FISH POPULATION FLUCTUATION ESTIMATES BASED ON FIFTEEN YEARS OF REEF VOLUNTEER DIVER DATA FOR THE MONTEREY PENINSULA, CALIFORNIA

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ABSTRACT

A database of fish surveys conducted by volunteer recreational divers trained by Reef Environmental Education Foundation (REEF) was used to examine fish populations in Monterey Peninsula, California, between 1997 and 2011. Over 3,000 surveys were conducted as part of this ongoing citizen science effort. Variations in relative density over time are reported for 18 fish species, including several fisheries-targeted species. Two recruitment pulses of young-of-the-year rockfish (*Sebastes* spp.) were observed over the study period, with subsequent increases in older rockfish. Several predator species increased and subsequently declined, peaking two years after prey populations. Strong concordance was found between REEF data and those collected by Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), a consortium of academic institutions. Results show that data collected by REEF has great potential to augment and strengthen professional research data and serve as a valuable baseline to evaluate marine reserves.

INTRODUCTION

Citizen science data collection efforts have proven to be a cost-efficient way to collect much needed information for conservation and management efforts (Pattengill-Semmens and Semmens 2003; Dickinson et al. 2012; Holt et al. 2013). Citizen science efforts marshaled by Reef Environmental Education Foundation (REEF) have accumulated a rich, long-term database of marine life surveys using volunteer divers trained and supported by a small professional staff (Pattengill-Semmens and Semmens 2003; REEF 2013). Since 1993, REEF has engaged over 14,000 recreational SCUBA divers across North and Central America, Hawaii, and the South Pacific to conduct fish surveys. As of July 2013, over 172,000 surveys had been conducted worldwide, with the results made publicly available on REEF's Web site, www.REEF.org. These data have proven key to providing fisheries-independent data in stock assessments, documenting change in populations due to management zones, evaluating regional patterns in biodiversity, and tracking invasive lionfish range expansion in the Caribbean. A complete list of publications that include REEF data can be found on www.REEF.org.

Using a numerical conversion method to calculate population estimates from REEF log-scale data (Wolfe and Pattengill-Semmens 2013), fifteen years of fish data for the nearshore reefs of the Monterey Peninsula, California, were examined. The study area encompasses south Monterey Bay and Carmel Bay, and extends northeast to the Monterey shale beds and southwest to Point Lobos (fig. 1). REEF survey results were also compared to transect surveys conducted by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), a consortium of scientists from universities along the U.S. West Coast.

The primary objectives of this study were: (1) to determine if fish population trends are evident in this time series data, (2) to compare those trends with another data set using a different methodology (PISCO), (3) to determine if REEF data can be calibrated to a common density index, and (4) to evaluate whether the REEF data offer unique and/or complementary information that can be used by researchers, agencies, and policy makers.

METHODS

REEF Volunteer Survey Project Roving Diver Technique: The REEF Volunteer Survey Project started collecting data in the marine waters of California in 1997. REEF volunteers conduct fish surveys using the Roving Diver Technique (RDT; Schmitt and Sullivan 1996). The RDT is a visual survey method designed to generate a comprehensive species list, along with sighting frequency and relative abundance estimates. During RDT surveys, divers swim freely throughout a dive site and record every observed identifiable fish species. Divers are encouraged to explore not only reef structure, but also scan for pelagic species overhead and investigate crevices, ledges, and rock/sand interfaces. During a survey, divers assign each recorded species to one of four $\log_{10}$ abundance categories. Surveyors enter species data along with survey time and environmental information into an online data entry interface (optical scanforms used prior to 2007). REEF staff carefully review the survey reports before transferring the information into the per-

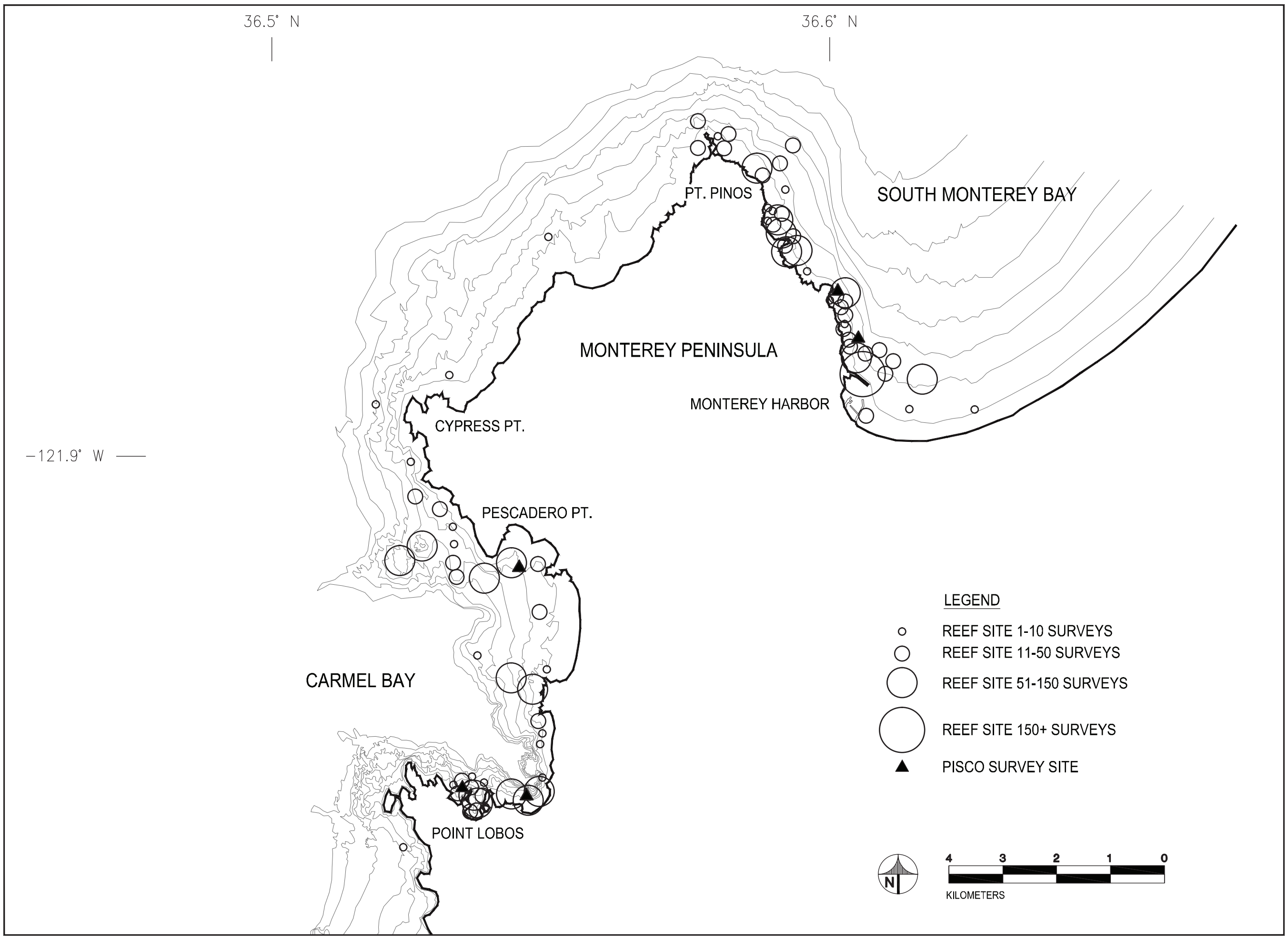


Figure 1. Rocky reefs surround much of the Monterey Peninsula, California (bathymetric contours from Seafloor Mapping Lab, CSUMB) . Circle symbols indicate REEF fish survey sites; triangle symbols indicate sites surveyed by both REEF and PISCO.

manent database, culling or correcting obvious errors and contacting divers if anomalous or unusual sightings are reported. Summary data can then be accessed by the public at REEF's webpage (http://www.REEF.org) by geographic location. REEF staff generate raw data files on request for scientists and resource agencies.

