

Abstract—We estimated annual abundance of juvenile blue (*Sebastes mystinus*), yellowtail (*S. flavidus*), and black (*S. melanops*) rockfish off northern California over 21 years and evaluated the relationship of abundance to oceanographic variables (sea level anomaly, nearshore temperature, and offshore Ekman transport). Although mean annual abundance was highly variable (0.01–181 fish/minute), trends were similar for the three species. Sea level anomaly and nearshore temperature had the strongest relationship with interannual variation in rockfish abundance, and offshore Ekman transport did not correlate with abundance. Oceanographic events occurring in February and March (i.e., during the larval stage) had the strongest relationship with juvenile abundance, which indicates that year-class strength is determined during the larval stage. Also of note, the annual abundance of juvenile yellowtail rockfish was positively correlated with year-class strength of adult yellowtail rockfish; this finding would indicate the importance of studying juvenile abundance surveys for management purposes.

Relationship between abundance of juvenile rockfishes (*Sebastes* spp.) and environmental variables documented off northern California and potential mechanisms for the covariation

Thomas E. Laidig (contact author)

James R. Chess

Daniel F. Howard

Email address for T. E. Laidig: tom.laidig@noaa.gov

National Marine Fisheries Service
Southwest Fisheries Science Center
Fisheries Ecology Division
110 Shaffer Road
Santa Cruz, California 95060

Success of annual recruitment of juvenile rockfishes (*Sebastes* spp.) from the pelagic to a demersal phase is highly variable and leads to large fluctuations in year-class strength in the fisheries (Ralston and Howard, 1995). With the abundance of many rockfish stocks at historic low levels, assessment of recruitment is paramount for fishery managers to improve plans for sustainable harvests. Fisheries models (such as the stock synthesis model) often include recruitment data (PFMC¹). In recent years, larval and juvenile rockfish abundance data have been included in stock assessments for bocaccio (*S. paucispinis*) and cowcod (*S. levis*) (MacCall², Butler et al., 2003). If the larval or juvenile abundance data do not accurately reflect the numbers of adults, the models can either over- or underestimate the biomass available to the fishery.

Rockfishes are viviparous, giving birth to larvae that reside in open water for several months before recruiting from the plankton to a more benthic life (Love et al., 2002). The habitat where rockfish initially recruit varies among species and includes floating drift algae (e.g., splitnose rockfish, *S. diploproa* [Shaffer et al., 1995]), soft sediments (e.g., stripetail rockfish, *S. saxicola* [Johnson et al., 2001]), and deeper rocky areas with crevices (e.g., rosy rockfish, *S. rosaceus* [Love et al., 2002]). A major area of recruitment is the nearshore

environment, where numerous species of rockfish recruit in the kelp canopy, sand channels, on rocky outcrops, and in midwater among the kelp stipes (Anderson, 1983).

The factors that influence the magnitude of juvenile recruitment of rockfishes are not well known. VenTresca et al.³ suggested that upwelling was the major factor contributing to the annual variability of juvenile rockfish abundance off Monterey, California. Ralston and Howard (1995) found that the highest survival of blue (*S. mystinus*), and yellowtail rockfish (*S. flavidus*), occurred when sea surface temperature and upwelling were at intermediate levels. Ainley et al.

¹ PFMC (Pacific Fisheries Management Council). 2002. Status of the Pacific Coast groundfish fishery through 2001 and acceptable biological catch for 2002, 26 p. PFMC, 7700 NE Ambassador Place, Suite 200, Portland, Oregon 97220.

² MacCall, A. D. 2002. Status of bocaccio off California in 2002. In Appendix to the status of the Pacific coast groundfish fishery through 2001 and acceptable biological catches for 2002, 58 p. Pacific Fisheries Management Council, 7700 NE Ambassador Place, Suite 200, Portland, Oregon 97220.

³ VenTresca, D. A., J. L. Houk, M. J. Padack, M. L. Gingras, N. L. Crane, and S. D. Short. 1996. Early life-history studies of nearshore rockfishes and lingcod off central California, 1987–92. Cal. Fish Game. Resources Division. Admin. Rep. 96-4, 77 p.

(1993), using seabird diet to assess the abundance of juvenile rockfishes, also reported the greatest abundance of rockfishes in years of intermediate upwelling. Yoklavich et al. (1996) and Johnson et al. (2001) observed that, during years when upwelling was delayed, those rockfishes released later in the year had increased survivorship. In addition, Pastén et al. (2003) observed that monthly tidal cycles were important in estimating the numbers of newly recruited black rockfish (*S. inermis*) in the western Pacific.

In our study, we examined the relationship between the annual abundance of juvenile rockfishes recruiting to the nearshore kelp beds off northern California and three oceanographic variables (sea level anomaly, nearshore temperature, and offshore Ekman transport) over 21 years. Three species of juvenile rockfishes (blue, yellowtail, and black rockfish, [*S. melanops*]) were surveyed. Parturition (the release of larvae from the mother) in these species occurs in the winter and the resulting pelagic larvae and juveniles spend between three to five months in the offshore midwater environment (Love et al., 2002). All juveniles of these species migrate in mid to late spring and early summer from the offshore pelagic environment to nearshore midwater and benthic environments on or next to rocky outcrops, commonly with dense algal growth; this movement we define here as juvenile recruitment (Anderson, 1983).

Materials and methods

Surveys of young-of-the-year (YOY) rockfishes were conducted annually between 1 July and 15 September from 1983 to 2003 within two kelp beds along the northern California coast (Dark Gulch [39°14'N; 123°46'W] and Salmon Point [39°12'N; 123°46'W]) in Mendocino County (Fig. 1). Each kelp bed included high-relief bedrock interspersed with low-relief cobble and sand areas. They were bounded by shoreline on two sides, a sand channel on one side, and deep water on the remaining side, and thus each kelp bed was isolated.

Strip transects were conducted by using SCUBA. Researchers swam in one direction 2 m above the sea floor and counted all juvenile rockfishes within 3 m in any direction for one minute. At the end of each one-minute survey, the numbers of each species were recorded. The researcher would then haphazardly choose another direction to swim and conduct rockfish counts for another minute. Surveys were made throughout the kelp bed at both sites from the surface to 20 m. YOY rockfishes were distinguished from older conspecifics by their size (less than 80 mm standard length in August) and from other rockfish species by body shape and pigment patterns (Anderson, 1983; Love et al., 2002).

