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SEPTEMBER 1994

PROGRESS IN ROCKFISH RECRUITMENT STUDIES

By

Staff of the Tiburon Laboratory
Edited by Maxwell B. Eldridge

ADMINISTRATIVE REPORT T-94-01

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Southwest Fisheries Science Center Administrative Report T-94-01

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Southwest Fisheries Science Center
National Marine Fisheries Service
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Tiburon, California 94920

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INTRODUCTION

Rockfish (Sebastes spp.) make up a major portion of landings from the west coast groundfish fishery (37,363 MT in 1991 or 45% of total groundfish landings exclusive of Pacific whiting). In this fishery, variability in year-class strength is a major source of uncertainty in management. This is the ninth annual report on studies conducted at the NMFS Tiburon Laboratory to measure this variation and to understand its source. This report covers the period from March 1993 to March 1994 and is the combined result of efforts from the Laboratory's three research Investigations: Groundfish Analysis, Groundfish Communities, and Groundfish Physiological Ecology. Research is summarized by life history stage: pelagic young-of-the-year (YOY) juvenile, benthic YOY juvenile, and adult. Objectives, methods, and previous results have been presented in earlier reports from this series (Lenarz and Moreland, 1985; Hobson *et al.*, 1986; Larson, 1987; Whipple, 1988; Hobson, 1989; Ralston, 1990; Whipple, 1991; Adams, 1992; Ralston, 1993).

STUDIES OF PELAGIC JUVENILES

The juveniles of Sebastes spp. school in the coastal pelagic environment for their first several months following parturition, and during this period are sampled by midwater trawl and from gut contents of predators.

Progress in Midwater Trawl Assessments

Since 1983 the Groundfish Analysis Investigation has fielded annual sea surveys designed to estimate the relative abundance of pelagic YOY juvenile rockfish (Table 1). This series of cruises has been conducted aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel David Starr Jordan between March and June, a time when pelagic stage YOY of most commercial species are sampled most readily. These surveys use a standard 26 x 26 m modified Cobb midwater trawl, with a cod-end liner of 1.27 cm stretched mesh. Spatially replicated "sweeps" of a series of standard stations are conducted in the study area between Pt. Reyes to the north and Cypress Point in the south (see Fig. 1 in Adams, 1992). As part of the survey design, the study area is subdivided into seven geographical strata, with five to six standard stations located within each stratum.

During the past year, one pelagic juvenile survey cruise was conducted (DSJ-9307). This cruise spanned a 32-day period during May-June and resulted in three consecutive sweeps through the study area. At each station a 15-minute nighttime trawl sample was taken at standard depth (30 m where possible, 10 m at shallow stations), and a CTD cast was made. In addition, at some stations standard trawls were made at 10-, 30-, and 100-m depth to provide information concerning the vertical distribution of pelagic YOY rockfishes. Supplemental CTD data were also gathered during the day along tracklines that criss-crossed the entire study area.

Table 1.--Summary of midwater trawl surveys conducted by the Groundfish Analysis Investigation for pelagic YOY rockfishes (Sebastes spp.) off the central California coast (1983-93).

Cruise	Sweep	Begin		End	Number of Standard Hauls
DSJ-8301	1	June 8	-	June 24, 1983	21
DSJ-8401	1	June 12	-	June 27, 1984	25
DSJ-8505	1	June 5	-	June 30, 1985	30
DSJ-8608	1	June 3	-	June 11, 1986	34
	2	June 11	-	June 18, 1986	28
	3	June 20	-	June 25, 1986	28
DSJ-8703	1	April 10	-	April 22, 1987	35
DSJ-8705	1	May 23	-	June 1, 1987	35
	2	June 2,	-	June 12, 1987	36
	3	June 12	-	June 21, 1987	35
DSJ-8804	1	April 16	-	April 22, 1988	29
DSJ-8806	1	May 22	-	June 2, 1988	35
	2	June 2	-	June 11, 1988	37
	3	June 11	-	June 18, 1988	33
DSJ-8904	1	May 14	-	May 24, 1989	33
	2	May 24	-	June 4, 1989	34
	3	June 4	-	June 13, 1989	33
DSJ-9003	1	March 28	-	April 6, 1990	38
DSJ-9005	1	May 13	-	May 22, 1990	34
	2	May 22	-	June 1, 1990	33
	3	June 1	-	June 10, 1990	32
DSJ-9105	1	May 14	-	May 24, 1991	35
	2	May 24	-	June 3, 1991	52
	3	June 3	-	June 10, 1991	34
DSJ-9206	1	May 11	-	May 19, 1992	31
	2	May 19	-	May 31, 1992	25
	3	June 2	-	June 17, 1992	32
DSJ-9307	1	May 13	-	May 21, 1993	32
	2	May 21	-	June 1, 1993	35
	3	June 3	-	June 13, 1993	33

Following the cruise, the identity of rockfish specimens was confirmed in the laboratory (Table 2), standard lengths were measured, and a subsample of otoliths was collected. As in previous years, the data were then compiled, edited, and added to the midwater trawl database.

