EL NIÑO EFFECTS ON THE SOMATIC AND REPRODUCTIVE CONDITION OF BLUE ROCKFISH, *SEBASTES MYSTINUS*

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ABSTRACT

The condition factors and gonadal indices of blue rockfish off central California declined during the 1982–83 and 1992–93 El Niño events. These periods were characterized by higher-than-normal spring sea-surface temperatures (SST), indicating weak upwelling of cold, nutrient-laden water into the nearshore euphotic zone. Resulting spring primary productivity was low. Blue rockfish, an important component of the central California sportfish catch, are primarily macrozooplankton feeders. Current literature suggests that they rely on plankton blooms during the spring upwelling period to build fat reservoirs in preparation for reproduction in the fall.

The condition factor of adult blue rockfish showed a general pattern of negative correlation with SST. The highest correlation was with fall SST ($R = -0.739$, $P = 0.0025$); however, correlations were also significant at the 5% level with annual and spring SST. Low monthly mean somatic condition factors of blue rockfish during El Niño years, compared to non-El Niño years, imply lower energy reserves for reproductive development. Mean female gonadal indices were also below long-term means in El Niño years.

INTRODUCTION

Fishery biologists have long scrutinized the relationship between fluctuations in the environment and the productivity of fish populations. Recent literature regarding the 1982–83 and 1992–93 El Niño events in the California Current region documented that these events were characterized by the reduced entrainment of cool, nutrient-enriched water into the euphotic zone, low surface chlorophyll concentration, and weak primary productivity (McLain and Thomas 1983; McGowan 1984; Norton et al. 1985; Hayward 1993; Lenarz et al. 1995). These anomalous conditions resulted in reduced productivity at higher trophic levels. For example, the paucity of large copepods (attributed to low phytoplankton levels) in waters off Oregon and Washington in 1983 was thought to have a detrimental effect on larval sablefish, *Anoplopoma fimbria* (Grover and Olla 1987). Lenarz and Wyllie Echeverria (1986) reported that low fat and ovary volumes in female yellowtail rockfish, *Sebastes flavidus*, may have resulted from poor feeding conditions during the 1982–84 El Niño period. Spratt (1987) found that weight-at-age and overall mean weight of herring, *Clupea harengus pallasi*, in the San Francisco Bay fishery was depressed in 1983. A significant decline in the growth increments of commercially caught young widow rockfish, *Sebastes entomelas*, along the Oregon coast was observed by Woodbury (Southwest Fisheries Science Center, Tiburon, pers. comm.), who suspected that the 1982–83 El Niño was the probable cause. Lenarz et al. (1995) also found that the 1982–83 and 1992–93 El Niño events affected the growth and somatic condition of adult rockfish off central California.

The Central California Marine Sport Fish Survey, a project of the California Department of Fish and Game, has collected life-history and stock-status information on nearshore rockfish off central California since 1950. Local sport fish populations are showing the effects of heavy utilization, highlighting the need for alternative management strategies to provide a high quality of sportfishing in the future (Reilly et al. 1993). The present objective of the sport fish survey is to determine the feasibility of establishing marine reserves as a management strategy to enhance nearshore rockfish populations. A crucial aspect of this objective is to examine the relationships among the somatic and reproductive condition of adults, oceanographic events, and the ultimate recruitment success of young-of-the-year (YOY) fishes.

The blue rockfish, *Sebastes mystinus*, a ubiquitous, schooling, nearshore rockfish, has been numerically the most important sport fish in central and northern California (Miller and Gotshall 1965; Miller et al. 1967; Reilly et al. 1993). Blue rockfish are primarily plankton feeders whose food consists mainly of jellyfish, crustaceans, and tunicates (Gotshall et al. 1965; Hobson and Chess 1988). Blue rockfish grow fastest during spring upwelling when these planktonic organisms are abundant (Miller and Geibel 1973). Guillemot et al. (1985) suggest that upwelling periods provide energy for simultaneous fat accumulation, somatic growth, and gametogenesis for some rockfish. Blue rockfish are viviparous (Boehlert and Yoklavich 1985). Insemination occurs from July through September, and females release larvae from December through January (Wyllie Echeverria 1987).