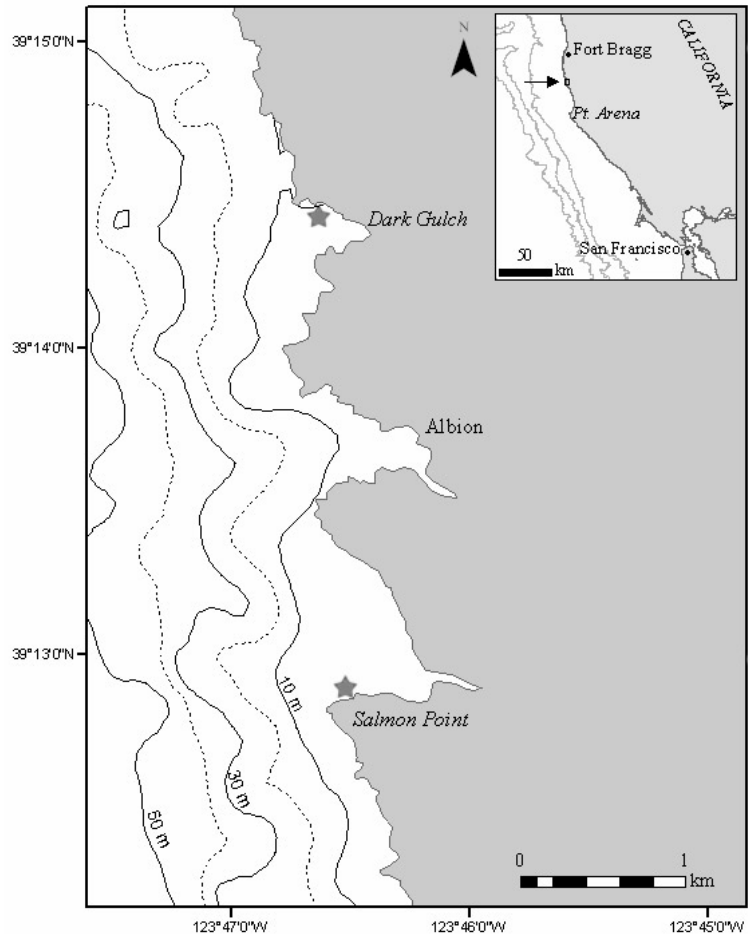


Figure 1

The survey sites in Mendocino County, California. Dark Gulch and Salmon Point kelp beds are represented by the stars.

Surveys were conducted only when appropriate conditions occurred. First, surveys were conducted between the hours of 0900 and 1700 to standardize light conditions. Second, surveys were made only when underwater visibility was greater than 4 m. Underwater visibility was measured by Secchi disk, transect line, and by estimating the distance at which objects (i.e., fishes and rocks) could be seen. Third, swell height had to be less than 2 m for diver safety and to standardize sea conditions.

An index of annual abundance (index) for each species of juvenile rockfish was computed by pooling all one-minute surveys for a year at each study site, and dividing by the total number of one-minute surveys for that year. We used a paired t-test to compare species-specific indices between the two study sites. Data were log-transformed to equalize the variance among years. We used cross-correlation analysis to examine patterns in the index among species. For no time series (either biological or environmental) was there a significant autocorrelation present. Therefore, our observations complied with the assumption of independence.

We related three oceanographic data sets (sea level anomaly, nearshore temperature, and offshore Ekman transport) to abundance data. Sea level anomaly data were collected from a shore station (with an acoustic gauge measuring in mm) at Arena Cove, CA (38°54'N), and monthly means were obtained from the University of Hawaii Sea Level Center. These data represent a measure of change in sea level height over time and were adjusted for local atmospheric conditions. Sea level anomalies reflect water movement—a positive anomaly being associated with poleward flow and a negative anomaly associated with equatorward flow. Nearshore temperature data were continuously collected at the Dark Gulch site throughout the study. Temperature monitors were located in two areas of the kelp bed, one at 8 m and the other at 15 m water depth. Temperature was recorded hourly and these data were averaged daily, monthly, and seasonally. The offshore Ekman transport data were determined from data gathered by a buoy 20 km offshore of 39°N (Albion, CA). Monthly mean offshore Ekman transport was derived from geostrophic wind stress data determined from atmospheric pressure values at mean sea level (at 6-hour intervals) and obtained from Environmental Research Division, Southwest Fisheries Science Center (NOAA⁴). Offshore Ekman transport was used as a measure of cross-shelf water transport. The offshore flow of surface water causes deep, cold, nutrient-rich water to be brought to the surface to replace the displaced surface waters (the process of upwelling). Monthly and seasonal values were determined for all oceanographic data sets and years, and the seasonal values represented the mean from January to June. The months of July to December were not considered in our analysis because this time period was after the time of juvenile rockfish recruitment to the kelp bed.

The comparison of the abundance index for each species and the oceanographic variables involved numerous statistical tests. Cross-correlation coefficients were computed in pairwise comparisons of the index and the oceanographic data. For each year in the time series, we used both seasonal and monthly means of the oceanographic variables and the annual log-transformed index. We also applied principal components analysis (PCA) to evaluate the relationships among monthly oceanographic variables, and also the relationships among the log-transformed index of the three species. We used canonical correlation analysis (CCA) to explicitly examine the correlations between these oceanographic and rockfish PCAs. PCA develops an ordination space constrained to be a linear combination of the variables (i.e., the eigenvectors). CCA does the same, except the ordination space is constrained to be a linear combination of the other set of variables. The fish data, there-

fore, are displayed in a space defined by a combination of the oceanographic data (the canonical scores).

Year-specific catch-at-age data for adult yellowtail rockfish were compared with the juvenile yellowtail rockfish abundance index to evaluate the relationship between juvenile rockfish abundance and subsequent landings of adults in the fishery. No age data were available for the adult blue or black rockfishes. Age and catch data of adult yellowtail rockfish commercially caught in trawls from 1997 to 1999 were retrieved from the CALCOM database⁵ for the three closest ports to our study sites (Bodega Bay, Fort Bragg, and Eureka, CA). We used expanded age compositions by year class, which were determined from a subset of aged fish for that region. For example, in 1997 there were 10 year-classes in a subset of fish that were aged from Bodega Bay, whereas only six year classes existed in the subset of aged fish for 1998 from Bodega Bay. Year-specific catch-at-age data were determined for each year and port and regressed against the log-transformed index. Significance levels were determined for each port-year combination and for all ports combined.