Enhancements to Local Area Network Improve Computing Capabilities

During the past year the number of computers supported by the Laboratory's Local Area Network (LAN) has doubled in size. The network provides an Ethernet connection using coaxial cables and the TCP/IP protocol to link four Sun Microsystems workstations, eleven 386/486 personal computers, and one Macintosh Quadra in three different buildings. Sun's PC-NFS network

Table 2.--Species composition of pelagic juvenile rockfish taken during DSJ-9307.

Scientific Name	Common Name	N	%
Sebastes jordani	shortbelly rockfish	2,284	42.1
Sebastes goodei	chilipepper	1,249	23.0
Sebastes auriculatus	brown rockfish	1,216	22.4
Sebastes saxicola	stripetail rockfish	315	5.8
Sebastes caurinus	copper rockfish	82	1.5
Sebastes entomelas	widow rockfish	78	1.4
Sebastes mystinus	blue rockfish	36	0.6
Sebastes spp.	unidentified rockfish	31	0.6
Sebastes flavidus	yellowtail rockfish	30	0.6
Sebastes paucispinis	bocaccio	26	0.5
Sebastes hopkinsi	squarespot rockfish	25	0.5
Sebastes pinniger	canary rockfish	15	0.3
Sebastes melanops	black rockfish	7	0.1
Sebastes crameri	darkblotched rockfish	7	0.1
Sebastes levis	cowcod	5	0.1
Sebastes semicinctus	halfbanded rockfish	5	0.1
Sebastes serranoides	olive rockfish	5	0.1
Sebastes rufus	bank rockfish	5	0.1
Sebastes rastrelliger	grass rockfish	2	<0.1
Sebastes wilsoni	pygmy rockfish	1	<0.1

software and Hummingbird's eXceed X-windows emulator enables the PCs to act as full-functioning X-windows terminals on the UNIX-based Sun work-stations. PC-NFS also allows the PCs to access the workstation disk drives through the network as though they were local to the PC. The workstations run on the SPARC RISC cpu processor whose performance is superior to the 386 and 486 processors used in the personal computers. Software available on the workstations includes the C, Pascal, and Fortran programming languages as well as SAS, S+ and Mathematica. The workstations also provide over two gigabytes of file storage for shared laboratory databases.

The network enables laboratory scientists to share data over the network and distribute their computing load among the work-stations and personal computers. Program development and small computing jobs can be handled on the PCs, while large production and modeling runs are completed by the workstations. Peripheral devices accessible on the network include two Hewlett Packard laser jet printers, two QIC 150 Mb tape drives, one Exabyte 5 Gb tape drive, one modem, and one CDROM drive. (D. Roberts)

Processing of CTD Data

The Groundfish Analysis Investigation has taken over the routine processing of CTD data gathered during cruises aboard the R/V David Starr Jordan. All raw CTD data from cruises DSJ-9203, DSJ-9206, DSJ-9304, and DSJ-9307 were processed through a series

