

Abstract.— Shortbelly rockfish *Sebastes jordani* is an abundant species that could support a large commercial fishery off central California. Prior studies of shortbelly rockfish growth were based on age data obtained from scales or whole otoliths. We show that broken and burnt otoliths provide reliable ages that are substantially different than those derived from previous methods. This new information was used to update estimates of the von Bertalanffy growth curve parameters, the natural mortality rate, and potential yield. We found that shortbelly rockfish live for up to 22 years. Males grew more slowly and reached a smaller maximum size than females. Estimates of natural mortality from three predictive models ranged from 0.212 to 0.378 for males and 0.203 to 0.437 for females. Assuming M is 0.20–0.35 and using biomass estimates from hydroacoustic surveys, we estimated that potential yield in the Ascension Canyon–Farallon Islands area ranges from 13,400 to 23,500 metric tons.

Age, Growth, and Potential Yield for Shortbelly Rockfish *Sebastes jordani*

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Shortbelly rockfish *Sebastes jordani* is an abundant species in California waters. In midwater trawl surveys of juvenile rockfish conducted off central California, shortbelly rockfish were far more abundant than any other rockfish species (Wyllie Echeverria et al. 1990). The biomass of shortbelly rockfish in the Ascension Canyon–Farallon Islands area was estimated from hydroacoustic studies (E. Nunnely, NMFS Alaska Fish. Sci. Cent., Seattle, WA 98115-0070, pers. commun., Jan. 1989) to be 295,000 metric tons (t) in 1977 and 152,700 t in 1980. These estimates are one to two times the estimated coastwide virgin biomass for widow rockfish *S. entomelas* (Lenarz and Hightower 1988), a species that supports a significant commercial fishery. Currently, there is no commercial or sport fishery for shortbelly rockfish, but interest in surimi production or a new method of bone softening of whole fish (Okada et al. 1988), combined with their high abundance, could lead to the development of a substantial commercial fishery. If a commercial fishery does develop, it will be important to have accurate life-history information for management purposes.

Previous studies of shortbelly rockfish life-history characteristics have

been based on age data from scales (maximum age 10 years, Phillips 1964) or whole otoliths (maximum age 12 years, Lenarz 1980). However, studies of other rockfish species (Six and Horton 1977, Beamish 1979, Kimura et al. 1979, Chilton and Beamish 1982, Boehlert and Yoklavich 1984, Stanley 1986, Leaman and Nagtegaal 1987) have shown that ages obtained from those structures tend to be underestimates, and that broken and burnt or sectioned otoliths are a more reliable method for determining fish age. W. Lenarz (Tiburon Lab., NMFS Southwest Fish. Sci. Cent., Tiburon, CA 94920, pers. commun., Jan. 1989) indicated that surface ageing of shortbelly rockfish otoliths was difficult and felt that the ages could have been greater than reported. For that reason, the objective of this study was to update the estimates of age, growth, and potential yield of shortbelly rockfish, based on examination of broken and burnt otoliths.

Materials and methods

Adult shortbelly rockfish were captured occasionally in 1983–88 midwater trawl surveys designed to monitor the abundance of juvenile

rockfish (Wyllie Echeverria et al. 1990). Samples were also obtained from a 1980 bottom-trawl survey of demersal adult rockfish (Gunderson and Sample 1980), and a 1981 fishery development survey using a midwater trawl (Kato 1981). The cod-end mesh size for these surveys ranged from 0.4 to 1.5 inches, and fish ages 1 and older were vulnerable to the gear. Otoliths were collected from 2238 fish from 48 tows at various locations along the northern California-central Oregon coast (Table 1). Sagittal otoliths were removed, cleaned, and either stored dry or in ethanol until they could be examined.

Following Kimura et al. (1979) and Lenarz (1987), we examined the edges of broken and burnt otoliths collected from all months to determine whether marks formed on an annual basis. We attempted to get at least 100 fish per month (pooled over years); however, sample sizes were less than 100 for February, August, September, October, and December (Fig. 1). The broken and burnt otoliths were examined without knowledge of sex, length, or date of capture. A dark burned edge was classified as winter growth; otherwise, the edge type was classified as summer growth. A few otoliths that appeared to be from older fish, for which edge type could not be identified clearly, were omitted from the study. Percent frequency of summer growth was plotted against month to examine periodicity in the formation of marks.