Results

Over 21 years, 172 dives and 3333 one-minute surveys were completed, averaging 8.2 dives/year and 158.7 one-minute surveys/year (Table 1). The average number of one-minute surveys per dive was 19.4 surveys/dive (calculated by dividing the total number of one-minute surveys by the total number of dives). Total number of dives per year varied from 4 in 1993 to 14 in 1983, and the number of one-minute surveys varied from 80 in 1993 to 330 in 1983. The total number of dives at Dark Gulch was 113, whereas only 59 dives were conducted at Salmon Point. Similarly, nearly twice as many one-minute surveys were completed at Dark Gulch (2165) compared to Salmon Point (1168). This difference was mainly due to sea conditions; Salmon Point sometimes experiences larger ocean swells (because it is less protected), making sampling unsafe.

The abundance index for each species varied among years but was not significantly different (*t*-test; *n*=21; *P*>0.05) between the two study sites. For this reason, the data from both sites were pooled. The index was highly variable for all species (Fig. 2). For blue rockfish, the index varied from 181 fish/min in 1987 to 0.26 fish/min in 1992. For yellowtail rockfish, the index ranged from 162 fish/min in 1985 to 0.03 fish/min in 1994. Abundance of black rockfish peaked in 1999 at 22 fish/min and was lowest in 1998 at 0.01 fish/min.

⁴ NOAA (National Oceanic and Atmospheric Administration). Environmental Research Division. Southwest Fisheries Science Center. NOAA/NMFS/SWFSC, 1352 Lighthouse Ave., Pacific Grove, CA 93950-2097. Website: <http://www.pfeg.noaa.gov> (accessed 15 March 2006).

⁵ CALCOM (California Cooperative Survey). Commercial landings sampling program maintained by California Department of Fish and Game, 350 Harbor Blvd., Belmont, CA 94002; Pacific States Marine Fisheries Commission, 350 Harbor Blvd., Belmont, CA 94002; and Fisheries Ecology Division, SWFSC, NMFS, NOAA, 110 Shaffer Rd., Santa Cruz, CA 95060. Website: 128.114.3.187 (accessed on 15 March 2006).

Table 1

Number of dives and total number of one-minute surveys of juvenile rockfishes by year at each dive site. Data were collected between 1 July and 15 September, 1983–2003.

Year	Number of dives			Number of 1-minute surveys		
	Dark Gulch	Salmon Point	Total	Dark Gulch	Salmon Point	Total
1983	12	2	14	270	60	330
1984	8	3	11	185	99	284
1985	8	4	12	94	35	129
1986	9	2	11	124	30	154
1987	9	3	12	94	18	112
1988	4	3	7	62	38	100
1989	5	3	8	119	68	187
1990	4	2	6	71	33	104
1991	3	3	6	60	60	120
1992	3	3	6	60	60	120
1993	2	2	4	40	40	80
1994	3	3	6	60	60	120
1995	4	3	7	80	40	120
1996	4	1	5	88	22	110
1997	5	3	8	124	71	195
1998	7	2	9	188	40	228
1999	6	5	11	133	89	222
2000	4	3	7	82	84	166
2001	3	3	6	62	63	125
2002	4	4	8	85	87	172
2003	6	2	8	84	41	125
Total	113	59	172	2165	1168	3333
Average	5.4	2.8	dives/year 8.2	103.1	55.6	surveys/year 158.7
Standard deviation	2.6	0.9	2.7	54.7	22.8	63.9

Year-to-year variability was generally synchronous among the three species (Fig. 2). Abundance was below average for the three species in 1983–84, and 1989–98. Above average abundance in all three species occurred in 1985, 1987, 1988, and in 2001. Black rockfish attained relatively greater numbers in 1986, 1999, 2000, and 2003 compared to the other two species. In addition, blue rockfish experienced higher than average abundances in 2001 and 2002 compared to the other species. Generally, the index for black rockfish was lower than for the other two species, but black rockfish abundance was extremely high in 1999, but the abundance of the other two species was below average. Indices for blue and yellowtail rockfish were significantly correlated ($P < 0.001$, $r = 0.91$), and the index for black rockfish was not significantly correlated with either of the other two species. Using the log-transformed index, we found that blue, yellowtail, and black rockfish were all significantly correlated ($P < 0.01$, $r = 0.76$) with each other. We used the log-transformed index for the remaining analyses.

In evaluating seasonal oceanographic variables, sea level anomaly and nearshore temperature were sig-

nificantly and positively correlated ($P < 0.05$, $r = 0.53$), nearshore temperature and offshore Ekman transport were significantly and negatively correlated ($P < 0.05$, $r = -0.69$), and sea level anomaly and offshore Ekman transport were not significantly correlated. There was no significant correlation between the seasonal oceanographic variables and the index for any species.

With PCA, 65% of the variability in the monthly oceanographic ($_O$) data sets was explained by the first eigenvector ($PC1_O$). $PC1_O$ was characterized by the contrast between Ekman transport and the other two variables (Table 2). The second eigenvector ($PC2_O$) explained 30% of the variability and was associated with high sea level anomaly. For the rockfish abundance ($_F$) indices, 77% of the variability was explained in the first eigenvector ($PC1_F$), which was associated with the abundance time series of all three species. The second eigenvector ($PC2_F$) explained 15% of the variability and was associated with the contrast between blue rockfish abundance and the other two species, especially late in the time series. Although $PC3_F$ explained only 8% of the variability in these time series, it was associated