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Our objective in this paper is to examine how the somatic and reproductive condition of adult rockfishes relates to oceanographic events. We have chosen blue rockfish as an indicator of the annual variability in this relationship because this species' importance in sport and commercial fisheries has resulted in a long time series of length, weight, and high-quality reproductive information. Additionally, we suspect that blue rockfishes' food supply and ultimately their somatic and reproductive condition is influenced by spring upwelling.

METHODS

Study Area and Data Sources

From 1981 to 1994, blue rockfish were collected along the central California coast between Santa Cruz and Port San Luis (table 1). Specimens were collected in depths of 5 to 40 m throughout the year by hook-and-line fishing or by pole spear. Most specimens were processed the day of capture; a small number were refrigerated and processed the day after capture. Information recorded for each fish included standard and total length (mm), wet body weight (g), wet gonad weight (g), and stage of maturation (Lea et al., in press).

The two equations used to calculate the condition factor of individual fish were derived from length-weight relationships calculated by linear regressions of natural log transformations of the observed total length (TL) and wet weight of 4015 adult and 3129 young-of-the-year (YOY) blue rockfish. Condition factors were calculated as follows:

Condition factor = observed total weight/ expected total weight where:

Adult expected total weight = $0.000008976\ TL^{3.1118}$

YOY expected total weight = $0.000006482\ TL^{3.1679}$

TABLE 1
Numbers of Male, Female, and Young-of-the-Year (YOY) Blue Rockfish Analyzed for Condition Factor (CF) and Gonadal Index (GI)

	Male		Female		YOY
Year	CF	GI	CF	GI	CF
1981	18	3	80	13	—
1982	13	4	56	11	—
1983	66	13	153	24	—
1984	55	15	149	30	—
1985	19	—	51	5	—
1986	23	—	70	17	—
1987	65	4	183	46	104
1988	29	4	150	12	427
1989	26	14	208	75	334
1990	41	6	214	62	805
1991	47	4	286	99	671
1992	106	23	712	126	41
1993	44	13	481	230	460
1994	69	7	184	31	287

We followed the methods suggested by Beauchamp and Olson (1973) to adjust the above regression coefficients for the biases introduced by log transformations. We found the calculated condition factors to have a strong seasonal cycle. Annual means of condition factors, which we used for comparisons with oceanographic factors, were therefore standardized by subtracting the respective monthly mean from each fish's condition factor. This correction was necessary to remove the bias that would have resulted from the different seasonal distribution of sampling which occurred in some years.

We used the gonadal index (GI) equation as an index of reproductive condition (DeVlaming et al. 1982). This index uses the gonad weight/fish length cubed relationship as an indicator of the reproductive state of the fish and is derived by the formula

$$GI = (GWT\ /\ TL^3) \times 10^5$$

where:

GWT = weight of gonad in grams
TL = total length of fish in millimeters
10^5 = value to bring index to unity

The time period we used to estimate the annual gonadal index differed for males (the breeding season, June–September) and females (the parturition season, November–January; Wyllie Echeverria 1987). We used only reproductively developing individuals (Lea et al., in press) to calculate the mean gonadal index for the month and year.

We calculated quarterly mean SST from monthly means of daily observations taken at the Granite Canyon Pollution Laboratory (GCPL), located 18 km south of Monterey, California.

Annual mean upwelling indices (UPIs) were calculated from monthly means at 36°N, 122°W; these means were obtained from the Pacific Fisheries Environmental Group, Monterey, California. The UPI is derived from atmospheric pressure fields and is an estimate of the offshore component of Ekman transport (Bakun 1973).

RESULTS

Sea-Surface Temperature

Elevated SST taken at the GCPL indicated the two major El Niño events (1982–83 and 1992–93) that occurred along the central coast from 1981 through 1994 (figure 1). Sea-surface temperatures during the first half of 1982 were only slightly above the mean, but from the second half of 1982 throughout 1983 they were well above the mean. Sea-surface temperatures were about average in 1984, slightly cooler in 1985, and warmer than average in 1986 and 1987. During the next 4 years (1988–91) annual SST averaged half a degree cooler than the mean. Although SSTs were not as high in 1992–93