Identification and methodology training is made available to REEF volunteers through classroom sessions, webinars, and self-teaching materials (Pattengill-Semmens and Semmens 1998; Semmens et al. 2000). Field identification of Pacific coast fishes is based on regional field guides (Eschemeyer et al. 1983; Gotshall 2001; Love et al. 2002; Humann and DeLoach 2008). Divers are instructed to only report species they can positively identify. REEF surveyors advance through five experience levels (Novice: 1–3 and Expert: 4–5), based on the number of surveys completed and passing scores on comprehensive identification exams.

REEF surveys are conducted throughout the West Coast. The area studied here is identified as REEF Geographic Zone Code 4114 (South Davenport–Point Lobos Reserve), and more specifically the area extending west and south from the south Monterey Bay shale beds through Point Lobos (fig. 1). REEF surveys are conducted year round, with more surveys reported for summer months than winter. The months with the highest number of surveys in the study region are May, when REEF Advanced Assessment Team members conduct an annual Monterey Field Survey over four days; and July, when Great Annual Fish Count organized events take place.

REEF summarizes count results by reporting sighting frequency, *SF*, defined as the fraction of dives when a given species is seen; and log-density index, *DEN*, defined as:

$$DEN = \frac{S + 2F + 3M + 4A}{S + F + M + A} \tag{1}$$

where, for a given species, area, and period,

S = *number of dives reporting Single (1),*
F = *number of dives reporting Few (2–10),*
M = *number of dives reporting Many (11–100), and*
A = *the number dives reporting Abundant (over 100).*

Converting SFMA data to Expected Arithmetic Mean: Wolfe and Pattengill-Semmens 2013 documented a novel approach to calculating estimates of mean numbers of fish from REEF order-of-magnitude count data, using disaggregated SFMA data rather than the aggregate log-density index *DEN*. The alternative method yielded a threefold tighter confidence interval over *DEN* (Wolfe and Pattengill-Semmens 2013). A brief description of the calculation is given here.

An "Average of Few" variable is formulated, based on the proportion of adjacent count categories Single and Many. Similar variables are calculated for the Many and Abundant categories, as follows:

$$AvgF = \frac{2S + 4.16F + 10M}{S + F + M}$$

$$AvgM = \frac{11F + 33.8M + 100A}{F + M + A} \qquad (2)$$

$$AvgA = \frac{200M + 348A}{M + A}$$

Parameters 2, 10, 11, and 100 are *a priori* constants based on the Few category being defined as 2 to10 and Many being defined as 11 to 100. The other parameters (4.16, 33.8, 200, and 348) are best-fit parameters based on least squares regression.

The variables *AvgF, AvgM,* and *AvgA*, multiplied by their corresponding category counts *F, M* and *A*, are then summed and divided by the total nonzero counts to give the average sightings per dive:

$$ExpectedMean(NonZeroSurveys) = \frac{S + F \cdot AvgF + M \cdot AvgM + A \cdot AvgA}{S + F + M + A} \qquad (3)$$

Finally, the expected mean for nonzero surveys is multiplied by the sighting frequency (fraction of nonzero sightings) to calculate an overall average number of fish of a given species seen per dive.

$$ExpectedMean(AllSurveys) = SightingFrequency \cdot ExpectedMean(NonZeroSurveys) \qquad (4)$$

The average fish seen per dive was normalized for slight variations in year-to-year bottom time, under the assumption that fish sightings are essentially proportional to bottom dive time, with longer dives covering more distance to encounter more fish. Wolfe and Pattengill-Semmens 2013 quantified the confidence interval as a function of the number of nonzero surveys, based on several sources of error, including:

1. Conversion or Translational Error: Converting SFMA data to Arithmetic Mean
2. Observational Error, including the following components:
   a. Variation between divers at the same dive site, swimming different routes across the same site,
   b. Variation between dives at the same site over the year,
   c. Variation in the mix of dive sites surveyed from year to year (boat vs. shore, Carmel vs. Monterey Bays).

The *combined* translational and observational 90% confidence interval (5% high and low tails) can be expressed as a function of the number of nonzero sightings, *n*, per year:

$$Confidence\ Interval\ Typical\ Species_{90\%} = 0.02 + \frac{2.03}{(n-1)^{0.48}} \qquad (5a)$$

$$Confidence\ Interval\ Abundant\ Species_{90\%} = -0.26 + \frac{3.20}{(n-1)^{0.38}} \qquad (5b)$$

In the confidence intervals above, "abundant species" are those where the proportion of Abundant counts to total nonzero sightings, $A/(S + F + M + A)$ exceeds 10%, while all other species are designated "typical." Because the underlying count distribution is log-normal, skewing to zero, the error bars above and below the mean are not equal. Therefore, the error bars are expressed as multipliers and divisors of the expected mean (example: a 90% confidence interval of $^{x}/30\%$ is the mean multiplied and divided by 1.30 instead of $^{+}/_{-}$ 30%; see Limpert et al. 2001).

Fish species populations trends: Using the calculated estimates derived from the method described above (and more fully in Wolfe and Pattengill-Semmens 2013), variations in relative density over time are reported for 18 fish species, including fisheries-targeted species such as blue rockfish (*Sebastes mystinus*), cabezon (*Scorpaenichthys marmoratus*), kelp greenling (*Hexagrammos decagrammus*), and lingcod (*Ophiodon elongatus*).

PISCO survey comparison: REEF data for eight species were compared with those collected through the PISCO program, using data collected in the Monterey Peninsula area between 1999 and 2008. PISCO is a large-scale visual survey effort by academic research divers (PISCO 2012). PISCO collects data on fish populations and trends using 30m x 2m x 2m transects.

TABLE 1
Comparison of REEF and PISCO surveys methods for the years 1999–2008

	REEF	PISCO
Number of Survey Sites	85	5
Number of Surveys	1860 Dives	960 Transects
Survey Extent	Dive Site	Transect
Distance Per Survey	250 m (est.)	30 m
Total Distance Surveyed	470 km (est.)	29 km
Width of Survey	Limited by Visibility	2 meters
Type of Count	Order of Magnitude	Exact
Size of Fish Recorded?	No*	Yes
Type of Surveyor	Non-scientist Volunteer	Scientific Researcher

*Exception: Rockfish less than or equal to 5 cm recorded as YOY rockfish (*Sebastes* spp.).

Fish species, abundance, size, and gender (for species with readily apparent sexual dimorphism) are recorded. PISCO has conducted regular underwater transect surveys at five dive sites in Monterey and Carmel Bays since 1999. PISCO fish surveys take place from approximately mid-August through October, a time of year that captures both early and late season young-of-the-year (YOY) rockfish recruits. Three portions of the water column are sampled: bottom, midwater, and upper kelp canopy. PISCO bottom data were used in comparisons presented here.

Table 1 compares the general characteristics of the two survey methods. Assuming a REEF survey average swimming speed of approximately 5 m per minute (unpublished data) and an average dive duration of 50 minutes, the average distance covered in a REEF survey is about 250 m. Therefore the total distance surveyed by REEF between 1999 and 2007 in 1860 surveys is about 470 km. This is approximately 16 times the distance surveyed by PISCO (960 transects x 30 m/transect) for the same period. Note that because the width of a PISCO transect is limited to 2 m, while the width of a REEF survey is limited by visibility (typically farther than 1 m to each side), the ratio of benthic area surveyed is probably greater than distance surveyed.

To quantify extent of covariance between the two data sets, Pearson's correlation coefficient (r) was calculated from year-to-year data pairs for each species. YOY rockfish were identified as a special case. Because the standard deviation of the REEF/PISCO ratio increased in proportion to individuals counted, the seven non-YOY species were combined into an aggregate analysis, comparing logn of PISCO counts against logn of REEF counts. For this aggregate data set, Pearson's r and corresponding p-value were calculated, along with mean REEF/PISCO multiplier and associated standard error and 90% confidence interval.