Table 2

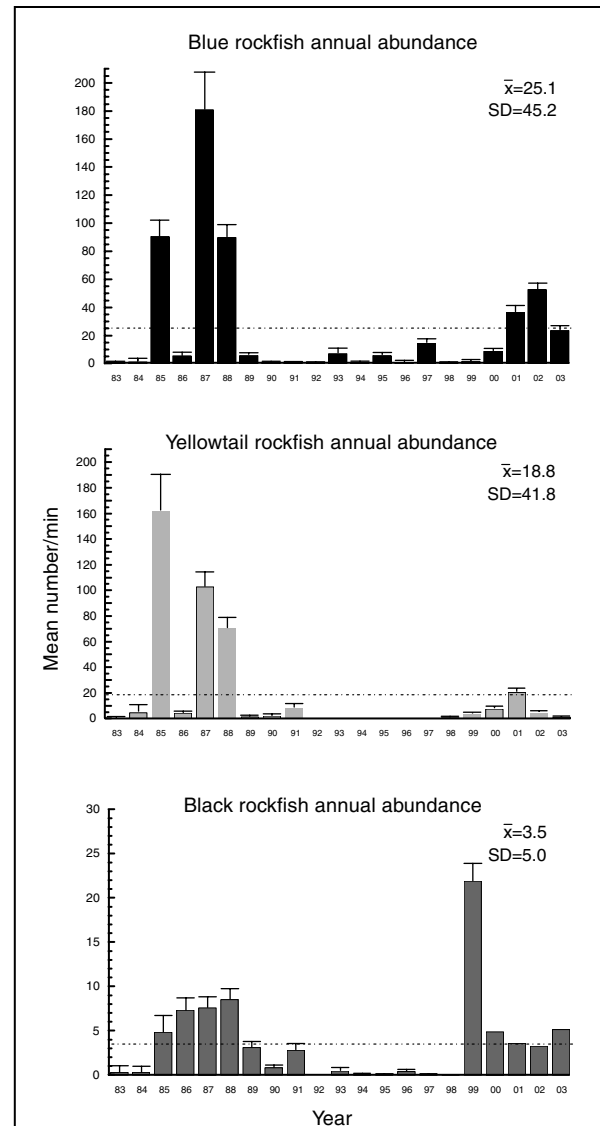
Eigenvectors determined from the principal components analysis (PCA) for the monthly oceanographic variables (_O) and log-transformed annual juvenile rockfish abundance (_F) index by species

	PC1 _O	PC2 _O	PC3 _O
% variance explained	64.5	29.5	6.0
Nearshore temperature	0.68	-0.04	0.73
Sea level anomaly	0.46	0.80	-0.39
Ekman transport	-0.57	0.40	0.56
	PC1 _F	PC2 _F	PC3 _F
% variance explained	77.1	14.6	8.3
Blue rockfish	0.55	0.83	0.13
Yellowtail rockfish	0.60	-0.28	-0.75
Black rockfish	0.58	-0.49	0.64

with the unique pattern in abundance of black rockfish, especially in contrast to yellowtail rockfish.

Correlations varied between the log-transformed abundance indices and the monthly means of the oceanographic variables (Table 3). All three species were significantly and negatively correlated with sea level anomaly during some of the months from January to June. For nearshore monthly temperature, there was a similar pattern of negative correlation with index for all species during January to June. Only blue rockfish were significantly correlated ($P < 0.001$, $r = 0.58$) with offshore Ekman Transport, and only in February (Table 3). Months of high nearshore temperature or sea level anomaly resulted in low juvenile rockfish abundances. For example, when the abundance index for blue rockfish was compared with sea level anomaly in February (Fig. 3), years of highest abundance of blue rockfish were always years of low sea level anomaly (i.e., 1985, 1987, 1988, 2001, and 2002), but years of low sea level anomaly did not always lead to particularly high rockfish abundance (i.e., 1989). However, years of highest sea level anomaly (e.g., 1983, 1992, and 1998) resulted in the lowest blue rockfish abundance.

The results of the CCA also indicate that low annual abundance was associated with years of high nearshore temperatures and high sea level anomaly. The first canonical correlation was 0.57, which was significantly different from zero ($P < 0.0001$), and explained 97 % of the covariance between the two data sets. The remaining two canonical correlations were not significant and explained little of the variability. Blue, yellowtail, and black rockfish were negatively correlated with the first canonical variable for the oceanographic data set (-0.43, -0.45, and -0.55, respectively; Fig. 4). This indicates that fish abundances were low when temperatures and sea level anomalies were high.

**Figure 2**

Mean annual juvenile rockfish abundance index for all one-minute surveys in two kelp beds for blue (*Sebastes mystinus*), yellowtail (*S. flavidus*), and black (*S. melanops*) rockfish by year. Note the different scale for black rockfish. Error bar=one standard error. The 21-year mean (represented by a dashed line) and the standard deviation for each species are given on each plot. The sample size for each year is reported in Table 1.

The data for year-class strength of commercially caught adult yellowtail rockfish corresponded with the annual abundance index for juvenile yellowtail rockfish (Table 4), and were significantly correlated for all ports combined for 1997 ($P < 0.01$, $n = 29$, $r = 0.48$) and 1999 ($P < 0.04$, $n = 31$, $r = 0.36$), but not for 1998 ($P < 0.1$, $n = 21$, $r = 0.37$). For 1997, juvenile rockfish abundance was significantly correlated with adult fish numbers at Bodega

Bay ($P < 0.02$, $R = 0.43$, Fig. 5A), Ft. Bragg ($P < 0.001$, $r = 0.62$), and Eureka ($P < 0.01$, $r = 0.78$). In 1998, Bodega Bay was the only port where adult fish numbers were significantly correlated ($P < 0.05$, $r = 0.38$, Fig. 5B) with juvenile abundance. In 1999, Eureka was the only port where adult fish numbers were significantly correlated ($P < 0.05$, $R = 0.35$) with juvenile abundance. From the 1998 adult numbers in Bodega, 1985 was the largest year class of adult yellowtail rockfish, which corre-

sponded to the highest index for juvenile yellowtail rockfish (Fig. 5B).

Discussion

The 21-year time series of juvenile rockfish abundance allowed us to examine long-term change in recruitment of commercially and recreationally important species off the coast of California. The year-to-year variability in recruitment likely relates to variability in year-class strength of the population entering the fisheries. The synchrony in recruitment variability among the three rockfish species indicates that similar environmental processes affect the abundance of all three species. By examining oceanographic variables, we determined that sea level anomaly and nearshore temperatures in February and March were important influences on juvenile rockfish abundance.