We used between- and within-reader comparisons to evaluate the consistency of broken and burnt otolith readings. To evaluate between-reader agreement, two readers independently examined a random subsample of 200 otoliths. To evaluate within-reader agreement, a random subsample of 200 otoliths was read twice, independently, by one reader. To compare ages obtained by otolith surface versus broken and burnt otoliths, one reader obtained ages for a random subsample of 200 otoliths, first from the surface and then independently from the broken and burnt halves.

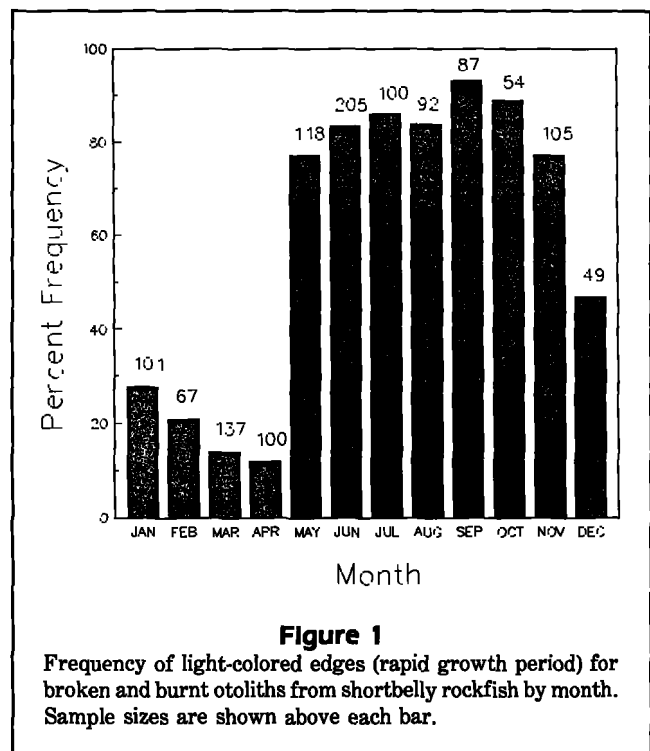
We used the von Bertalanffy growth equation (Ricker 1975) to relate length and age:

$$L_t = L_\infty (1 - e^{-k(t - t_0)})$$

where L_t = total length (mm) at age t ,
 L_∞ = estimate of average maximum length attained,
 k = growth completion rate,
 t_0 = theoretical age when fish is length 0.

Table 1
 Number of trawl tows containing adult shortbelly rockfish by area and year. Numbers in parentheses indicate total number of fish in the samples.

Region	1980	1981	1982	1983	1986	1988
Cape Blanco to Newport, OR	2 (175)	2 (100)		3 (130)		
Point Arena	1 (54)	1 (18)				
Farallon Islands		1 (49)			1 (107)	
Pescadero	1 (108)	2 (10)				2 (60)
Ascension Canyon	6 (423)	3 (147)	3 (152)	1 (126)	2 (91)	2 (101)
Monterey						2 (97)
Point Sur		13 (630)				
Total	10 (760)	21 (954)	3 (152)	4 (256)	3 (198)	6 (258)



Parameter estimates were obtained using nonlinear regression analysis (SAS Institute Inc. 1987). Growth equations were fitted separately for males and females and compared using the Extra Sum of Squares Principle (Draper and Smith 1981, Ratkowsky 1983).

To calculate potential yield, we estimated natural mortality (M) using several methods: (1) a regression equation relating maximum observed age and total mortality (Z , which equals M in this case) (Hoenig 1983); (2) an exponential model, in which the estimate of Z was based on both maximum observed age and sample size (Hoenig 1983); and a regression equation relating M to water temperature, average maximum length,

and growth completion rate (Pauley 1980). We used mean annual temperature for Ascension Canyon at a depth of 200 meters (8°C, Lynn et al. 1982). We did not estimate M using a catch curve (Ricker 1975) because shortbelly rockfish size tends to increase with depth and latitude (Lenarz 1980). For that reason, our opportunistic samples would not be expected to produce an unbiased estimate of the true age distribution.