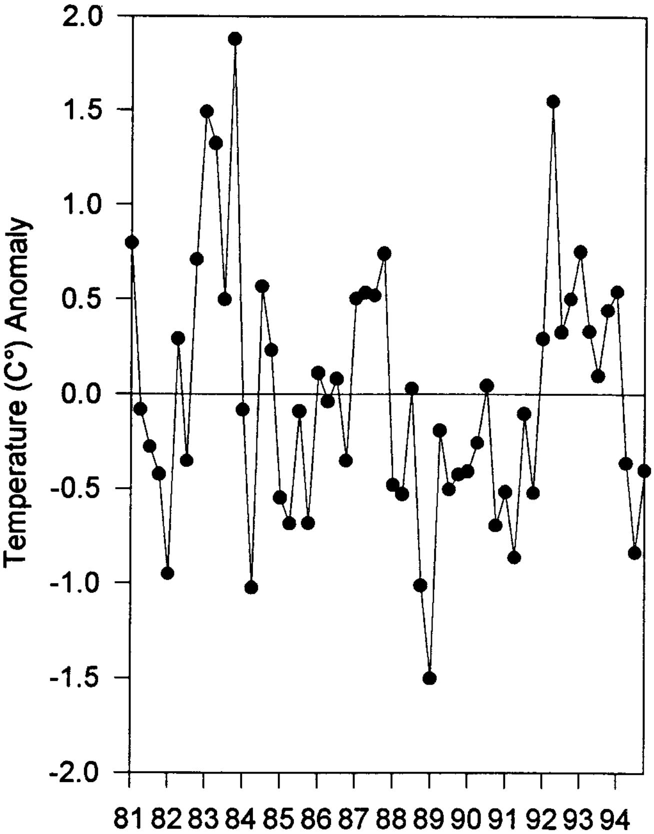

Figure 1. Quarterly sea-surface temperature anomalies derived from daily readings taken at Granite Canyon Pollution Laboratory, Monterey County, California.

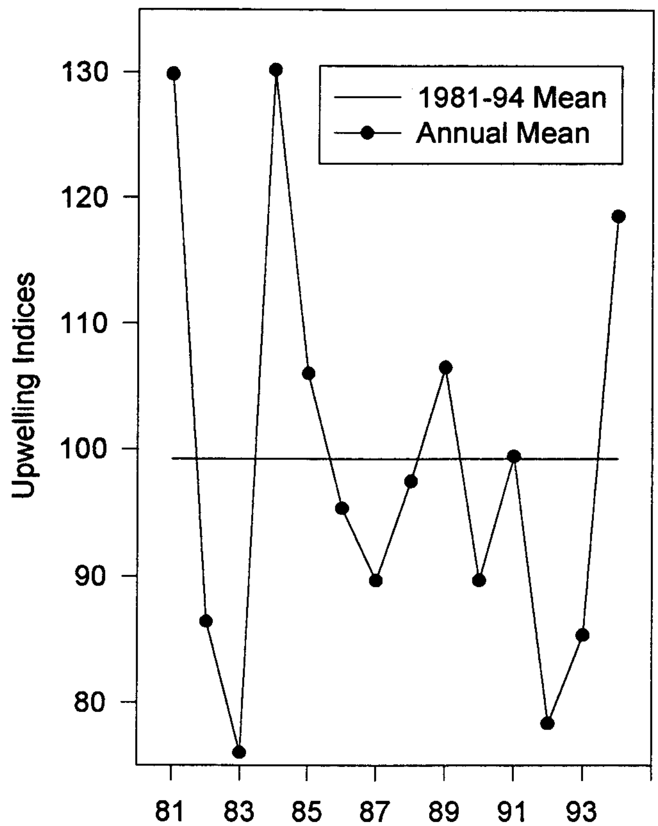

Figure 2. Annual upwelling indices calculated at 36°N, 122°W.

as in 1983, they were above the 14-year mean throughout most of both years. Sea-surface temperatures cooled in 1994 to half a degree below the 14-year mean.

Upwelling Indices

Annual mean UPIs at 36°N, 122°W were low during the 1982–83 and 1992–93 El Niño events (figure 2). Minimum UPIs in 1983 and 1992 correspond to maximum SST taken at the GCPL during those years. From 1981 through 1994 the highest UPIs occurred in 1981 and 1984. From 1985 through 1991 and in 1994 the annual UPI fluctuated only slightly from the 1981–94 mean.