Young-of-the-year (YOY) trends: In addition to evaluating trends in several fish species, trends in YOY rockfish (*Sebastes* spp.) were also evaluated. While the RDT protocol does not typically differentiate life history stages or size classes, starting in 2000, REEF surveyors began reporting YOY rockfish separately. The REEF protocol defines YOY rockfish as individuals with total length less than or equal to 5 cm. For surveys between 1997 and 1999, zero counts cannot be misconstrued as an absolute absence of YOY rockfish, although anecdotal information and other data sets suggest YOY rockfish populations were quite low.

YOY data sets from two other diver visual surveys are also included: PISCO transect data and 3-minute timed swim count data within a 3 m area from NOAA researcher Tom Laidig (Laidig et al. 2007 for northern California data; Laidig per.comm. for central California data). There are a few differences in the data sets worth noting. PISCO defines YOY as less than 15 cm in total length and Laidig defines YOY as 8 cm and less (compared with <5 cm in the REEF program). For purposes of comparison here, PISCO staff provided the authors with data for YOY rockfish limited to the 5 cm cohort. The time frames of the data sets also varied: Laidig reported data from 1983–2011; PISCO reported data from 1999–2008; REEF reported YOY data 2000–11.

RESULTS

REEF Data Population Trends, 1997 to 2011

During the 15-year period evaluated here (1997–2011), 3,158 REEF surveys were conducted at 85 sites in the study region (figs. 1, 2). A total of 344 volunteers contributed to this data set. A small subset of these volunteers (25) contributed the majority (68%) of the surveys. Approximately one-third of the surveys (1,080) were by Expert-rated surveyors. Survey effort was consistently above 150 surveys per year since 2002, except in 2007 (fig. 2). During the study period, REEF surveyors reported a total of 166 fish species (REEF 2013). Table 2 lists the sighting frequency (%*SF*) and log-density index (*DEN*), for the 35 most common species seen at dive sites around the Monterey Peninsula. The rocky reefs of this study are dominated by several species of rockfish, seaperch, greenlings, midwater planktivores, and several cryptic benthic dwellers.

A positive correlation between YOY rockfish (*Sebastes* spp.) and visibility (a proxy for plankton density) was documented, based on the number of YOY documented compared with the percentage of dives with visibility less than three meters (fig. 3). Both the YOY rockfish and percentage of low visibility dives peaked in 2001, with a lower pulse in 2010.

The pattern in YOY recruitment and subsequent peaks in post-YOY blue rockfish reveals a two year lag (fig. 4), with high YOY peaks in 2001–02 and 2009–10.

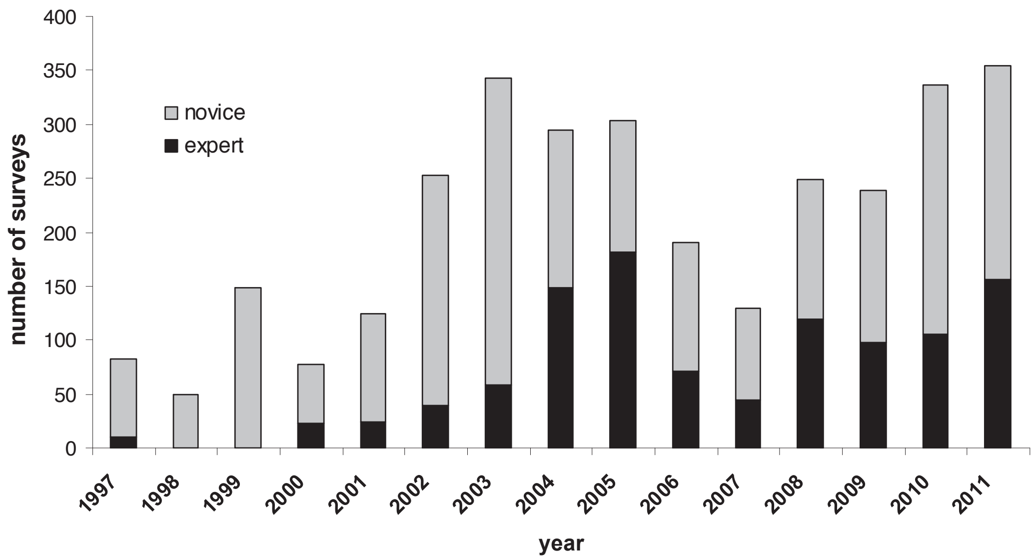


Figure 2. Number of REEF surveys per year in the Monterey Peninsula area ranged from a low of 50 in 1998 to a high of 353 in 2011.

TABLE 2
REEF Survey Data Summary: Most frequently observed fish species in south Monterey Bay and Carmel Bay (REEF geocode 4114–0000), 1997 through 2011. *SF* = Sighting Frequency (percentage of all dives). *DEN* is a log-density index defined as $(S + 2F + 3M + 4A)/(S + F + M + A)$.

Rank	Common Name	Scientific Name	SF%	DEN
1	Blue Rockfish	*Sebastes mystinus*	75.8	2.9
2	Painted Greenling	*Oxylebius pictus*	71.6	2.2
3	Blackeye Goby	*Rhinogobiops nicholsii*	68.2	2.3
4	Kelp Rockfish	*Sebastes atrovirens*	67.9	2.2
5	Kelp Greenling	*Hexagrammos decagrammus*	61.3	1.8
6	Striped Seaperch	*Embiotoca lateralis*	59.5	2.1
7	Pile Perch	*Rhacochilus vacca*	59.5	2.0
8	Black Perch	*Embiotoca jacksoni*	50.3	2.0
9	Gopher Rockfish	*Sebastes carnatus*	50.1	2.0
10	YOY Rockfish	*Sebastes* spp.	44.8	2.9
11	Lingcod	*Ophiodon elongatus*	42.4	1.5
12	Black-And-Yellow Rockfish	*Sebastes chrysomelas*	37.2	1.7
13	Black Rockfish	*Sebastes melanops*	35.7	1.9
14	Senorita	*Oxyjulis californica*	35.4	2.8
15	Olive/Yellowtail Rockfish*	*Sebastes serranoides/flavidus*	34.0	2.0
16	Speckled Sanddab	*Citharicthys stigmaeus*	30.4	2.4
17	Cabezon	*Scorpaenichthys marmoratus*	28.5	1.3
18	Copper Rockfish	*Sebastes caurinus*	28.4	1.7
19	Kelp Perch	*Brachyistius frenatus*	24.3	2.0
20	Rubberlip Seaperch	*Rhacochilus toxotes*	22.0	1.8
21	Snubnose Sculpin	*Orthonopias triacis*	18.3	1.5
22	Tubesnout	*Aulorhynchus flavidus*	17.4	2.5
23	Rainbow Seaperch	*Hypsurus caryi*	16.5	2.1
24	Vermilion Rockfish	*Sebastes miniatus*	14.4	1.4
25	Coralline Sculpin	*Artedius corallinus*	11.0	1.4
26	Treefish	*Sebastes serriceps*	10.7	1.3
27	California Sheephead	*Semicossyphus pulcher*	10.2	1.6
28	Scalyhead Sculpin	*Artedius harringtoni*	9.9	1.6
29	Blacksmith	*Chromis punctipinnis*	9.7	2.2
30	Brown Rockfish	*Sebastes auriculatus*	6.9	1.8
31	Grass Rockfish	*Sebastes rastrelliger*	6.3	1.4
32	China Rockfish	*Sebastes nebulosus*	5.9	1.3
33	Opaleye	*Girella nigricans*	5.5	1.6
34	Kelp Bass	*Paralabrax clathratus*	5.0	1.5
35	Wolf Eel	*Anarrhichthys ocellatus*	4.8	1.1

* Combined into a single category, since many experts believe these two species cannot be distinguished reliably by divers underwater.