Results and discussion

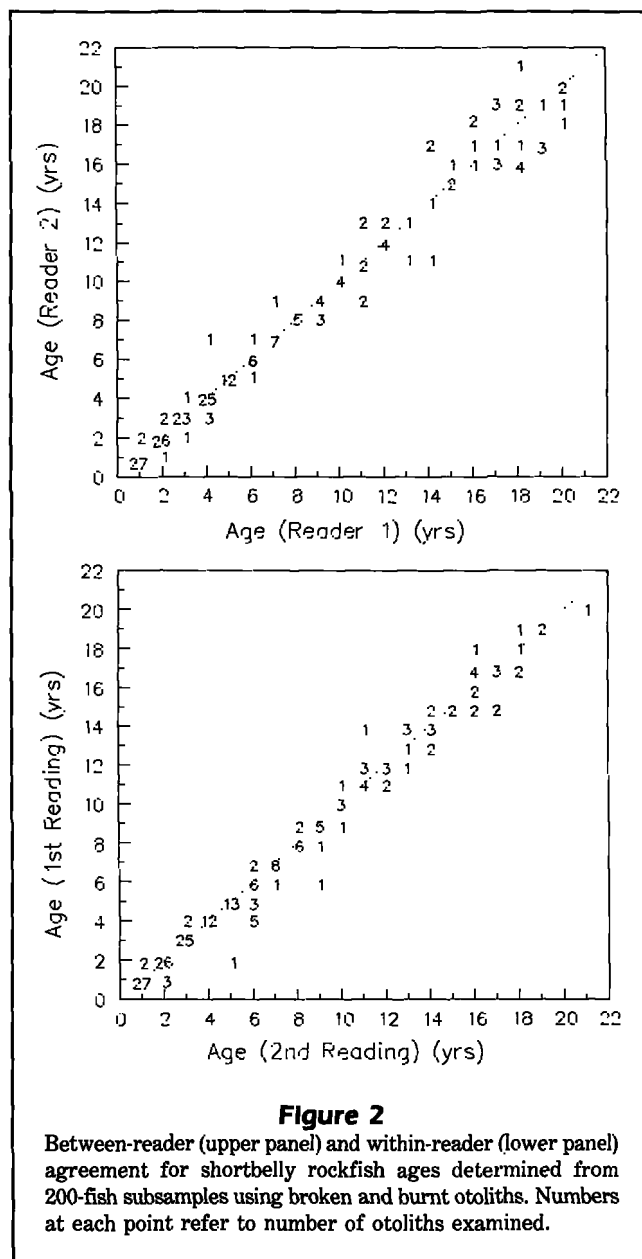
Age and growth

The edge-type analysis of broken and burnt otoliths supported our interpretation that marks were formed annually, generally between December and April (Fig. 1). This was similar to the findings of Kimura et al. (1979) for yellowtail rockfish *S. flavidus* and one month earlier than for widow rockfish *S. entomelas* (Lenarz 1987).

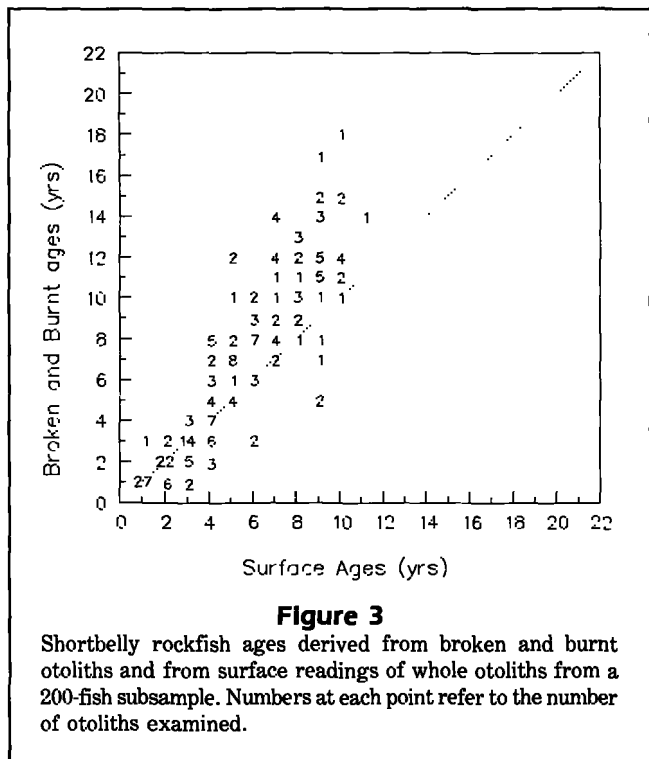
Between- and within-reader agreement was higher for shortbelly rockfish than for other rockfish species. Between-reader agreement was 76% to the year and 87% within one year; within-reader agreement was 77% to the year and 95% within one year (Fig. 2). Using whole otoliths, Six and Horton (1977) reported between-reader agreement for yellowtail rockfish *S. flavidus* to be 24% to the year and 71% within one year. For canary rockfish *S. pinniger*, Six and Horton (1977) reported within-reader agreements of 37 and 21% to the year for whole and sectioned otoliths, respectively. The higher levels of agreement for shortbelly rockfish could be due in part to their relatively young age, as percent agreement declined with increasing age beyond about age 4 (Fig. 2).