Year-to-year variability in young rockfish abundance has been documented in other studies off the west coast of the United States. Yoklavich et al. (1996) found a twenty-fold increase in the abundance of pelagic larval rockfishes off central California in 1993 compared to numbers obtained during a similar time period in 1992. They attributed this difference to increased offshore transport and possibly lower predation rates. Moser et al. (2000) observed large fluctuations in annual larval rockfish abundance off southern California from 1951 to 1998, which was attributed to the reproductive output of each species and oceanographic variables. Mearns et al. (1980) determined that the variability in recruitment of juveniles was the major source of seasonal and annual fluctuations in rockfish catches for strip-tail and calico rockfish (*S. dallii*). Matthews (1989) observed that recruitment levels varied between years for three species of rockfishes recruiting to nearshore habitats. Ainley et al. (1993) discovered a three-fold difference in pelagic juvenile rockfish abundance in seabird diets in central California between similar periods in 1985 and 1986, and they attributed this to cross shelf advection of larvae in January and February. Ralston and Ianelli (1998) reported a large variability in juvenile bocaccio abundance over a 13-year period and attributed some of this variability to El Niño events.

Year-class strength was likely established in the period from February through March during the larval stage of the three

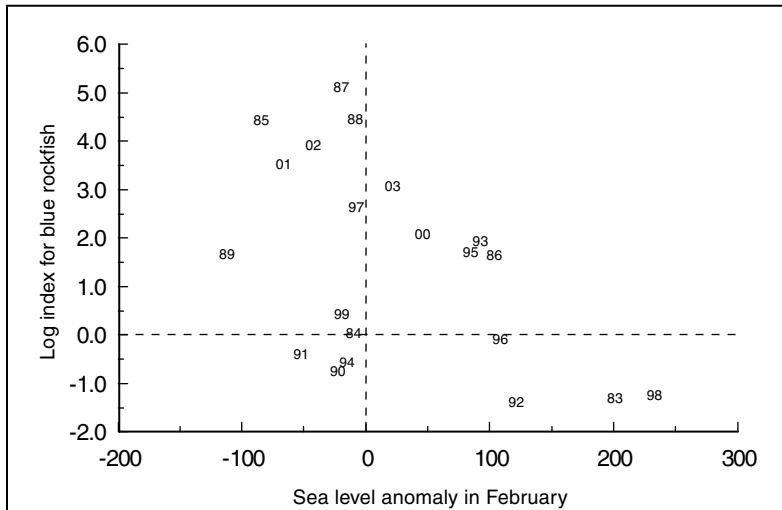


Figure 3

An example of the log-transformed annual abundance index for blue rockfish (*Sebastes mystinus*) and average sea level anomaly in February for each year of the survey (1983–2003). Numbers represent individual years. Dashed lines represent the zero line for both axes.

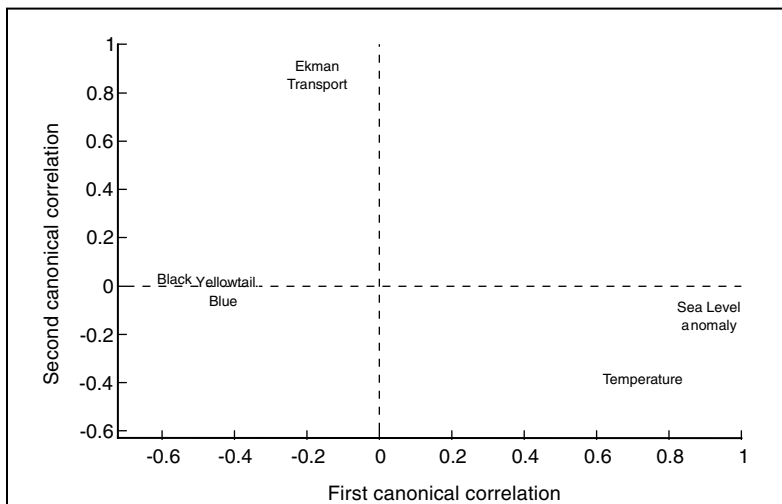


Figure 4

The first and second canonical correlations for the annual abundance index (INDEX) for each rockfish species and the oceanographic factors with the axes defined by the oceanographic data set. Dashed lines represent zero line for both axes.

Table 3

Correlations between the log-transformed annual juvenile rockfish abundance index by species and the oceanographic variables by month. * = $P < 0.05$; ** = $P < 0.01$; + = $P < 0.1$.

	Jan	Feb	Mar	Apr	May	Jun
Sea level anomaly						
Blue rockfish	-0.36	-0.71**	-0.63**	-0.51*	-0.37+	-0.40+
Yellowtail rockfish	-0.48*	-0.53*	-0.57**	-0.55**	-0.55**	-0.35
Black rockfish	-0.64**	-0.53*	-0.52*	-0.42+	-0.65**	-0.55**
Temperature						
Blue rockfish	-0.22	-0.53*	-0.52*	-0.41+	-0.19	-0.21
Yellowtail rockfish	-0.32	-0.54*	-0.53*	-0.48*	-0.46*	-0.32
Black rockfish	-0.54*	-0.62**	-0.55**	-0.47*	-0.65**	-0.48*
Offshore Ekman transport						
Blue rockfish	0.05	0.58**	0.42+	0.01	-0.02	0.03
Yellowtail rockfish	0.27	0.27	0.39+	0.21	0.17	-0.01
Black rockfish	0.29	0.25	0.19	0.29	0.40+	0.01

Table 4

Correlation coefficients between the log-transformed annual juvenile rockfish abundance index and year-specific adult yellowtail rockfish (*Sebastes flavidus*) commercial landings, by year class, at three ports closest to the study area. * = $P < 0.05$; ** = $P < 0.01$; + = $P < 0.1$. Listed in parentheses is the number of year classes determined in each year and the number of adult yellowtail rockfish otoliths that were aged (no. of year classes, number of otoliths aged).

	All ports	Bodega	Bragg	Eureka
1997	0.48 (10, 172)**	0.43 (10, 16)*	0.62 (10, 84)**	0.78 (9, 72)**
1998	0.37 (9, 141)+	0.38 (6, 30)*	0.21 (9, 89)	0.32 (7, 22)+
1999	0.36 (12, 198)*	0.32 (9, 84)+	0.25 (11, 37)	0.35 (12, 77)*

species of rockfishes in our study. The abundance of all three species were significantly and negatively correlated with sea level anomaly and nearshore temperature during this time period. Ralston and Howard (1995) also argued that year-class strength was set in the larval period for rockfishes with winter parturition. They analyzed data from midwater trawls in May and June and compared them with data from nearshore surveys in summer. Because there was a strong correlation between the two data sets, they postulated that the year-class was set earlier in the year than May, probably during the larval stage. VenTresca et al.³ also reported evidence of the establishment of year-class strength in the larval stage. In 1992, they found large concentrations of larval rockfishes in January, but three to four months later very few juveniles appeared in midwater trawls. They surmised that the El Niño conditions of elevated water temperatures and reduced upwelling resulted in poor survival.