BIOLOGICAL DATA

Condition Factor

Condition factors in male, female, and unsexed YOY blue rockfish have somewhat similar seasonal patterns (figure 3). Condition factor is at a minimum in the early spring and rises sharply to a maximum in early summer. In males, condition factor starts to drop in early fall; in females and unsexed YOY it does not decline until winter. The seasonal decline in the condition factor of males

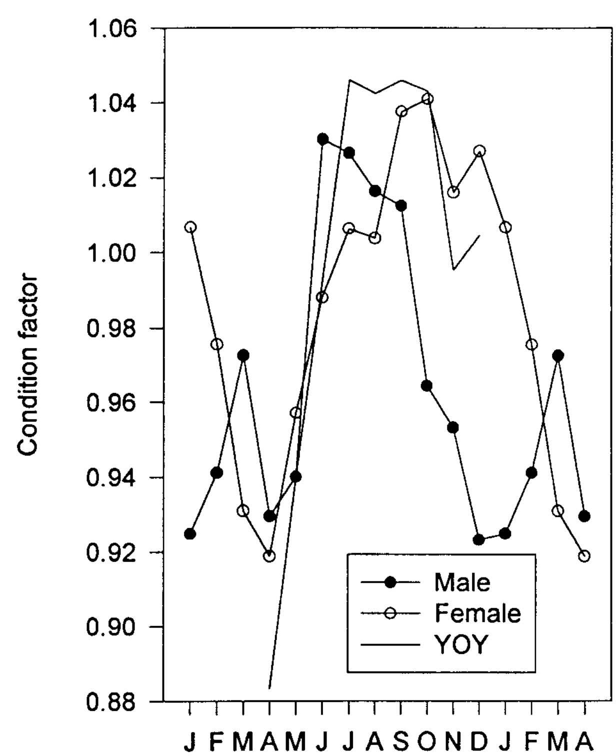

Figure 3. Seasonal condition factors of male, female, and young-of-the-year (YOY) blue rockfish, 1981–94.

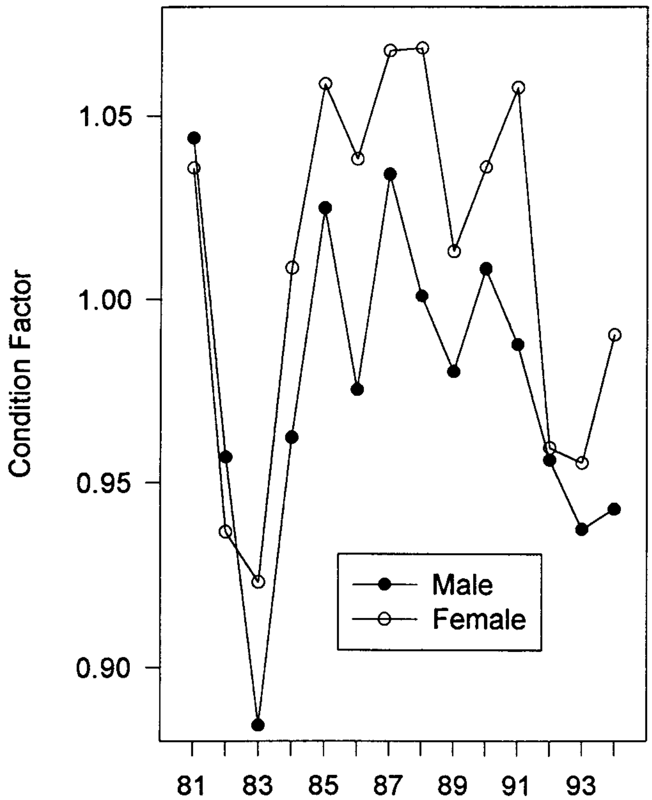

Figure 4. Corrected annual seasonal condition factors of male and female blue rockfish, 1981–94.

corresponds to the end of the breeding season; the seasonal decline of females is associated with their parturition period (Lea et al., in press). Young-of-the-year recruit to the nearshore kelp forest in April. Their growth is rapid during the spring plankton blooms but levels off in late summer as suitable food sources diminish (VenTresca et al., in press).