The comparison between ages derived from examination of the otolith surface and from broken and burnt halves revealed a systematic bias for fish older than age 4. Ages obtained from the otolith surface tended to be less than ages obtained from broken and burnt otoliths (Fig. 3). Beamish (1979) and Stanley (1986) reported similar results for Pacific ocean perch *S. alutus*.

Shortbelly rockfish live substantially longer than previously reported. The oldest fish we found was 22 years old as opposed to the previous estimate of 12 years (Lenarz 1980). There have been similarly large revisions in estimated maximum age of commercially important groundfish species off the west coast of Canada (Beamish and McFarlane 1987). Only 2 of 23 species were estimated to have maximum ages less than 20 years, and 13 *Sebastes* spp. (not including *S. jordani*) had maximum ages ranging from 36 to 140 years (Beamish and McFarlane 1987).



Fitted growth curves differed significantly by sex, with males having a slower growth rate and a smaller maximum size ($F_{crit}(3, 1000, 0.01) = 3.80$, $F_{calc} = 115.23$) (Fig. 4). Although sample sizes were small, there was some evidence that the oldest females were smaller than somewhat younger females (Fig. 4). This could be due to shrinkage in older fish through senescence (Liu and Walford 1969); natural selection favoring small, older fish that use available energy for reproduction rather than continued growth (Leaman and Beamish 1984); or higher mortality for faster-



growing fish (e.g., due to size-selective fishing mortality). The same trend has been observed for yellowtail rockfish and Pacific ocean perch *S. alutus* (Leaman and Beamish 1984).

Our fitted von Bertalanffy growth curves (Table 2, Fig. 4) differed considerably from those reported by Lenarz (1980) and Phillips (1964). Our L_{∞} values (Table 2) were lower than the estimates obtained from whole otolith ages (Lenarz 1980) or the combined-sex estimate obtained from scales (Phillips 1964). The decreases in L_{∞} as maximum age increased are consistent with Hirschhorn's (1974) observation that a change in the range of ages used to fit the von Bertalanffy growth curve can result in changes to the parameter estimates. Wilson (1985) reported that use of the broken and burnt technique on *S. diploproa* and *S. pinniger* significantly altered von Bertalanffy parameter estimates. Our estimate of k for males was lower than that reported by Lenarz whereas the value for females was higher. The combined-sex estimate of k reported by Phillips (1964) was greater than either estimate obtained in this study. These differences in growth rate may be due to the increase in maximum age as well as differences in depths and areas sampled.