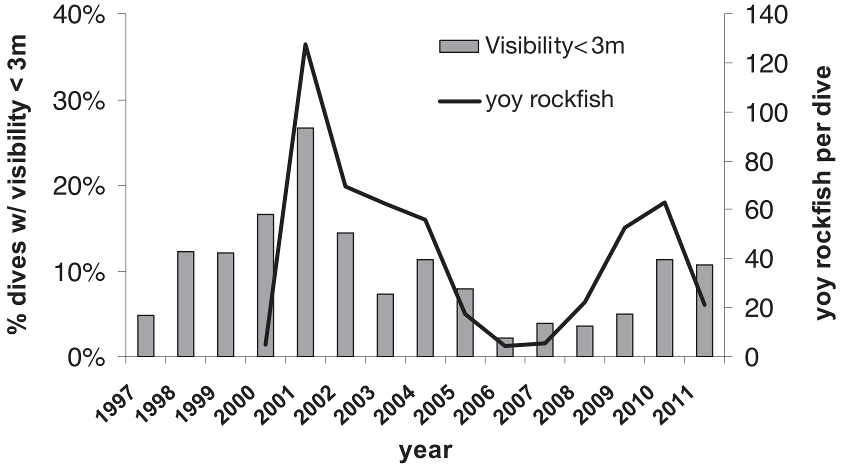


Figure 3. Year-to-year variation in percentage of dives with visibility less than three meters (grey bars) compared to fluctuations in YOY rockfish (*Sebastes* spp.) seen per dive (heavy black line).

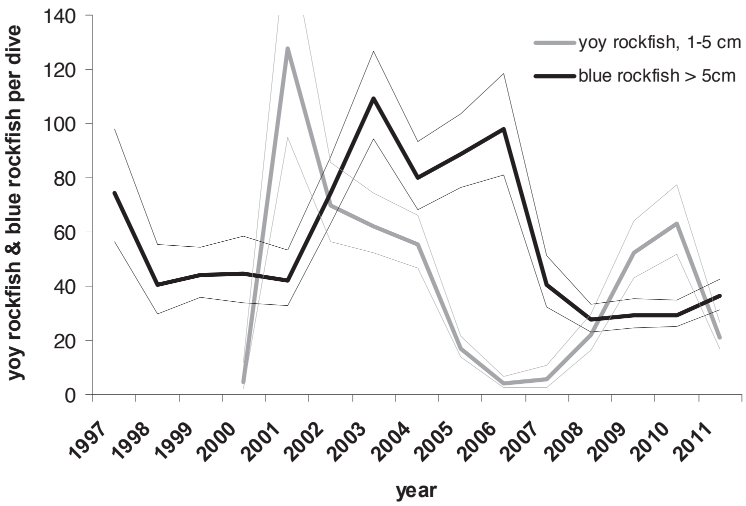


Figure 4. YOY rockfish (*Sebastes* spp., 1–5 cm) and blue rockfish (*Sebastes mystinus* >5 cm) annual average seen per REEF dive for the years 1997 to 2011, normalized for bottom time. The fine lines above and below each thick line indicate the 90% confidence interval (5% high and low tails).

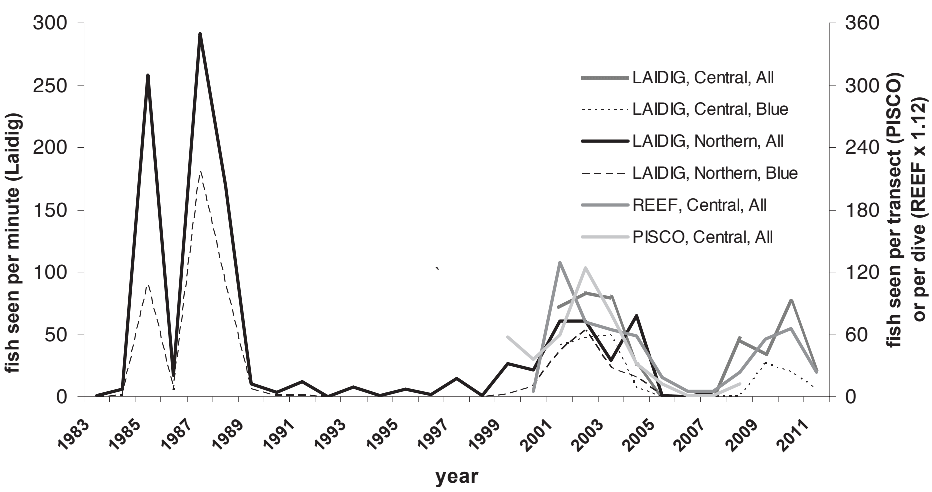


Figure 5. Comparison of Laidig data (Laidig et al. 2007) for blue and total rockfish YOY for northern California (Mendocino County, 1983–2007) and central California (Monterey, 2001–11), PISCO (1999–2008) for all rockfish YOY and REEF (2000–11) for all rockfish YOY. PISCO counts are fish seen per 30 m transect, REEF counts are fish seen per dive, and Laidig counts are fish seen in one minute intervals.

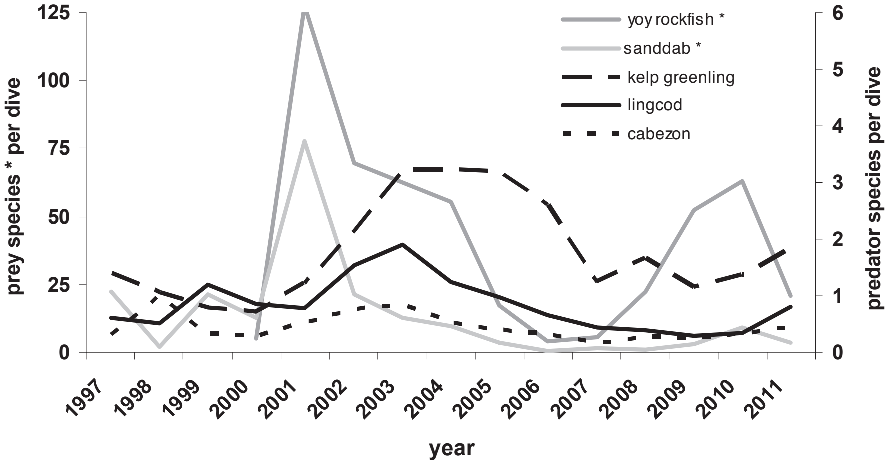


Figure 6. Selected prey and predator fish species annual average seen per REEF dive for the years 1997 to 2011, normalized for bottom time. Prey species (*) are YOY rockfish (*Sebastes* spp.), and speckled sanddab (*Citharicthys stigmaeus*). Predator species are lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), and kelp greenling (*Hexagrammos decagrammus*).

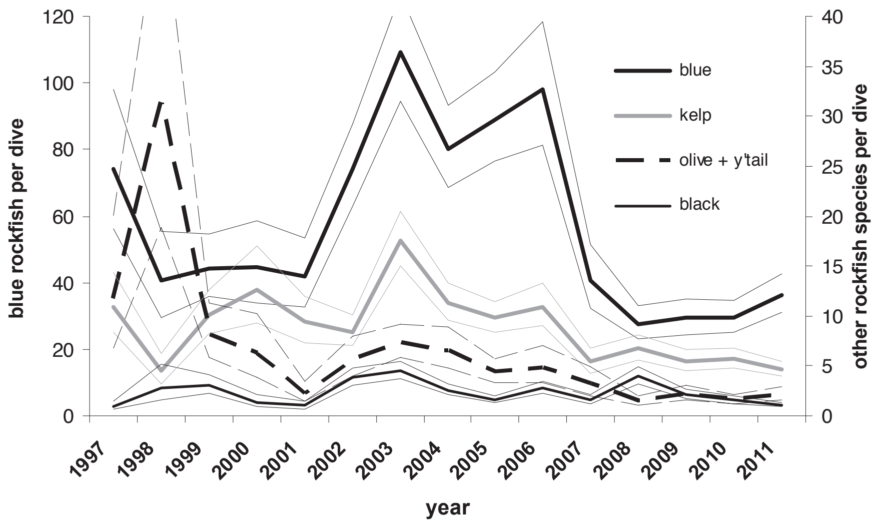


Figure 7. Four species of midwater rockfish annual average seen per REEF dive for the years 1997 to 2011, normalized for bottom time. Midwater rockfish species are blue (*Sebastes mystinus*), black (*S. melanops*), kelp (*S. atrovirens*), and a combined category of olive (*S. serranoides*) and yellowtail rockfish (*S. flavidus*). The fine lines above and below each thick line indicate the 90% confidence interval (5% high and low tails).