Although condition factors in males and females exhibited slightly different seasonal cycles, seasonally adjusted interannual patterns were more congruent (figure 4). Seasonally adjusted female condition factors were "closest" to male values during and after El Niño periods (1982–84 and 1992–93), when both were at a minimum. From 1983 through 1994, female condition factors were generally higher than those of the males.

The condition factors of all sexually mature adults were lowest in 1982–83, and not until 1985—two years after El Niño—did adult condition factors recover to the 1981 level (figure 5). From 1985 to 1991 the condition factor of blue rockfish was relatively stable, although there were minor declines in adult condition factors in 1986 and 1989. A second major decline of adult condition factor occurred during the 1992–93 El Niño. Except for the first three years of sampling, the condition factors of YOY blue rockfish were similar to those of adults. Young-of-the-year condition factors rose in 1990 and

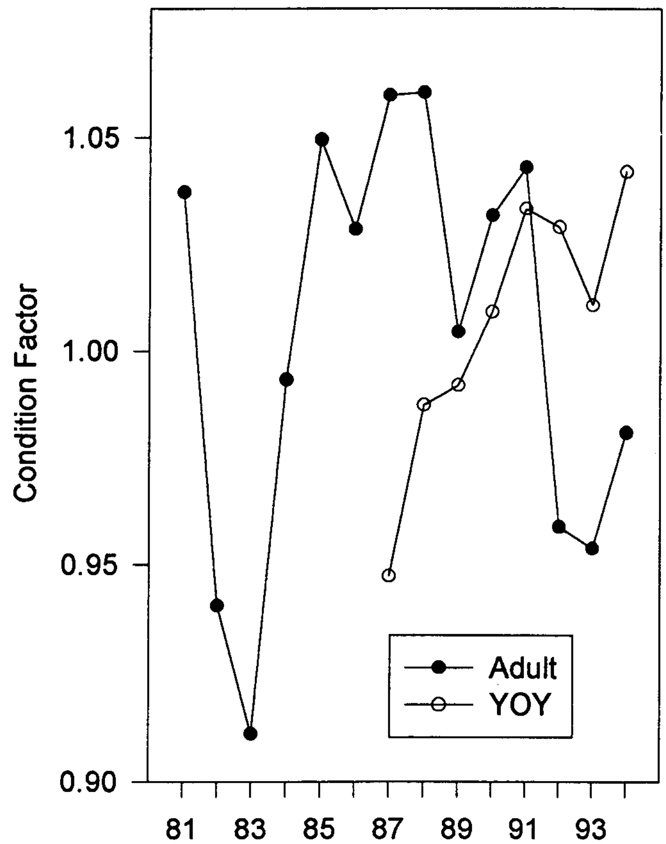

Figure 5. Corrected annual seasonal condition factors of sexually mature adult and young-of-the-year (YOY) blue rockfish, 1981–94.

1991, declined in 1992 and 1993, and rose again in 1994 (figure 5).

As would be expected from the previous results, the seasonal condition factor cycles of males and females collected during the 1982–83 and 1992–93 El Niño events were lower and more variable than those collected during non-El Niño years (figures 6 and 7). Condition factors in males had essentially the same seasonal pattern in the non-El Niño years and in the 1992–93 El Niño, although the values were substantially lower during the 1982–83 El Niño. During the 1982–83 El Niño, males showed virtually no spring–summer increase in condition factor, and monthly values fluctuated considerably. In females the seasonal pattern that occurred in non-El Niño years (i.e., minimum in April, stable maximum from July through December, and decline from January to April) did not occur during the two El Niño periods. During the lesser El Niño of 1992–93, condition factors were considerably lower than during non-El Niño years in all months. A rapid spring increase did not occur, but rather condition factor peaked in September. During the major El Niño of 1982–83 the condition factor of females, like that of males, did not exhibit the "normal" spring–summer increase, and