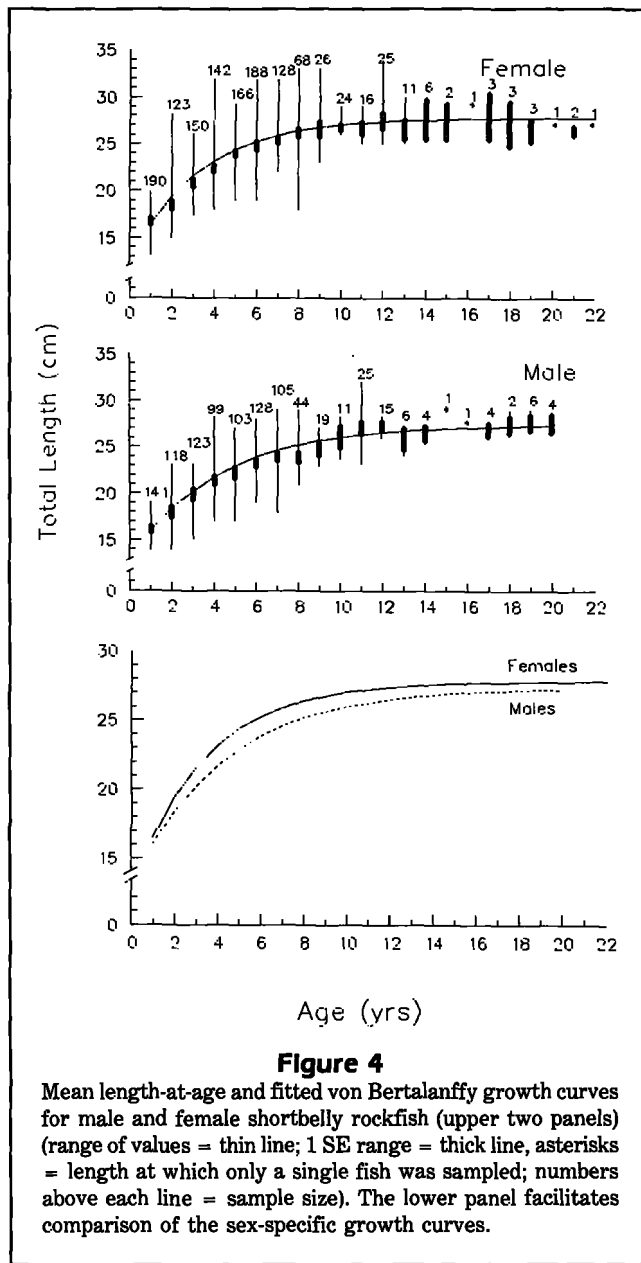


Table 2
Estimates of the von Bertalanffy growth parameters from scales, whole otoliths, and broken and burnt otoliths. Note: Phillips (1964) did not report separate values by sex; Lenarz (1980) did not report t_0 values.

Method	Sex	L_{∞} (mm)	t_0 (yr)	k (yr ⁻¹)	Source
Scales	Combined	315	-0.270	0.275	Phillips (1964)
Whole otoliths	Male	290	—	0.298	Lenarz (1980)
	Female	324	—	0.211	
Broken and burnt otoliths	Male	279	-3.649	0.184	Present study
	Female	281	-2.514	0.253	

Natural mortality

Using Hoenig's (1983) regression equation, we estimated that $M = 0.212$ for males and 0.203 for females. We obtained higher estimates using Hoenig's (1983) exponential model (males 0.378 , females 0.374) and Pauley's (1980) regression equation (males 0.356 , females 0.437). Our sample sizes used in Hoenig's exponential model may have been overestimates (relative to true simple random samples from the population) because of the within-tow correlation. The effective sample size would probably be between 48 (the number of tows) and the number aged per sex (males 959, females 1279). Given the uncertainty of the above estimates, we assume that 0.20 – 0.35 is a reasonable range for M until a catch-curve estimate can be made. Catch-curve estimates for other *Sebastes* spp. from British Columbia waters were lower, ranging from 0.03 to 0.10 with a range of maximum observed ages from 32 to 77 years (Leaman 1986). Based on a catch-curve analysis, Lenarz and Hightower (1985) estimated that M for widow rockfish *S. entomelas* off Washington–Oregon–California ranged from 0.15 to 0.20 . Lenarz (1984) reported that the maximum observed age for Washington–Oregon–California widow rockfish was about 45 years.

Potential yield

The historical estimate of maximum sustainable yield (MSY), $44,250$ t, was based on the relationship $MSY = 0.5MB_0$ (Gulland 1971), where B_0 was an estimate of virgin biomass (PFMC 1982). The MSY estimate was based on an assumed M of 0.275 and the 1977 survey estimate of Ascension Canyon to Farallon Islands area biomass ($295,000$ t) (E. Nunnely, NMFS Alaska Fish. Sci. Cent., Seattle, WA 98115-0070, pers. commun., Jan. 1989).

Our revised estimates of MSY were obtained from a more conservative model ($0.3MB_0$) that Gulland proposed because the former equation was thought to overestimate MSY (Gulland 1983). We used $M = 0.20$ – 0.35 and the average of the 1977 and 1980 Ascension Canyon to Farallon Island area biomass estimates ($223,850$ t). The revised estimates of MSY ($13,431$ – $23,504$ t) should be viewed as highly preliminary, given that the 1977 and 1980 biomass estimates had confidence intervals in excess of 50% and were not significantly different.