Synchrony in juvenile abundance among rockfish species has been observed in other studies. Ralston and Howard (1995) ascertained that trends in abundance for juvenile blue and yellowtail rockfish from midwater trawls were highly correlated over the 10 years of their

study. Ammann (2001) discovered a comparable pattern in recruitment of juvenile yellowtail and black rockfish to the kelp bed environment in 1999 and 2000. Stephens et al. (1984) reported that juvenile abundance of both blue and olive rockfish (*S. serranoides*), dropped to virtually zero during the years 1978–81. In our study, blue, yellowtail, and black rockfish covaried over a period of 21 years.

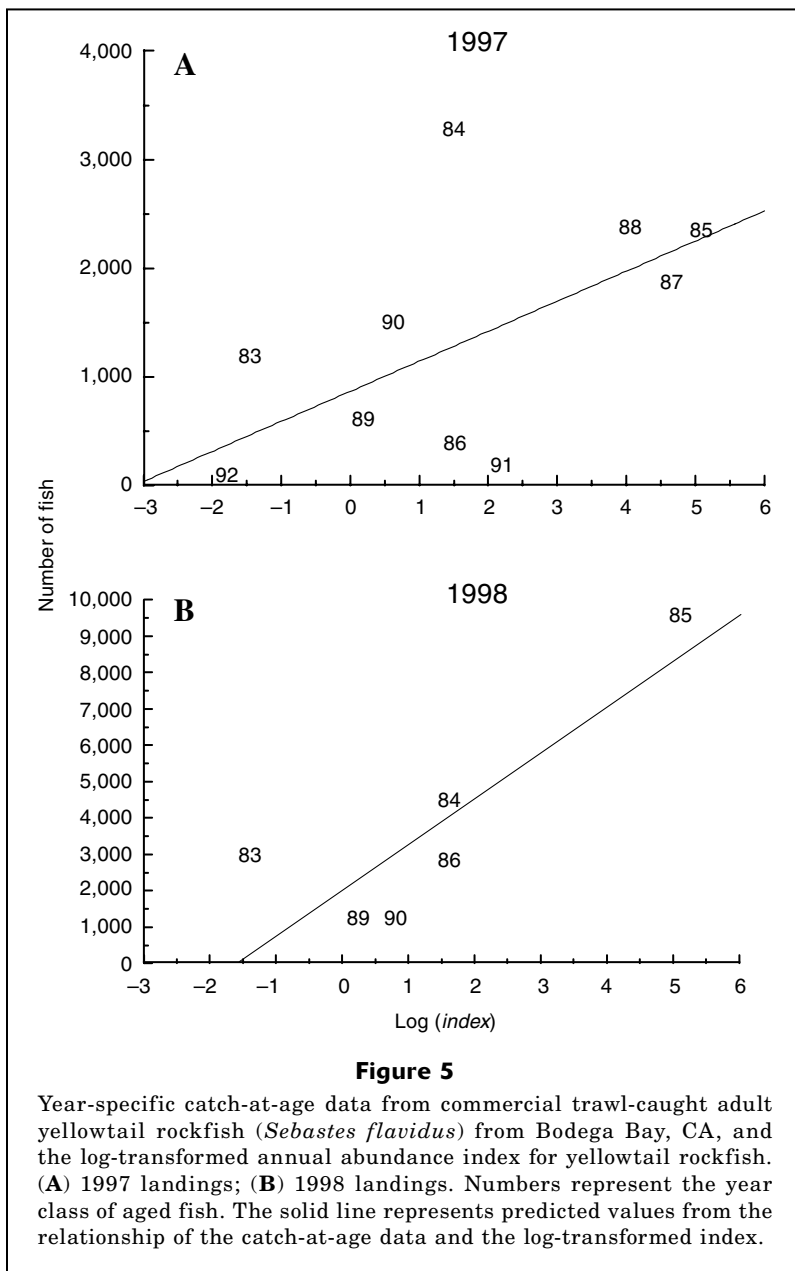
Although offshore Ekman transport, or upwelling, has been suggested as a predictor of year-class strength, we found it to have little correlation with the abundance of juvenile rockfishes from northern California. Maximum upwelling off the central California coast occurs in late spring and summer (Rosenfeld et al., 1994; Yoklavich et al., 1996). This upwelling occurred after the larval period for winter-spawning *Sebastes* spp., and therefore after the timing of year-class determination. Larson et al. (1994) found that larger pelagic juveniles were often close to shore even when upwelling was strong, indicating that later-stage pelagic juveniles were not directly affected by upwelling. If water movement onshore and offshore influences the population size of juvenile rockfishes, perhaps this effect occurs during the early stages.

Temperature and sea level anomaly proved to be important correlates with year-class strength for juvenile rockfishes. Of the three environmental variables examined, nearshore temperature and sea level anomaly were significantly and negatively correlated with the abundance of all three species. Moser et al. (2000) reported a similar relationship, with reduced abundance of larval bocaccio and cowcod during periods of high temperature off southern California. Ralston and Howard (1995) reported a negative correlation between recruited juvenile blue and yellowtail rockfish year-class strength and sea surface temperature in January through March. Stephens et al. (1984) surmised that warm water was the limiting factor in the low recruitment of juvenile blue and olive rockfish during 1978–81

off southern California. Ainley et al. (1993) determined that sea level during February and sea surface temperature in March were negatively correlated with pelagic rockfish abundance for the period of 1973–90 off central California.

Temperature affects the growth rates of rockfishes, which, in turn, affects species abundance. Johnson et al. (2001) determined that growth rates declined during months of high temperatures for juveniles of three rockfish species. However, Boehlert and Yoklavich (1983) found increased growth rates for juvenile black rockfish with increased temperature in the laboratory, except under starvation conditions. Therefore, reduction in growth rates may be due to lower prey availability during El Niño conditions (Mullin and Conversi, 1989). This lower growth rate of juvenile rockfishes during periods of high temperatures may lead to reduced survival and lower year-class strength.