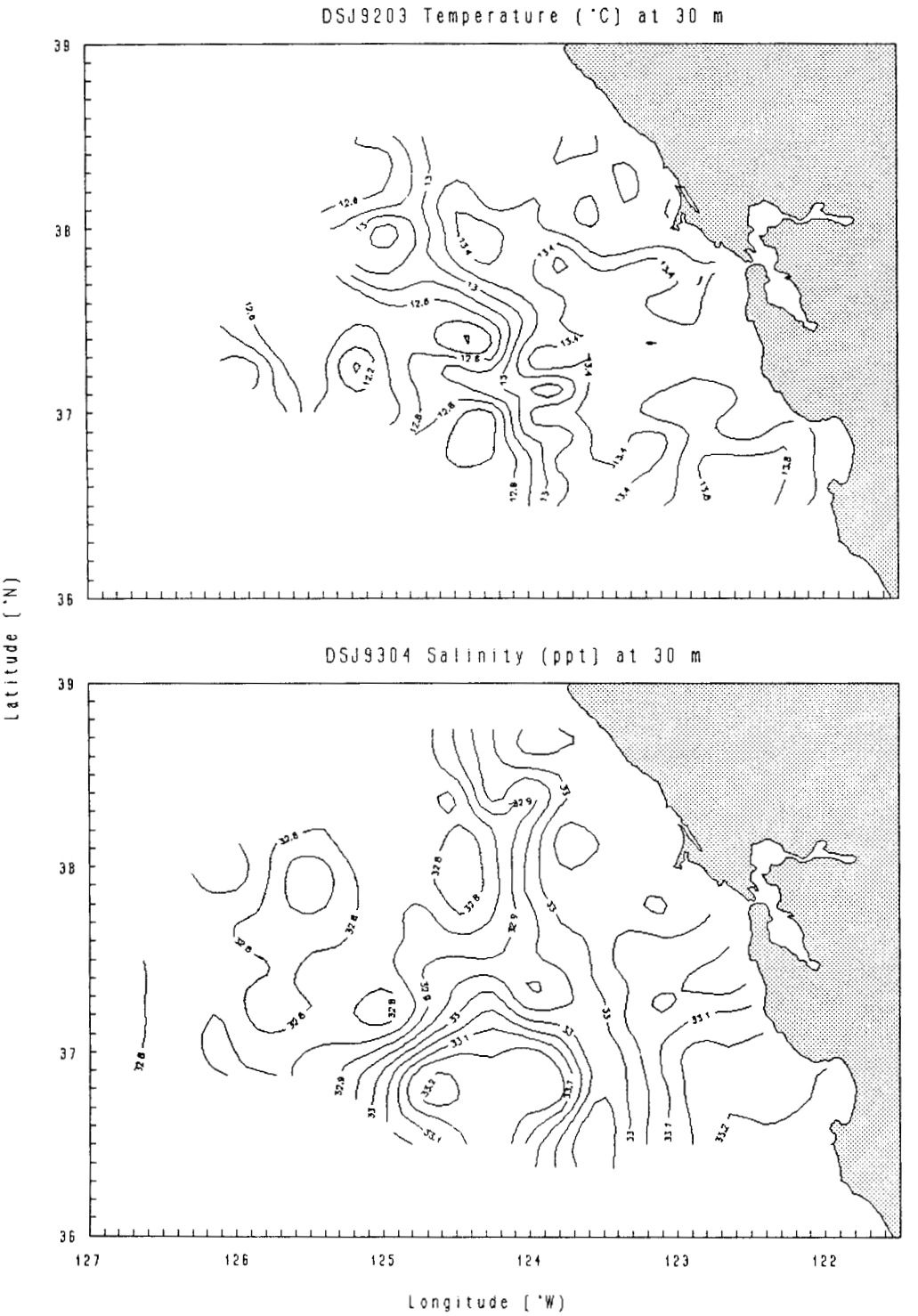

Figure 1. Contoured temperature (above) and salinity (below) observed at a depth of 30 m during MIK net surveys completed during March of 1992 (DSJ-9203) and 1993 (DSJ-9304).

of SEASOFT 4.011 modules using PC SAS programs to produce ASCII files which are stored on a SPARC 2 workstation networked to the Task's PCs. CTD temperature, salinity, and density at depth were then plotted and all plots were checked for spurious data. When possible, data spikes were edited. In addition, CTD temperature and salinity at the surface (2 meters depth) were compared with temperature and salinity data recorded by the thermosalinometer (TS) aboard the vessel to assess if there were any calibration problems. The ASCII files were processed using UNIX SAS on the SPARC 2 in order to generate separate files for 2-, 10-, 30-, 100-, 200-, 300-, and 500-m depth, which could then be used to generate horizontal contours using SURFER. The use of UNIX SAS greatly reduced the processing time. Contour files generated by SURFER were imported into FREELANCE and further edited, resulting in the final contour plots as shown in Figure 1. With these procedures, CTD data can be fully processed into contour plots within a week after the completion of a cruise. (K. Sakuma)

Size Selectivity of Midwater Trawl

The primary objective of the midwater trawl survey is to obtain annual indices of pelagic juvenile rockfish abundance. Owing to the small size of fish captured in some years (Fig. 2), abundance indices may be biased by the selective properties of the trawl net. In particular, there was concern that the trawl, which is equipped with a 1.27-cm (½") stretched mesh liner, did not adequately sample small fish present in 1983, 1986, and 1992.