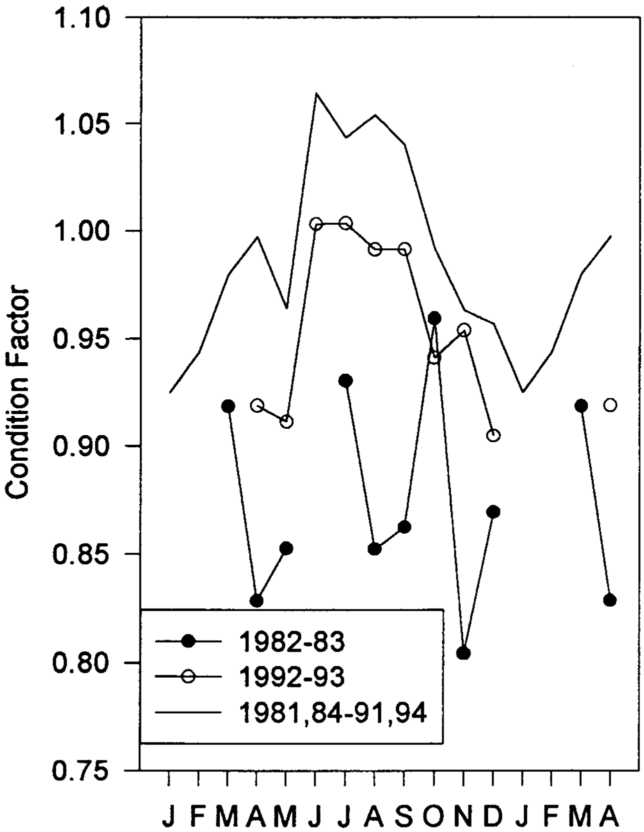

Figure 6. Seasonal condition factors of male rockfish during 1982–83; 1992–93; and 1981, 1984–91, and 1994.

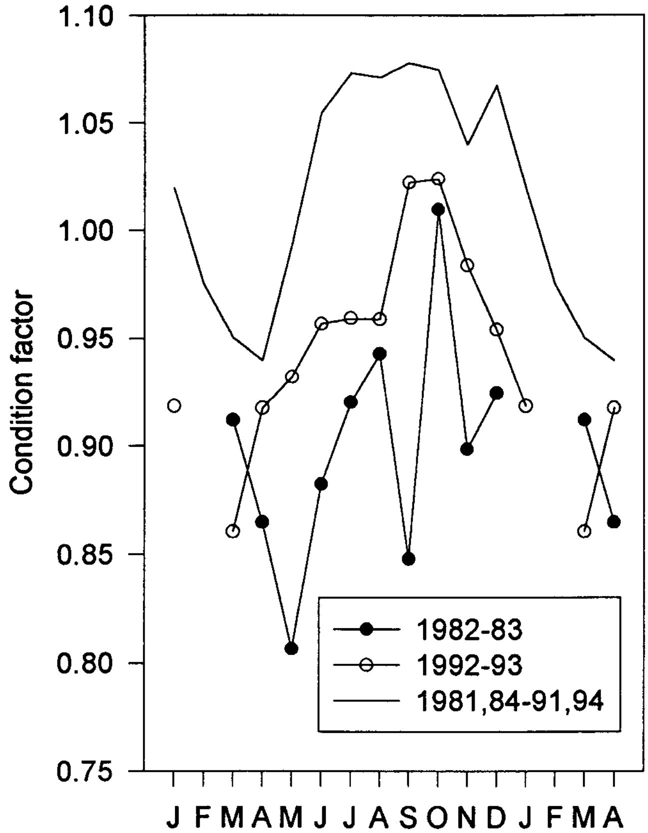

Figure 7. Seasonal condition factors of female rockfish during 1982–83; 1992–93; and 1981, 1984–91, and 1994.

monthly condition factor values were extremely variable. However, some of the monthly variations observed during the 1982–83 El Niño years, for both males and females, may be due to smaller sample size compared to the numbers of fish sampled during the 10 years grouped in the non-El Niño classification.

Gonadal Index

Male seasonal gonadal indices peaked in August; insemination occurred through October; and most testes were spent by January (figure 8). The August peak in male gonadal indices was preceded by two months (June and July) of maximum condition factor (figure 3). Female seasonal gonadal indices peaked in January, when most parturition occurred. Most ovaries were flaccid by March (figure 8). The January peak in female gonadal indices was preceded by four months (September through December) of maximum condition factor (figure 3).

