceus*) (Figure 17). The slope of the size-relative fecundity relationship differed by species and appeared to be steepest among single brooding species (i.e. Yellowtail, Blackgill and two species of Blue Rockfish) as compared to two multiple brooding species (Chilipepper and Rosy) (Figure 17). The samples collected during this study are currently being evaluated in an effort to link macroscopic and histological signs of multiple brooding, in order to better understand and quantify this phenomenon.

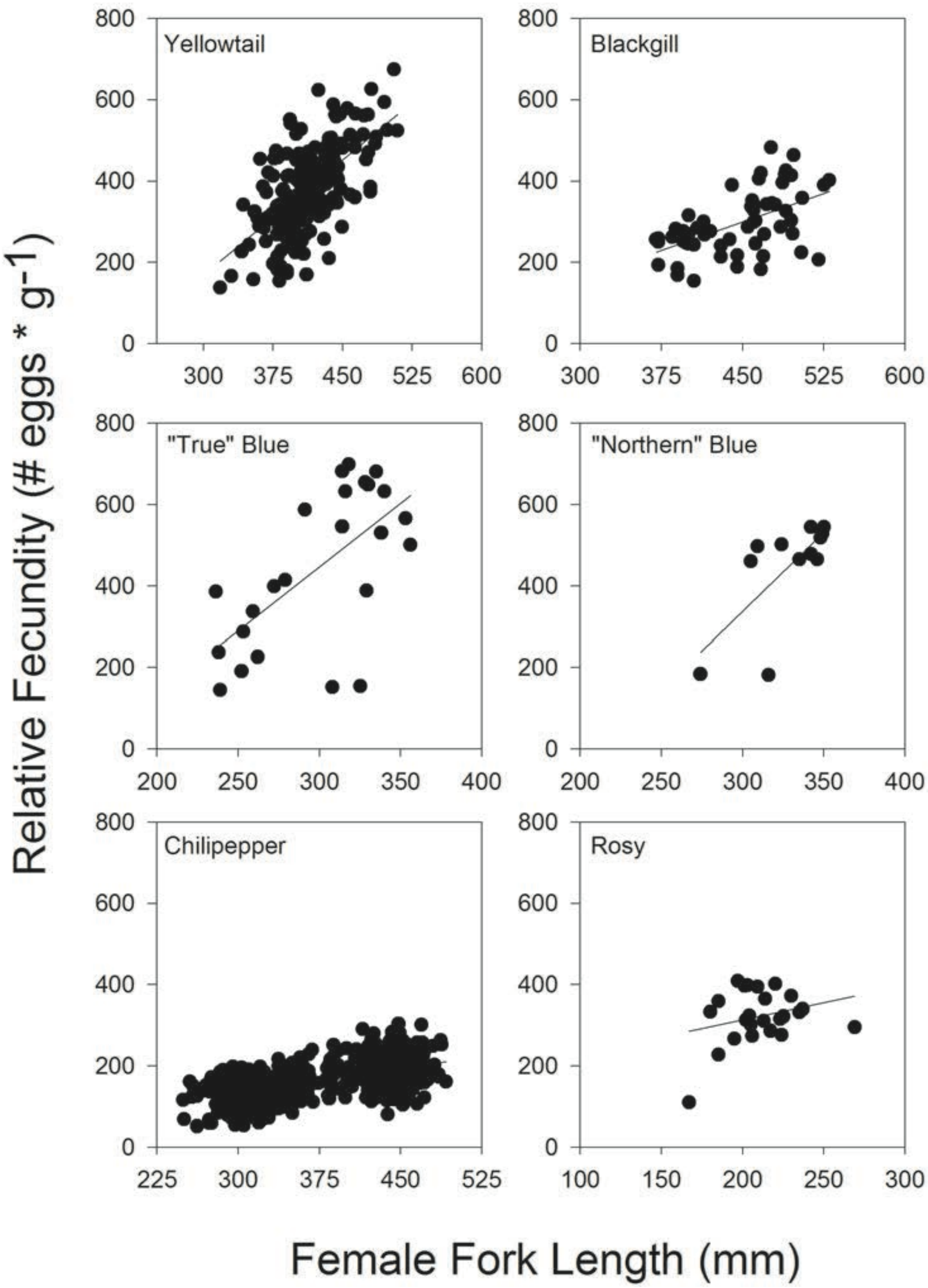

Figure 17: Size dependent relative fecundity relationships for Yellowtail, Blackgill, two species of Blue (yet to be named), Chilipepper and Rosy Rockfish. Fecundity information collected from 2009 to 2014 and updated with new data from the RCA project. Note that Blackgill includes only fecundity estimated from ovaries with vitellogenic eggs. Blackgill, a deep water slope species, were collected through a complementary cooperative research grant funded by NOAA.

Interannual variability

Fecundity data from this study for Yellowtail and Chilipepper were combined with prior data to examine interannual variability in egg production (Figure 18, Cordell Bank only, all estimates adjusted for female size). Relative fecundity estimates for both species were lowest around 2005-2006. Oceanographic conditions in 2005 were characterized by a late spring transition, delayed upwelling and poor oceanographic conditions in the California Current (Checkley and Barth 2009). Additionally, ocean temperatures off central California throughout the summer and fall of 2014 were uncharacteristically warm, with preliminary results indicating a reduction in egg production among Chilipepper females.

Contemporary estimates of female condition and relative fecundity for Yellowtail (2009-2013) were comparable to the historic dataset (1985-1990), indicating that interannual variability in environmental conditions play an important role in productivity. Condition of females in early stages of egg development (stage 2, unfertilized vitellogenic eggs) tracked closely with female egg production in both Yellowtail and Chilipepper, providing a link among oceanographic conditions, female condition and egg production.