While REEF surveyors did not differentiate between rockfish species in YOY counts until 2008, unpublished observations by the authors indicate that blue rockfish were the predominant YOY *Sebastes* observed in the 2001–02 peak years.

Data from three sources (REEF, PISCO, T. Laidig) are combined to further evaluate rockfish recruitment patterns (fig. 5). All three data sets revealed similar patterns in rockfish recruitment. The Pearson correlation coefficients are 0.69 between the REEF and PISCO 2000–08 data, 0.78 between the REEF and Laidig 2001–11 data, and 0.88 between the PISCO and Laidig 2001–08 data. Years of major recruitment of YOY rockfish to near-shore reefs were seen in 1987–88, 2001–02, and 2009–10 (fig. 5). Every subsequent peak is significantly less than its predecessor.

Fluctuations of two prey population cohorts, YOY rockfish and speckled sanddab (*Citharicthys stigmaeus*), are compared to three predator species (fig. 6): kelp greenling, cabezon, and lingcod. The prey species peaked in 2001, while the predator species peaked in 2003 and declined thereafter. In relative terms, the kelp greenling population appears to maintain peak numbers following 2003 longer than either cabezon or lingcod.

Population trends for several groups of species were evaluated, including midwater rockfish, schooling midwater species, seaperch, and warm water species (figs. 7–10). Following the influx of YOY rockfish in 2001

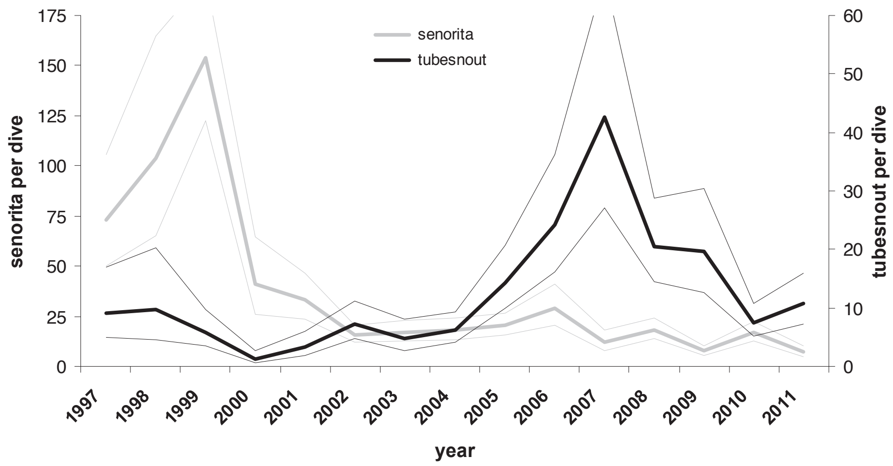


Figure 8. Senorita (*Oxyjulis californica*) and tubesnout (*Aulorhynchus flavidus*) annual average seen per REEF dive over the period 1999 to 2009, normalized for bottom time. The fine lines above and below each thick line indicate the 90% confidence interval (5% high and low tails).

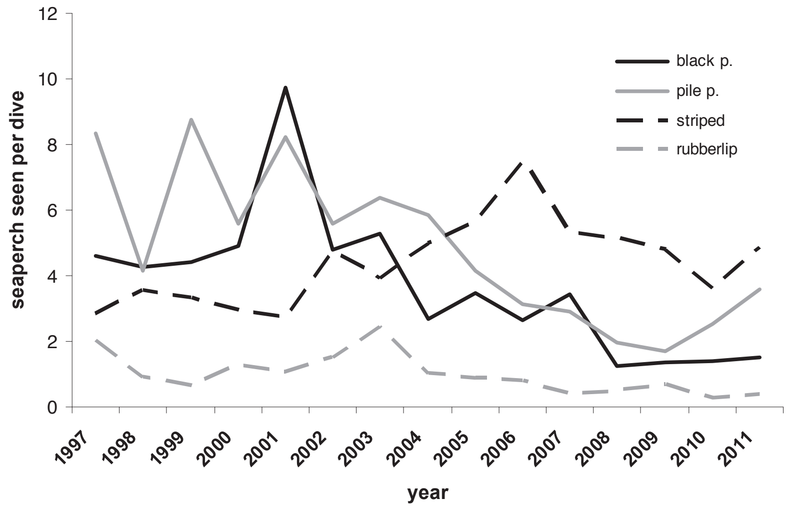


Figure 9. Four species of seaperch population density variation as indicated by annual average fish seen per REEF dive, over the period 1999 to 2009, normalized for bottom time. The seaperch species are: black (*Embiotoca jacksoni*), striped (*E. lateralis*), pile (*Rhacochilus vacca*), and rubberlip (*R. toxotes*).

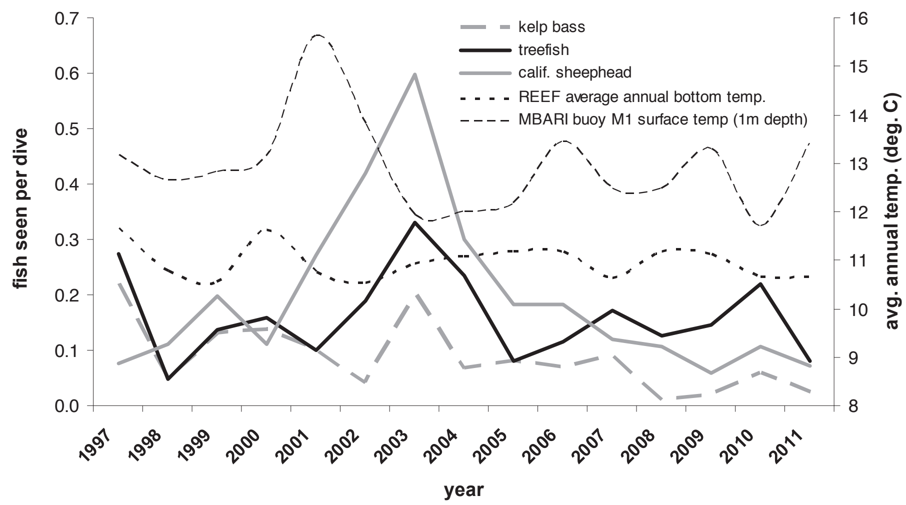
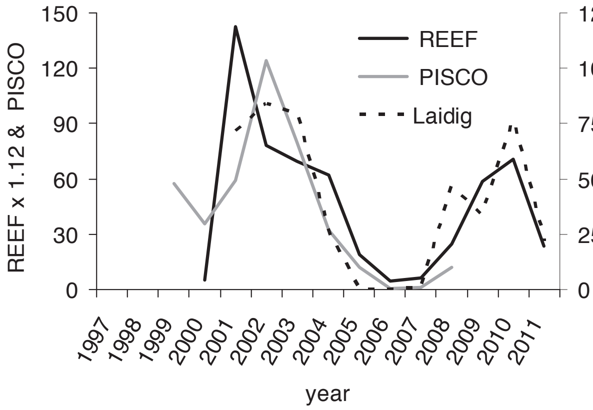
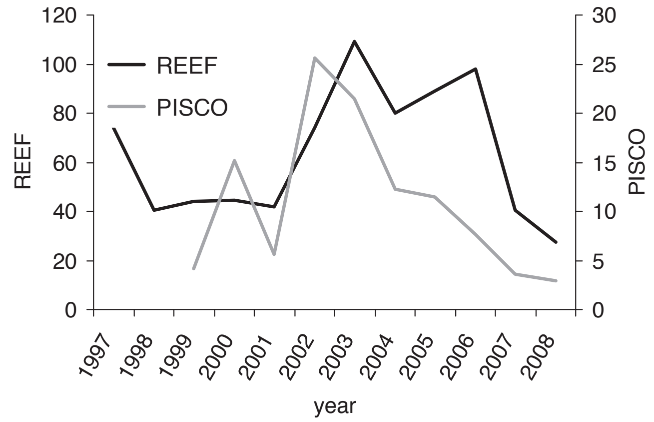