The annual time series of male gonadal indices showed little interyear fluctuation. The minimum value occurred during the 1982–83 El Niño; however, male gonadal indices remained high during the 1992–93 El Niño (figure 9). Minima for females occurred during El Niño years, and high gonadal indices occurred during non-El

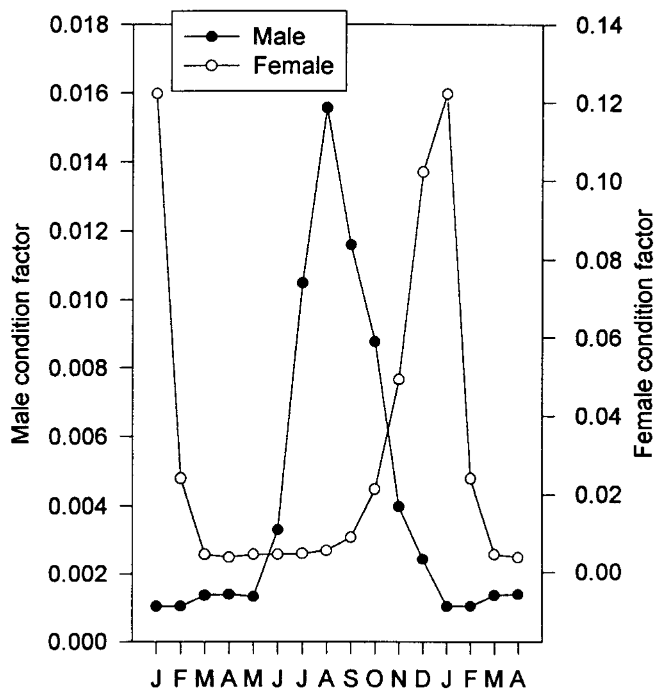

Figure 8. Seasonal gonadal indices of male (June–Sept.) and female (Nov.–Jan.) blue rockfish, 1981–94.

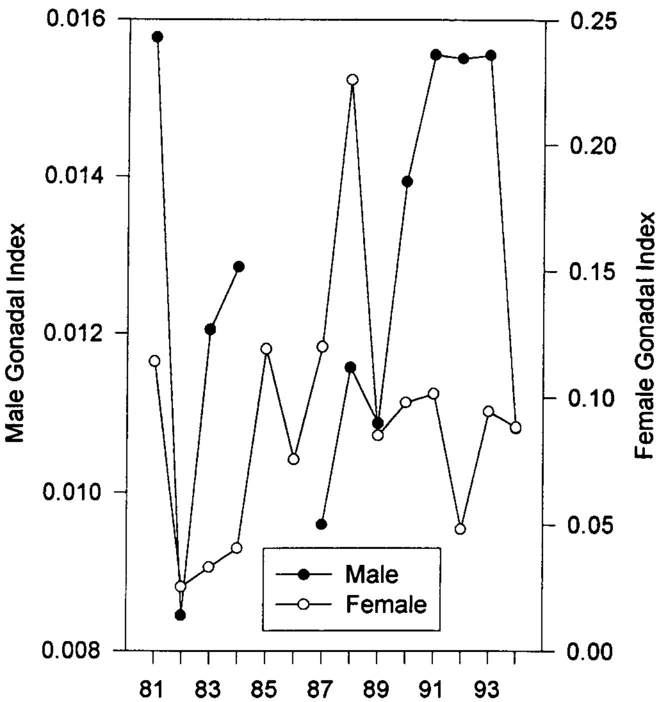

Figure 9. Annual gonadal indices of male and female blue rockfish, 1981–94.

Niño years. The maximum gonadal index in females occurred in association with the coldest period in the time series (figure 1). The recovery of female gonadal indices after the 1982 El Niño was slower than after the 1992 El Niño.

Statistical Relationships

To assess potential relationships with environmental factors, we performed standard Pearson correlation analyses comparing the time series of annual adult condition factors with annual and seasonal SST and UPI. As would be expected from the previously described pattern of lower condition factors during El Niño years, there was a general pattern of negative correlation with SST. The highest correlation was with fall SST ($R = -0.739$, $P = 0.0025$), but correlations with annual and spring SST were also significant at the 5% level (table 2). There were also significant (5%) positive correlations with spring and fall UPI. Correlations between condition factor and spring and fall environmental conditions were significant with both SST and UPI, whereas those with winter and summer SST and UPI were not significant.