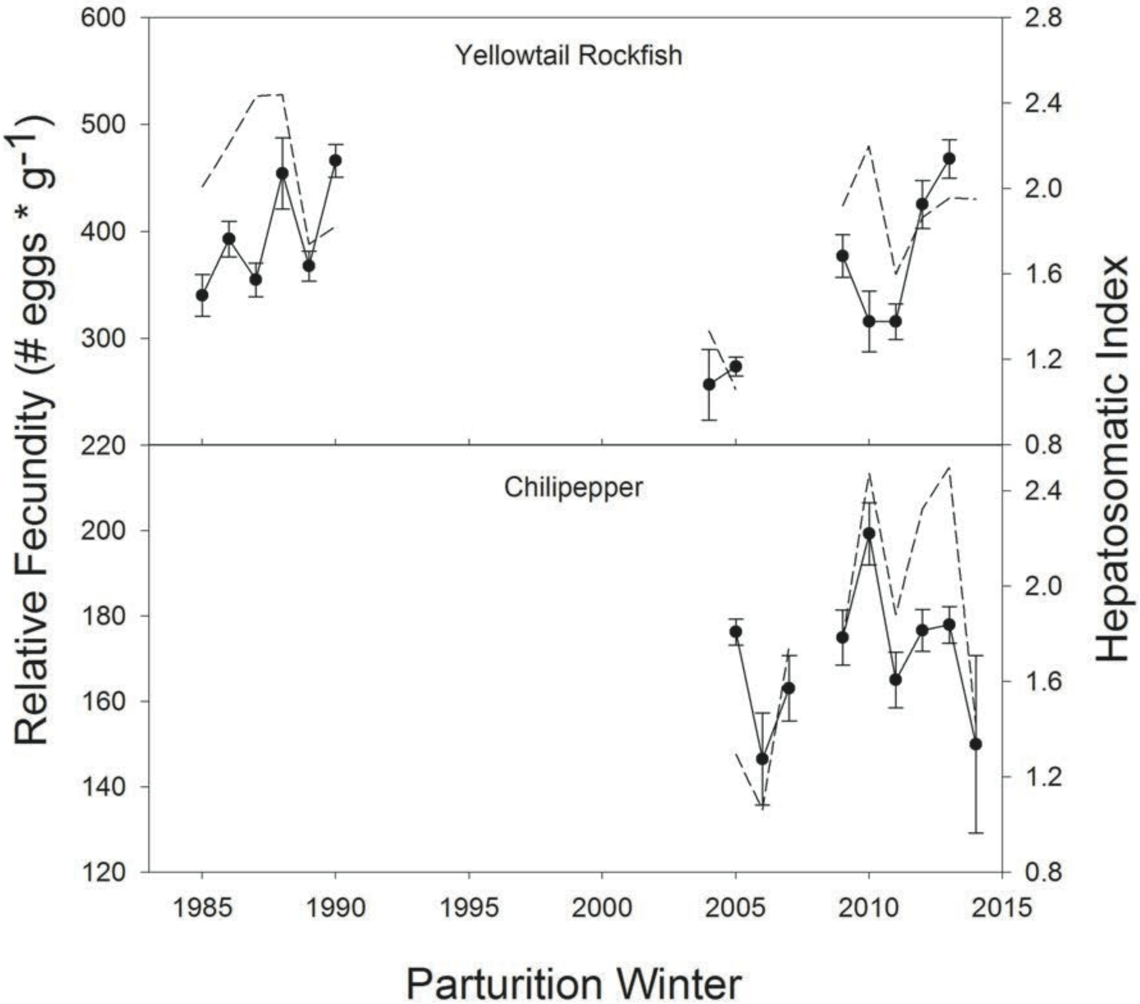

Figure 18: Time series (±SE) at Cordell Bank of mean relative fecundity estimates, adjusted for fish size (solid line, black circles). Right axis shows mean condition estimates (HSI, liver weight * somatic body weight^{-1}) of females with vitellogenic eggs (early development, dashed line). Data compiled from Eldridge and Jarvis 1995, Stafford et al. 2014, Beyer et al. 2015 and the current RCA project.

Summary of Results

- The top 6 species caught remained the same between 1996-1998 and 2012-2014, however, the proportion to total CPUE for species changed.
- Total CPUE increased at all sites (RCA and Reference) and was largely due to the increase in Yellowtail Rockfish.
- There was no significant difference in total CPUE between the RCA and REF sites in the current data set (2012-2014).
- Canary Rockfish increased in relative abundance at all sites (both inside and out).
- Yellowtail Rockfish increased in relative abundance at all sites (both inside and out).

- Yellowtail were significantly larger post closure at Cordell Bank and Half Moon Bay but significantly smaller in mean size at the Farallon Islands.
- Lingcod and Rosy Rockfish increased in parallel at all sites except Cordell Deep and Farallons RCA.
- Blue and Widow Rockfish were the only species with a larger mean size in the RCA as compared to the earlier sampling years.
- Canary, Yellowtail, and Blue Rockfish had a greater mean size than in reference areas both before and after the RCA closure.
- Estimates of female condition and relative fecundity for Yellowtail (2009-2013) were comparable to the historic dataset (1985-1990), indicating that interannual variability in environmental conditions play an important role in productivity.

Discussion

Overall CPUE increased as compared to pre-RCA cate rates. However, there were fewer significant differences when examining inside and outside the RCA today. It is critical to examine the breakdown of increases in CPUE on species basis because of the influence that recruitment of one or a few species can have. In addition, initial differences in abundance existed between sites before the RCAs were enacted. These differences may be due to oceanographic conditions which dictate food availability such as temperature, depth, and water movement. A more complete discussion of our results can be found in Marks et al. (2015).