The first attempt to quantify the selectivity of the trawl was made during the 1992 May-June survey (Ralston 1993). Those results indicated that the net representatively sampled juvenile shortbelly rockfish as small as 20 mm SL. To further study this topic, three nights were devoted to conducting additional trawls during the May-June survey in 1993. Similar methods were used in which a fine-mesh liner (0.635 cm; ¼") was used to capture small fish. Trawls were conducted in areas of high juvenile rockfish abundance. Each liner was used for half the night. All tows performed in a night began at the same position and were trawled in the same direction. A total of 21 trawls was made at three different stations. This year, length data from two species were analyzed, i.e., shortbelly rockfish (S. jordani) and brown rockfish (S. auriculatus). The length data were then analyzed to determine the size of juvenile rockfish that were fully retained by the larger mesh liner.

In 1993, the fish averaged 10-15 mm larger than in 1992. The length-frequency data revealed a bimodal distribution for shortbelly rockfish and a normal distribution for brown rockfish (Figs. 3 and 4). Ideally, elevated numbers of small fish need to be collected by the smaller mesh liner for the analyses to be informative. The length data collected for brown rockfish were not useful in identifying the minimum size of capture of the large mesh, as noted by the similar mean lengths. Large numbers of small shortbelly rockfish were collected at Station 3.