Stepwise multiple regression analyses with annual condition factor as the dependent variable and the annual and seasonal environmental time series as independent variables resulted in a model (including fall and summer SST) which accounted for 73% of the variance in the condition factor time series.

Gonadal indices of male blue rockfish peaked in August

TABLE 2
Correlation Coefficients among Condition Factor, Gonadal Index (GI), Sea-Surface Temperature (SST), and Upwelling Index (UPI)

	Adult condition factor	Female gonadal index	Male gonadal index
Female GI	0.736**	—	0.059
Male GI	0.122	0.059	—
Annual SST	−0.588*	−0.508	0.071
Winter SST	−0.330	−0.153	0.306
Spring SST	−0.583*	−0.395	0.001
Summer SST	−0.005	−0.129	0.178
Fall SST	−0.739**	−0.650*	−0.209
Annual UPI	0.376	0.156	0.074
Winter UPI	0.482	0.274	−0.322
Spring UPI	0.541*	0.206	0.351
Summer UPI	−0.158	−0.110	−0.139
Fall UPI	0.564*	0.338	−0.038

* significant at $P < 0.05$
** significant at $P < 0.01$
Winter = Dec.–Feb.; spring = Mar.–May; summer = June–Aug.; fall = Sept.–Nov.

(figure 6). Insemination occurred through October, and testes were spent by January. Female gonadal indices peaked in January (figure 7). By March, most parturition had occurred, and ovaries were flaccid. Because of these differences it was not surprising that male and female gonadal indices were not significantly correlated ($R = 0.059$, $P = 0.856$). Male gonadal indices were not significantly correlated with the adult condition factor or any environmental factors (table 2). Annual gonadal indices for females were strongly positively correlated with adult condition factors ($R = 0.736$, $P = 0.003$). The only environmental variable that they were significantly correlated with was fall SST, which also had the strongest correlation with adult condition factor (table 2).

DISCUSSION

Adult seasonal condition factors are at a minimum in early spring, following the summer insemination period for males and the winter parturition period for females and before the onset of upwelling. Condition factors quickly rise in the spring and remain high until the culmination of the reproductive periods. Adult annual condition factors are negatively correlated with SST in spring and fall, and positively correlated with UPI in spring and fall.

Female gonadal indices are significantly correlated with adult condition factors and SST in the fall. The high negative correlation of adult condition factors with SST in the fall may indicate the importance of this period for increasing body weight (fat reservoirs). Guillemot et al. (1985) suggest that upwelling periods may provide energy for the accumulation of fat reservoirs. Past literature (Gotshall et al. 1965; Miller and Geibel 1973; Hobson and Chess 1988) stresses the importance of spring upwelling in producing food for blue rockfish. It may be possible that female blue rockfish use the initial food production in spring for growth in length, and later in the year begin to store fat reservoirs for reproduction. The production of these fat reservoirs may be critical to increased gonadal production, as evidenced by the high correlation of gonadal indices with adult condition factor and fall SST.

Male gonadal indices seem unrelated to somatic condition factors or environmental variables (SST or UPI). Males develop gonadal tissues during the early spring (June and July), when upwelling is at an annual maximum (figure 2) and consequently food is most abundant. The males' highest condition factors also occur at this time. Therefore males may be developing gonadal tissues during the early spring when food is abundant rather than developing them from stored fat later in the year as do females. Also the amount of male gonadal tissue produced is small in comparison to total body weight—much smaller than in the females. It should also be noted that gonadal development in males and females appears to respond differently to El Niño events. Females show a strong negative correlation to SST and a pattern of lower gonadal indices during El Niño years, whereas males do not.

Although cold spring SST and increased upwelling were significantly correlated with increased annual condition factors, the "best" multiple regression model suggests that high SSTs in the summer and fall are more important determinants of both condition factor and female gonadal development.

To evaluate the effect that populations of sexually mature rockfishes within reserves have on recruitment, we must be able to determine these populations' annual variability in spawning potential. This study demonstrates that environmental perturbations are highly correlated with the somatic and reproductive condition of adult blue rockfish. This reproductive potential must now be correlated with recruitment success as well as with environmental events that occur during the planktonic stage of YOY blue rockfish.

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