Interpretation of the differences (or lack thereof) in mean lengths and length distributions must be made with considerable caution. Although a decline in mean lengths is typically associated with fishing pressure, such declines are often difficult to distinguish from strong recruitment or year class effects. Most of the fish populations studied here are known to have highly variable recruitment, and recent cool, high productivity ocean conditions have led to a number of strong year classes in many rockfish populations (2009, 2010). Thus, the decline in mean lengths in some species and locations is likely a consequence of stock rebuilding and recent strong year classes, particularly for stocks known to be rebuilding such as Canary Rockfish and Lingcod, more so than an indicator of increased (or differential) fishing mortality.

Because larger fish in these species migrate to deeper depths, one cannot detect if the greater size today is due to protection or life history traits. Regardless, higher protection is being given to fishes with greater mean lengths and, in turn, greater reproductive capacity. The RCAs are depth-based closures, and the increase in observed size by depth may simply reflect known ontogenetic shifts in the distribution of different size or age classes by depth, as most of these species tend to deeper water with greater size or age. Thus, changes in mean lengths or length structure of these populations needs to be evaluated concurrently with changes in catch rates and known or suspected trends in recruitment.

For all rockfish species examined to date, relative fecundity has been shown to increase with female size, providing continued evidence that the assumption of spawning biomass being directly proportional to larval production is incorrect. In all cases, older and larger females produced disproportionately more young per unit biomass compared to their smaller, younger counterparts. Note that all estimates in this study reflect brood fecundity and do not account for an increase in total annual fecundity by species capable of producing secondary broods. The majority of rockfish species release only a single brood of larvae per year; however, the following species are capable of producing secondary broods: Starry, Rosy, Greenspotted, Greenblotched, Pink, Swordspine, Speckled, Squarespot, Bank, Shortbelly, Bocaccio, Chilipepper, Cowcod, Greenstriped and potentially Brown Rockfish (Moser 1967, MacGregor 1970, Love et al. 2002). The number of broods and proportion of females producing secondary broods among multiple brooding species remains largely unknown, but preliminary data suggest that this phenomenon is related to geographic location (multiple broods appear to be more common in southern distributed species), maternal condition and maternal size.

Fecundity collections and information collected here on age, growth and maturity of fished species will also support future stock assessments by the SWFSC and provide much needed biological data on many data-poor species. Additionally, annual collections extended the time series of fecundity estimates and female condition to establish correlations of oceanographic conditions, climate and population productivity. We observed that years of poor oceanographic conditions lead to lower egg production in rockfish.

Our results continue to support a growing body of evidence that older, larger females are important for population replenishment. By collecting data on multiple rockfish species, we observed that the strength of this maternal size effect (slope of the size dependent relative fecundity relationship) varied by species and may be related to reproductive strategy (i.e. single vs multiple brooding species). Spatial management closures such as the RCA can be an effective strategy for protecting older and larger females since, in the case of many shelf/ shelf-slope rockfish species, larger females tend to reside in deeper waters.

Ongoing efforts will be made to detect changes in life history traits such as growth and maturity of species collected during the RCA project. Both immature and mature fish were collected over the course of the project, which will allow the stock assessment team at the SWFSC to update maturity schedules for upcoming groundfish assessments. Additionally, these contemporary results will allow for a comparison with historic data to detect changes that may have resulted from intense fishing pressure in the late 1980s and early 1990s, and to track how populations have recovered since the implementation of the RCAs and stricter fishing regulations.

Comparison of results with stock assessment models for these species should provide the opportunity to differentiate episodic recruitment events (e.g., strong year classes) from the effects of the RCA closures on fish populations. For example, the index initially developed from the 1980s and 1990s CPFV observer data for the bocaccio stock assessment reflects a spike in abundance following successful recruitment of the strong 1989 year class, which increased catch rates in 1990 and 1991, and decreased the mean size of fish at age (Figure 3). Interpretation of catch rate results with stock assessments will provide a more holistic perspective on recruitment events and other trends in stock status based on alternative data sources, while concurrently providing validation or additional information regarding such trends and events to assessment models.

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