Although growth can vary directly with temperature, temperature may also have an indirect effect on rockfish abundance. Strong El Niño events, associated with unusually high water temperatures lasting from a few months to over a year, have occurred off California in 1982–83, 1991–92, and 1997–98 (Fedorov and Philander, 2000; Rebstock, 2001). VenTresca et al. (1995) observed reduced condition factor and gonadal indices for blue rockfish during the 1983 and 1992 El Niños off central California when water temperatures were elevated. These reductions could lead to fewer larvae being produced and hence ultimately to a lower abundance of juveniles. El Niño events can also lead to changes in the strength and timing of the annual phytoplankton bloom, both of which can reduce the distribution and abundance of the zooplankton on which the juvenile rockfishes feed (Lenarz et al., 1995). This reduction in food availability could lead to lower growth or survival of the juvenile rockfishes. Keister et al. (2005) found several warm-water species of euphausiids, chaetognaths, and copepods in Oregon waters during the 1997–98 El Niño. Rebstock (2001) observed that during periods of high temperatures in 1983, 1992, and 1998, the species richness of copepods was lower than a 49-year average. Copepods are a preferred prey item for juvenile rockfishes (Reilly et al., 1992). A change in species richness may reflect a change in species composition to less desirable food sources (e.g., prey is less nutritious or less available to young rockfishes). Although the exact mechanism is not clear, we observed that the three



years of lowest abundance for juvenile rockfishes occurred during El Niño events.

The primary factors that lead to annual fluctuations in abundance were similar for blue, yellowtail, and black rockfish. These three species are found in similar areas at the planktonic stage (Lenarz et al., 1991; Larson et al., 1994). Therefore, it is expected that changes in ocean conditions affect all three species similarly. Nearshore temperature and sea level anomaly had high negative correlations with abundance for all three species, whereas offshore Ekman transport was not correlated with abundance. This finding implies that poor recruitment occurs during years of high temperature and strong, positive sea level anomaly (poleward flow), and vice versa. Our results indicate that recruitment is poor during periods of strong, positive sea level anomaly and that recruitment is strong only during years of negative sea level anomaly (equatorward flow). However, poor recruitment also occurs in some years with negative sea level anomaly. Therefore, other factors are probably involved in the process and can affect year-class strength in rockfishes. Some of the other factors that have been suggested to have at least some influence on rockfish recruitment include adult spawning biomass (Mason, 1998), increased predation by siphonophores and chaetognaths on larval stages during years of high sea temperature (Yoklavich et al., 1996), turbulence (Ainley et al., 1993), and diet of juvenile rockfishes (Reilly et al., 1992).

Large-scale multiyear oceanographic events (e.g., Pacific Decadal Oscillation and the El Niño-Southern Oscillation indices) also appear to affect juvenile rockfish abundance. Large changes in indices reflect regime shifts in ocean conditions, such as those occurring in 1977, 1989, and 1998 (Hare and Mantua, 2000; Benson and Trites, 2002). Although the mechanisms that affect or cause changes in abundance are unclear, our time series of juvenile rockfish abundance reflects these large-scale shifts in ocean conditions by the generally high recruitment prior to 1989, the much reduced recruitment from 1989 to 1998, and the generally higher recruitment after 1998.

We have continued our juvenile rockfish surveys to present, and have had the opportunity to determine the usefulness of our abundance index as a predictor of rockfish year-class strength. In 2005, average monthly temperature was elevated from January to June (as much as two degrees above average as measured by our temperature monitors). Interestingly, the abundance index of all three species of juvenile rockfishes from our surveys in 2005 was very low. Black and yellowtail rockfish abundances, in particular, were at the third lowest level estimated during what is now a 23-year time-series of recruitment. Therefore, our results demonstrate our ability to predict annual levels of abundance for these species of juvenile rockfishes.

Juvenile yellowtail rockfish abundance in our study reflected adult yellowtail rockfish abundance in the fishery. Mearns et al. (1980) also reported a relationship between juvenile abundance and subsequent adult

biomass for stripetail and calico rockfishes by following yearly cohorts from seasonal trawls in southern California over nine years. The high recruitment for bocaccio in 1985 was manifested in the recreational fishery in Monterey Bay, CA in subsequent years (Mason, 1998). Similar trends were observed with large year-classes of chilipepper, *S. goodei*, and yellowtail rockfish (Mason, 1998). Ralston and Ianelli (1998) also found that the abundance of juvenile bocaccio was an indicator of year-class strength in the fishery. Accordingly, the study of juvenile rockfish abundance can help predict good and bad year classes entering a fishery. These data can then be incorporated into fisheries models (see stock assessments for widow rockfish, *S. entomelas*, [He et al.⁶]) to better manage the stocks.

Acknowledgments

We first thank Edmund (Ted) Hobson for his initial conception of this project and his many years of data collection and direction. We also thank all the divers who helped with juvenile rockfish surveys, especially Kelly Silberberg for his many years of dedication to this project. We thank Peter Adams, Steve Ralston, Susan Sogard, Ralph Larson, Mary Yoklavich, and four anonymous reviewers for helpful comments on drafts of this manuscript. Lastly, we thank Craig Syms and Brian Wells for their generous help with statistical matters.

Literature cited

- Ainley, D. G., W. J. Sydeman, R. J. Parrish, and W. H. Lenarz. 1993. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California: A predator's perspective. Calif. Coop. Oceanic Fish. Invest. Rep. 34:133-139.
- Ammann, A. 2001. Evaluation of a standard monitoring unit for the recruitment of fish in central California. M.Sci. thesis, 92 p. Univ. California, Santa Cruz, CA.
- Anderson, T. W. 1983. Identification and development of nearshore juvenile rockfishes (genus *Sebastes*) in central California kelp forests. M.Sci. thesis, 216 p. California State Univ., Fresno, CA.
- Benson, A. J., and A. W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fish and Fisheries 3:95-113.
- Boehlert, G. W., and M. M. Yoklavich. 1983. Effects of temperature, ration, and fish size on growth of juvenile black rockfish, *Sebastes melanops*. Environ. Biol. Fish. 8:17-28.