The above estimates of MSY were based on the assumption that the fishing mortality rate (F) that produces MSY would be about equal to M . An alternative approach for obtaining a recommended F would be to determine the fishing mortality rate that reduced spawning biomass per recruit to 35% of the unfished

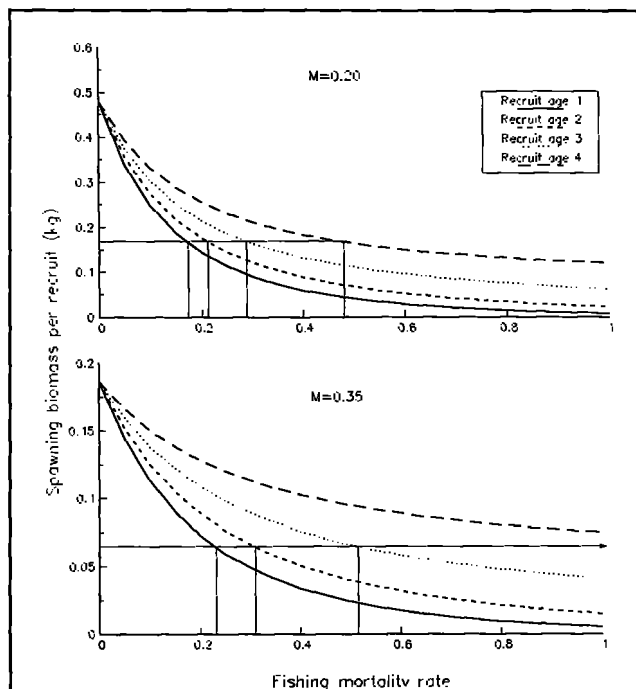


Figure 5

Female spawning biomass per recruit versus fishing mortality rate (F) at two levels of natural mortality (M) and four ages at recruitment. Horizontal lines represent spawning biomass per recruit equal to 35% of the level at $F=0$; vertical lines represent the associated F ($F_{35\%}$). $F_{35\%}$ exceeds 1.0 for $M = 0.35$ and recruitment age of 4 years.

level ($F_{35\%}$). That criterion is being used to manage most of the stocks in the Washington–Oregon–California groundfish fishery (PFMC 1990). Following Ricker's (1975) yield-per-recruit analysis, we calculated spawning biomass per recruit assuming $M = 0.20$ or 0.35 and linearly increasing maturity. Wyllie Echeverria (1987) reported that 50% of female shortbelly rockfish were sexually mature at age 2 and 100% at age 4. Those estimates were based on whole otolith ages; however, we found relatively good agreement between whole and broken-and-burnt otolith ages through age 4 (Fig. 3). The estimates of $F_{35\%}$ were similar to M if recruitment occurred at about age 2 (Fig. 5). Because shortbelly rockfish mature at a young age, estimates of $F_{35\%}$ increased considerably if recruitment was delayed. These results suggest that assuming $F = M$ when calculating potential yield should provide protection for the spawning stock.

Our estimates of MSY for the Ascension Canyon to Farallon Island area are greater than the current (coastwide) acceptable biological catch ($13,000$ t) established to permit development of a fishery (PFMC 1989);

therefore, a change in acceptable biological catch does not appear to be necessary to protect the stock. Estimates of shortbelly rockfish abundance (and potential yield) to the north and south of the surveyed area may not be feasible prior to development of a fishery. However, the limited data available suggest that other aggregations may exist. In a study of larval rockfish distributions from Baja California to Bodega Bay, California; MacGregor (1986) found that shortbelly rockfish larvae were most abundant in the Ascension Canyon to Farallon Islands area (49%). He also detected a large concentration in the Channel Islands off southern California (35%), suggesting the presence of a large number of adults in that area. Gunderson and Sample (1980) examined the distribution of pelagic adult rockfish from southern California to Vancouver, British Columbia. They found the highest concentration of shortbelly rockfish in the Ascension Canyon to Farallon Islands area but also detected concentrations in the Channel Islands, in the Point Sur area of California, and off Bodega Bay, California. A smaller concentration was found off the Columbia River in Oregon. These observations suggest that our estimates of MSY are conservative when applied coastwide. More refined estimates of potential yield should be possible once a fishery develops or once planned larval production surveys of the Ascension Canyon to Farallon Islands area have been conducted.

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