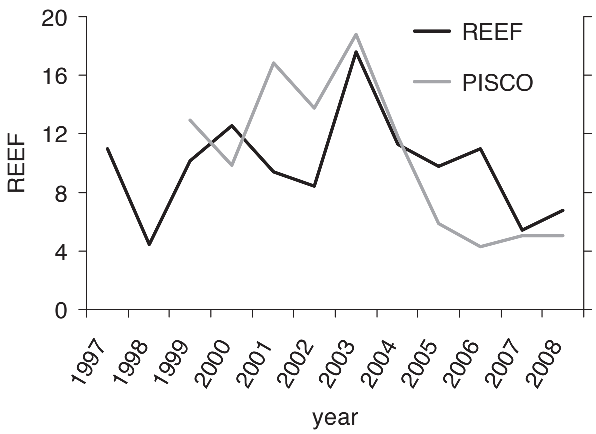
Figure 10. Warm water species annual average fish seen per dive over the period 1999 to 2011, normalized for bottom time. The three warm-water species are: California sheephead (*Semicossyphus pulcher*), kelp bass (*Paralabrax clathratus*), and treefish (*Sebastes serriceps*). Water temperature data from two sources also shown on the second Y-axis: MBARI buoy M1 surface temperature, and REEF divers' computer gauges' average annual bottom temperature.



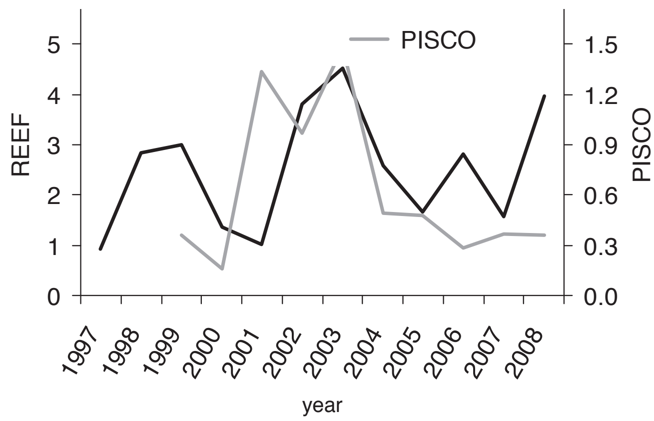
a. YOY Rockfish, *Sebastes* spp., 1-5 cm.



b. Blue Rockfish, *Sebastes mystinus*, >5 cm.



c. Kelp Rockfish, *Sebastes atrovirens*, > 5 cm.



d. Black Rockfish, *Sebastes melanops*, > 5 cm.

Figure 11. Comparison between REEF and PISCO fish counts for several species of rockfish (*Sebastes*). PISCO counts are fish seen per 30 m transect, for the years 1999 to 2008. REEF counts are fish seen per dive, for the years 1997 to 2011, except for young-of-the-year (YOY) rockfish, which cover the years 2000 to 2011. For YOY rockfish, Laidig data (Laidig et al. 2007) are also shown. Laidig counts are fish seen in one minute intervals, for the years 2001 to 2011.

(figs. 4, 5, 6), all midwater rockfish species evaluated, including blue rockfish (*S. mystinus*), black rockfish (*S. melanops*), kelp rockfish (*S. atrovirens*), and olive/yellowtail rockfish (*S. serranoides / S. flavidus*) (grouped because virtually indistinguishable underwater), peaked in 2003, with a secondary peak in 2006 (fig. 7). The two species of small, schooling midwater fishes evaluated, senorita (*Oxyjulis californica*) and tubesnout (*Aulorhynchus flavidus*), exhibited relatively low numbers throughout the study period, punctuated by strong but brief peaks in numbers (fig. 8). Of the four species of seaperch examined, black seaperch (*Rhacochilus jacksoni*) and pile seaperch (*R. vacca*) followed a similar pattern, while rubberlip seaperch (*R. toxotes*) and striped seaperch (*Embiotoca lateralis*) peaked in 2003 and 2006, respectively (fig. 9). The three species of warm water species evaluated, which included California sheephead (*Semicossyphus pulcher*), kelp bass (*Paralabrax clathratus*), and treefish (*Sebastes serriceps*), all followed similar patterns (fig. 10). Two annual average temperature trends are also plotted on Figure 10: bottom temperature as reported by REEF surveyors (based on dive gauges or computers) and 1 m depth temperature at the MBARI mooring M1 in outer Monterey Bay (MBARI 2012).

Comparison of REEF and PISCO data, 1999 to 2008

In order to evaluate the similarity in trends recorded between REEF and another organized monitoring effort conducted with a different methodology (PISCO), trends in several species based on the two data sets were examined. Trends in YOY rockfish are compared; YOY data collected by T. Laidig were also considered (fig. 11a). REEF surveyors measured peak numbers of YOY rockfish in 2001, followed by significant numbers in 2002–04, while PISCO documented a peak in 2002 with significant numbers in adjacent years 2001 and 2003, and Laidig counted high numbers between 2001–03. All three methods also documented a second upswing commencing in 2008 (fig. 11a).

TABLE 3
Comparison of REEF & PISCO Survey Results, 1999–2008

Common Name	Scientific Name	REEF / PISCO Ratio	Pearson Correlation Coefficient, r
YOY Rockfish	*Sebastes* spp.	1.12	0.66
Blue Rockfish	*Sebastes mystinus*	5.55	0.60
Black Rockfish	*Sebastes melanops*	4.65	0.29
Kelp Rockfish	*Sebastes atrovirens*	3.99	0.57
Kelp Greenling	*Hexagrammos decagrammus*	4.75	0.76
Painted Greenling	*Oxylebius pictus*	7.64, 4.79*	0.68, 0.82*
Cabezon	*Scorpaenichthys marmoratus*	4.46	0.62
Senorita	*Oxyjulis californica*	4.20	0.82
AVERAGE	Seven non-YOY species**	4.85***	0.932****

* with painted greenling years 1999-2001 removed
** all data included except YOY rockfish, n = 7 species x 10 years = 70 data pairs
*** 90% confidence interval (5% tails) = 4.85 ×/13%
**** p-value < 0.00001