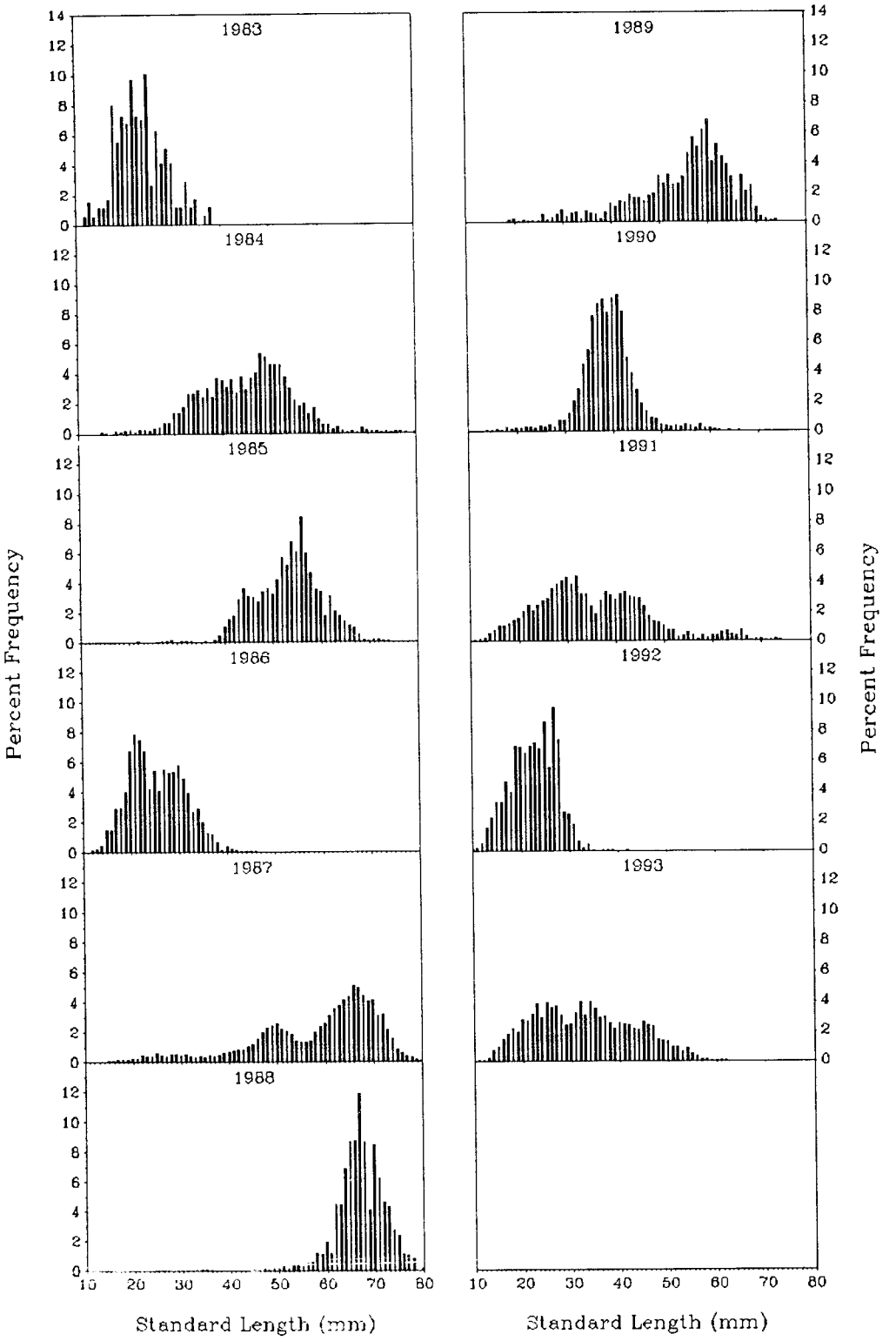

Figure 2. Length-frequency distributions of pelagic juvenile rockfish (1983-93). May-June samples and Table 3 species only.

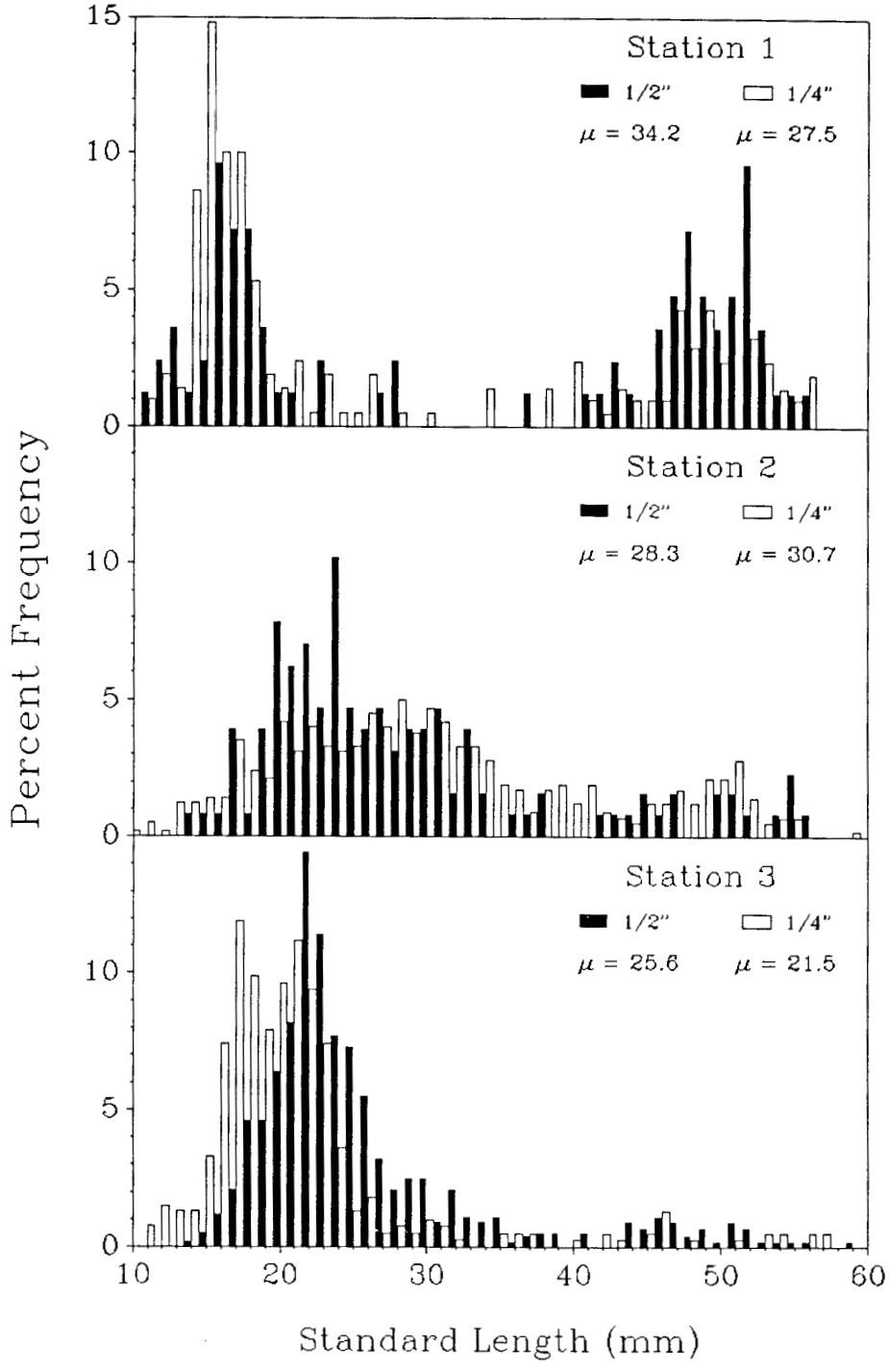

Figure 3. Length-frequency distributions of Sebastes jordani collected in trawls using liners of different mesh size.