⁶ He, X., D. E. Pearson, E. J. Dick, J. C. Field, S. Ralston, and A. D. MacCall. 2005. Status of the widow rockfish resource in 2005, 119 p. Pacific Fisheries Management Council, 7700 NE Ambassador Place, Suite 200, Portland, Oregon 97220.

- Butler, J. L., L. D. Jacobson, J. T. Barnes, and H. G. Moser.
2003. Biology and population dynamics of cowcod (*Sebastes levis*) in the southern California Bight. *Fish. Bull.* 101:260–280.
- Fedorov, A. V., and S. G. Philander.
2000. Is El Niño changing? *Science* 288:1997–2002.
- Hare, S. R., and N. J. Mantua.
2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Prog. Oceanogr.* 47:103–145.
- Johnson, K. A., M. M. Yoklavich, and G. M. Cailliet.
2001. Recruitment of three species of juvenile rockfish (*Sebastes* spp.) on soft benthic habitat in Monterey Bay, California. *Calif. Coop. Oceanic Fish. Invest. Rep.* 42:153–166.
- Keister, J. E., T. B. Johnson, C. A. Morgan, and W. T. Peterson.
2005. Biological indicators of the timing and direction of warm-water advection during the 1997/1998 El Niño off the central Oregon coast, USA. *Mar. Ecol. Prog. Ser.* 295:43–48.
- Larson, R. J., W. H. Lenarz, and S. Ralston.
1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. *Calif. Coop. Oceanic Fish. Invest. Rep.* 35:175–221.
- Lenarz, W. H., R. J. Larson, and S. Ralston.
1991. Depth distributions of late larvae and pelagic juveniles of some fishes of the California Current. *Calif. Coop. Oceanic Fish. Invest. Rep.* 32:41–46.
- Lenarz, W. H., F. B. Schwing, D. A. VenTresca, F. Chavez, and W. M. Graham.
1995. Explorations of El Niño events and associated biological population dynamics off central California. *Calif. Coop. Oceanic Fish. Invest. Rep.* 36:106–119.
- Love, M. S., M. Yoklavich, and L. Thorsteinson.
2002. The rockfishes of the northeast Pacific, 405 p. Univ. California Press, Berkeley, CA.
- Mason, J.
1998. Declining rockfish lengths in the Monterey Bay, California, recreational fishery, 1959–94. *Mar. Fish. Rev.* 60:15–28.
- Matthews, K. R.
1989. A comparative study of habitat use by young-of-the-year, subadult, and adult rockfishes on four habitat types in central Puget Sound. *Fish. Bull.* 88:223–239.
- Mearns, A. J., M. J. Allen, M. D. Moore, and M. J. Sherwood.
1980. Distribution, abundance, and recruitment of soft-bottom rockfishes (Scorpaenidae: *Sebastes*) on the southern California mainland shelf. *Calif. Coop. Oceanic Fish. Invest. Rep.* 21:180–190.
- Moser, H. G., R. L. Charter, W. Watson, D. A. Ambrose, J. L. Butler, S. R. Charter, and E. M. Sandknop.
2000. Abundance and distribution of rockfish (*Sebastes*) larvae in the Southern California Bight in relation to environmental conditions and fishery exploitation. *Calif. Coop. Oceanic Fish. Invest. Rep.* 41:132–147.
- Mullin, M. M., and A. Conversi.
1989. Biomasses of euphausiids and smaller zooplankton in the California Current—geographic and interannual comparisons relative to the Pacific whiting, *Merluccius productus*, fishery. *Fish. Bull.* 87:633–644.
- Pastén, G. P., S. Katayama, and M. Omori.
2003. Timing of parturition, planktonic duration, and settlement patterns of the black rockfish, *Sebastes inermis*. *Environ. Biol. Fish.* 68:229–239.
- Ralston, S., and D. F. Howard.
1995. On the development of year-class strength and cohort variability in two northern California rockfishes. *Fish. Bull.* 93:710–720.
- Ralston, S., and J. N. Ianelli.
1998. When lengths are better than ages: the complex case of bocaccio. *In* *Fishery stock assessment models: proceedings of the international symposium on fishery stock assessment models for the 21st century* (October 8–11, 1997, Anchorage, Alaska) (F. Funk, T. J. Quinn II, J. Heifetz, J. N. Ianelli, J. E. Powers, J. F. Schweigert, P. J. Sullivan, and C.-I. Zhang, eds.), p. 451–468. Lowell Wakefield Fisheries Symposium No. 15. Univ. Alaska Sea Grant College Program AK-SG-98-01, Fairbanks, AK.
- Rebstock, G. A.
2001. Long-term stability of species composition in calanoid copepods off southern California. *Mar. Ecol. Prog. Ser.* 215:213–224.
- Reilly, C. A., T. Wyllie Echeverria, and S. Ralston.
1992. Interannual variation and overlap in the diets of pelagic juvenile rockfish (genus: *Sebastes*) off central California. *Fish. Bull.* 90:505–515.
- Rosenfeld, L. K., F. B. Schwing, N. Garfield, and D. E. Tracy.
1994. Bifurcated flow from an upwelling center: a cold water source for Monterey Bay. *Continental Shelf Res.* 14:931–964.
- Shaffer, J. A., D. C. Doty, R. M. Buckley, and J. E. West.
1995. Crustacean community composition and trophic use of the drift vegetation habitat by juvenile split-nose rockfish, *Sebastes diploproa*. *Mar. Ecol. Prog. Ser.* 123:13–21.
- Stephens, J. S. Jr., P. A. Morris, K. Zerba, and M. Love.
1984. Factors affecting fish diversity on a temperate reef: the fish assemblage of Palos Verde Point, 1974–1981. *Environ. Biol. Fish.* 11:259–275.
- VenTresca, D. A., R. H. Parrish, J. L. Houk, M. L. Gingras, S. D. Short, N. L. Crane.
1995. El Niño effects on the somatic and reproductive condition of blue rockfish, *Sebastes mystinus*. *Calif. Coop. Oceanic Fish. Invest. Rep.* 36:167–174.
- Yoklavich, M. M., V. J. Loeb, M. Nishimoto, and B. Daly.
1996. Nearshore assemblages of larval rockfishes and their physical environment off central California during an extended El Niño event, 1991–1993. *Fish. Bull.* 94: 766–782.