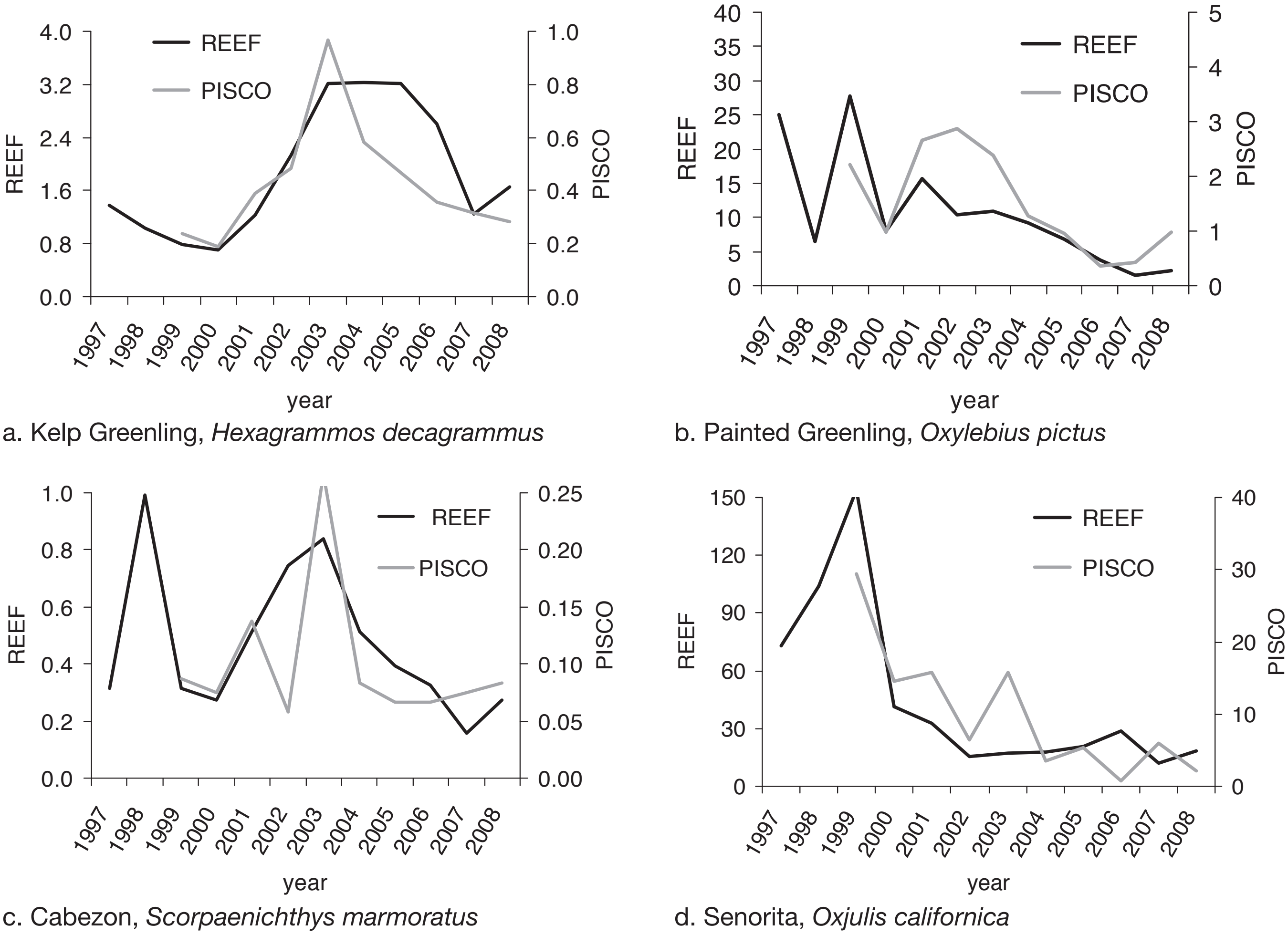


Figure 12. Comparison between REEF and PISCO data for several rocky reef fish species. PISCO counts are fish seen per 30 m transect, for the years 1999 to 2008. REEF counts are fish seen per dive, for the years 1997 to 2011.

Population trends for several other rocky reef fish species, as measured by REEF and PISCO, are compared in Figures 11b–d and 12a–d. Pearson's correlation coefficient (r) of yearly paired data comparisons for these species were calculated (table 3). All species exhibited a strong correlation between the abundance estimates generated from each of the data sets, with r exceeding 0.50 for seven of the eight species in the comparison study, and ranging as high as 0.82 for senorita (table 3). Black rockfish was the exception, with an r of 0.29. For most species, REEF's mean fish seen per RDT survey was four to five times that of a PISCO transect (table 3).

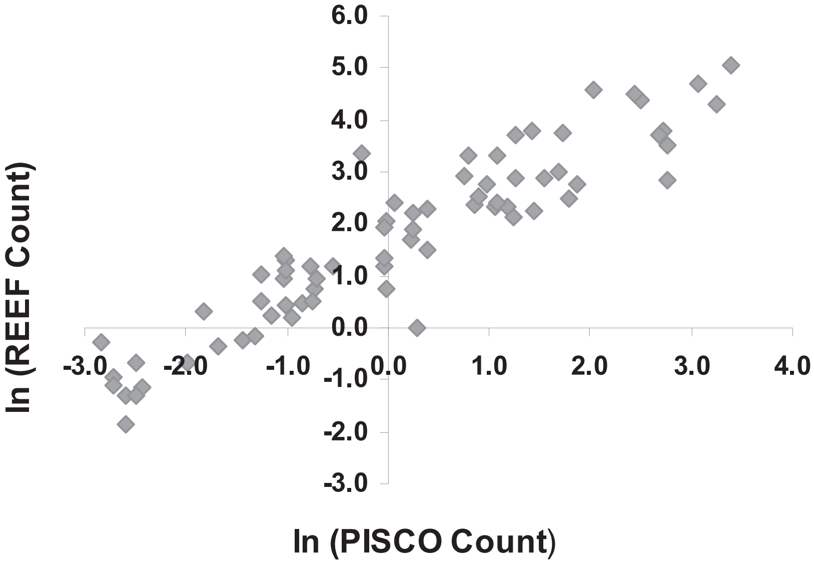


Figure 13. REEF counts versus PISCO counts plotted in log space, for seven species over ten years (n = 70, r = 0.932, p < 0.0001). REEF/PISCO mean multiplier = exp(ln(REEF)-ln(PISCO)) = 4.85 with 90% confidence interval of x/13%.

The exceptions were YOY Rockfish, with a very low multiplier (1.12), and painted greenling (*Oxylebius pictus*), with a high multiplier (7.64).

When data pairs for all seven non-YOY species over ten years were aggregated into a single analysis (n = 70), a very strong correlation was found (r = 0.932, p < 0.00001, fig. 13). The aggregate analysis indicated the REEF/PISCO multiplier is 4.85 with a 90% confidence interval of x/13%

DISCUSSION

The drop in visibility measured by REEF surveyors corresponded closely to the peaks in YOY rockfish documented by REEF data (figs. 2, 3) and others (fig. 5). The REEF YOY rockfish trends closely match those documented by Laidig and PISCO. The YOY peaks in 2001 and 2009–10 also coincide with the pelagic micronekton trawls of larval rockfish reported by Bjorkstedt et al. 2012, as well as the fluorescence (volts) anomaly measured by MBARI 2012 at surface and 60 m depths at mooring M1. These covariant trends substantiate the relationship between ocean conditions, plankton density, and rockfish recruitment widely reported in the literature (e.g., Carr and Syms 2006)

The data also suggest that the same blue rockfish cohort is being tracked as it ages from YOY to subadult to adult (fig. 4). This is evident in spikes of YOY rockfish (*Sebastes* spp., predominantly *S. mystinus*) followed two years later by peaks in subadult (>5 cm) and adult blue rockfish populations. It is also possible that the blue rockfish trend is caused by strong in- and out- migration to and from the nearshore reefs. However, radio-acoustic tracking (Jorgensen et al. 2006) demonstrate that these midwater schooling fish have surprisingly small home reef ranges, at least for the monthlong duration of that study, providing support for the idea that the REEF data reflect local, nonmigrating blue rockfish populations as they age. Trends for other rockfish species, peaking in 2003 after the 2001 YOY recruitment pulse, also suggest YOY to post-YOY aging (fig. 7).

Correlations between the REEF, PISCO, and T. Ladig data sets for all YOY rockfish species in central California (Monterey Peninsula) are very strong (fig. 5), suggesting all methods are successfully measuring the same underlying YOY rockfish populations.

Three peaks in YOY rockfish recruitment to inshore reefs over the last three decades were documented, with each peak smaller than the previous one (fig. 5). The successively smaller peaks may suggest a long-term downward trend in nearshore rockfish populations off northern and central California, or alternatively, that ocean conditions may be increasingly less favorable to larval rockfish survival and recruitment to nearshore reefs, or some combination thereof. Preliminary unpublished 2013 data (T. Laidig, per. comm. re ichthyoplankton trawls; REEF May 2013 Monterey field survey) indicates that the 2013 YOY rockfish recruitment may be very large, potentially reversing this apparent downward trend.

Population fluctuations for two prey species and three predator species are superimposed in Figure 6 to explore the hypothesis of whether a classic predator-prey cycle (Krebs et al. 2001; Estes et al. 2004) is being observed. Such a hypothesis is best vetted by a comprehensive population dynamics model that includes such considerations as the effect of changes in fishing regulations and pressures on predator mortality, relative contribution of different prey species to predator diet and influence of prey abundance on predator fitness, reproductive success, and reduced disease and mortality. Nevertheless, we briefly discuss potential causes for the patterns seen to encourage future population modeling efforts.

Population peaks seen in 2001 for YOY rockfish and speckled sanddab in the REEF data (fig. 6) closely matches micronekton trawls in outer Monterey Bay (Bjorkstedt et al. 2012). Rockfish larvae in the micronekton exhibit strong covariance with larval sanddab (*Citharicthys* spp.), Pacific hake (*Merluccius productus*), krill (euphausiids), and market squid (cephalopods), collectively known as the "groundfish assemblage." After a recruitment pulse, both YOY rockfish and speckled sanddab declined rapidly. YOY rockfish grow out of the REEF/RDT imposed 5 cm max YOY cohort in a year or less, aging into species-specific rockfish count categories that encompass both subadults and adults. After initial recruitment to the reef, YOY rockfish numbers rapidly decrease from the combined effects of predation and maturation into subadults. The secondary plateau in 2003 and 2004 is therefore due to additional recruitment. Due to the short life-span of speckled sanddab (3.5 years; Love 1996), their net decrease is likely due to predation in excess of post-2001 recruitment.

The recruitment pulse seen for YOY rockfish and speckled sanddab may also be indicators of an influx of other vertebrate and invertebrate prey. After the influx of prey species in 2001, kelp greenling, cabezon, and lingcod populations appeared to respond, rising to a peak in 2003 and declining thereafter. Lingcod are largely piscivorous, while kelp greenling and cabezon diets contain a larger fraction of invertebrates as well as small fish, including YOY rockfish (Love 2011). Hobson 2000 documented shifts in kelp greenling diets to YOY rockfish in heavy recruitment years. The observed population increases for both kelp greenling and cabezon may be due to a combination of YOY rockfish abundance and the concurrent abundance of other small fish (e.g., speckled sanddab) and invertebrates that recruited at the same time, fostered by the same oceanic conditions.

REEF surveyors record predator species at any size large enough to positively identify. If abundant prey increased either juvenile or adult predator survival rates and reproductive success (e.g., in the form of larger egg masses and decreased relative predation pressure on juvenile predators due to the abundance of alternative prey species), REEF data would document a relatively short term (one to three year) predator population response of smaller individuals. This response, consisting of small young individuals, is different from the much longer time needed to detect the presence of older reproductive females ("big mothers") associated with long-term improvements in fecundity and population resilience.

It is not immediately clear whether the increase and subsequent decline of the predator populations shown in Figure 6 reflects only local fertility and mortality rates. The trend may also include opportunistic immigration inshore from 2001 to 2003 when prey were plentiful, and then subsequent emigration to deeper waters as inshore reefs became less productive compared to deeper offshore waters. It is also important to note that changes to both commercial and recreational fishing regulations immediately prior to and during the period of this study may have had a significant effect on predator population mortality.

The sharp decline in senorita followed by an exponential increase in tubesnout populations (fig. 8) suggests that these schooling midwater species may flourish under different oceanic and ecological conditions. Senorita are a more southern species, so the peak in 1999 may follow a large recruitment during the strong El Niño of 1998 (Durazo et al. 2001). Tubesnout have northern affinities associated with La Niña and cooler conditions, with a population spike in 2007 corresponding to low MEI (multivariate ENSO index) values recorded in 2007 and 2008 (Bjorkstedt et al. 2012).

Seaperch population fluctuations appear to be largely unrelated to rockfish populations (fig. 9). This is not surprising given such dissimilar ecological niches occupied by rockfish and seaperch. The data were not normalized for boat versus shore dives or Monterey Bay versus Carmel Bay. Such variation has been shown to have little effect on YOY and blue rockfish and kelp greenling results (Wolfe and Pattengill-Semmens 2013), but the seaperch species may be more sensitive to dive site and associated habitat variation. Further analysis of the seaperch data, normalizing the data for dive site year-to-year variation, may be warranted.

Peaks in warm water species more prevalent along the southern California coast appear to lag one to two years after water temperature peaks, perhaps reflecting recruitment timing (fig. 10). The population peaks also coincide with dips in water temperature, a somewhat counter-intuitive result unless one considers previous warmer years. Treefish and kelp bass population peaks in 2003 and 2010 follow not only temperature peaks, but perhaps more importantly, the YOY rockfish influxes in 2001 and 2009, suggesting synchronous recruitment or a predator population response.

REEF and PISCO comparison

Because REEF divers are encouraged to explore an entire reef, not limited by transect length and width, REEF's RDT survey method has proven superior to traditional transect methods in documenting the full fish species biodiversity of a reef (Pattengill-Semmens and Semmens 1998; Schmitt et al. 2002; Holt et al. 2013). While a better sense of species biodiversity is gained, individual counts of each species during RDT surveys are not as precise as traditional transect surveys such as PISCO. However, what is lost in precision on a single dive can be regained through a large number of dives in the same area.

The similarity of trends between the two data sets suggests that both methods are successfully measuring the same underlying fish population and detecting the same trends. Of the eight species studied for the comparison, black rockfish had the weakest Pearson correlation coefficient. This weaker correlation is likely due to the broad confidence intervals of the estimated abundance for this species in both data sets; black rockfish is a less common rockfish species with significant patchiness and wide spatial variation. An aggregate analysis comparing PISCO-REEF data pairs for seven non-YOY species over ten years shows a very strong correlation (fig. 13), even when the outlier cases of black rockfish and the first three years of painted greenling REEF counts are included.

PISCO transects consistently cover a benthic area of 60 square meters, and therefore, PISCO data can be used to calibrate REEF data to convert it to density. For most species, REEF survey counts are about 4.9 times larger than PISCO counts (table 3), suggesting that fish density (individuals/ m^2) can be approximated from REEF counts by dividing by 300 m^2 (4.9 x 60 m^2). Given that an average REEF diver may cover a distance of 250 m, with an average survey width of at least two meters, it appears that REEF surveyors do not scour the bottom as thoroughly as PISCO surveyors—an expected outcome given the nature of the roving, non-point aspects of the RDT compared to transect surveys.

Multipliers significantly lower than 4.9 suggest that REEF surveyors are undercounting in relation to PISCO compared to typical species (table 3). YOY rockfish have a very low multiplier (1.12). REEF's undercount of YOY rockfish compared to PISCO is probably due to two factors: (1) REEF surveys occur year-round, with peak survey months in May and July, while PISCO surveys are conducted from mid-August to late October when rockfish YOY are most prevalent, and (2) omissions by novice REEF surveyors who cannot yet positively identify (and therefore count) these small fish as YOY rockfish.

Because most fish species populations change incrementally from one year to the next, smoother density curves measured over time suggest more accuracy and less statistical noise. PISCO's year-to-year population fluctuations for painted greenling, a small cryptic bottom dwelling fish, appear smoother than REEF data. On the other hand, population trends based on REEF data for kelp greenling, cabezon, and senorita all follow smoother sigmoidal curves than that documented by the PISCO data set, which appear more stochastic or jagged, suggesting more statistical noise around an underlying smooth trend. These findings suggest that PISCO may more effectively survey small cryptic bottom species, while REEF may more effectively survey larger species, including those targeted by fisheries.

Using the quantitative estimate methods described here and in Wolfe and Pattengill-Semmens 2013, the REEF database can be used to explore many additional questions, such as: (1) Are there key differences in fish species assemblages at smaller spatial scales, such as between Monterey Bay and Carmel Bays? And (2) Can statistically significant differences over time be detected between reefs within and outside of recently established Marine Protected Areas?

Conclusion: The REEF database of fish surveys conducted by volunteer recreational divers provides a rich source of information about population trends in the Monterey Peninsula area. As this study shows, the REEF Survey Program has proven to be a viable and worthwhile long-term volunteer effort by recreational divers, supported by a small professional staff and collected at no cost to the scientists and resource agencies that have access to these data. The findings in this paper demonstrate the value of continuing to train recreational divers in REEF survey techniques in California in order to generate a consistently large number of surveys over future years. Volunteer citizen science data collected by REEF has great potential to augment, strengthen, and broaden academic and professional research data. With its fifteen-year baseline, the REEF database should prove useful in comparing fish populations inside and outside the Marine Protected Areas recently established in California as part of the California Marine Life Protection Act. Furthermore, the strong concordance between REEF and PISCO data sets for a wide range of species reveals their complementary nature and provides support for use of both data sets when seeking to evaluate trends in nearshore fish species in California.

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