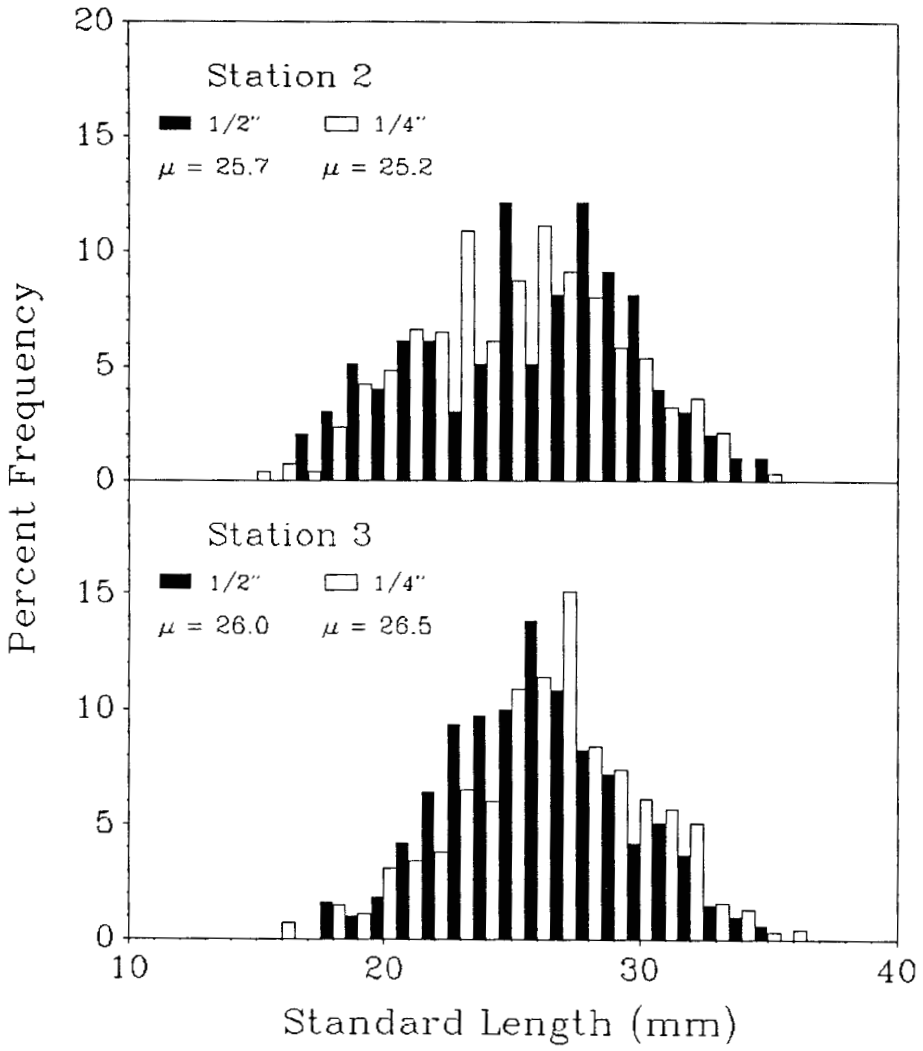

Figure 4. Length-frequency distributions of Sebastes auriculatus collected in trawls using liners of different mesh size.

Additional analysis included computing the ratio of catch at size from each liner (1.27-mm liner catch divided by the 0.635-mm liner catch; Fig. 5). With equal effort, this ratio should start at zero for the smallest sizes and should attain a value of 1.00 at the size where both nets sample with equal efficiency. The data were pooled over 5-mm intervals to increase sample sizes. Although small sample size still limits the power of the analysis, three of the five cases indicate that the larger mesh liner adequately captured juvenile rockfish at a size of 20 mm SL. For the second year, we conclude that 25 mm SL is a conservative estimate of the full vulnerability cutoff point of juvenile rockfish to the trawl used during these surveys. (D. Woodbury)

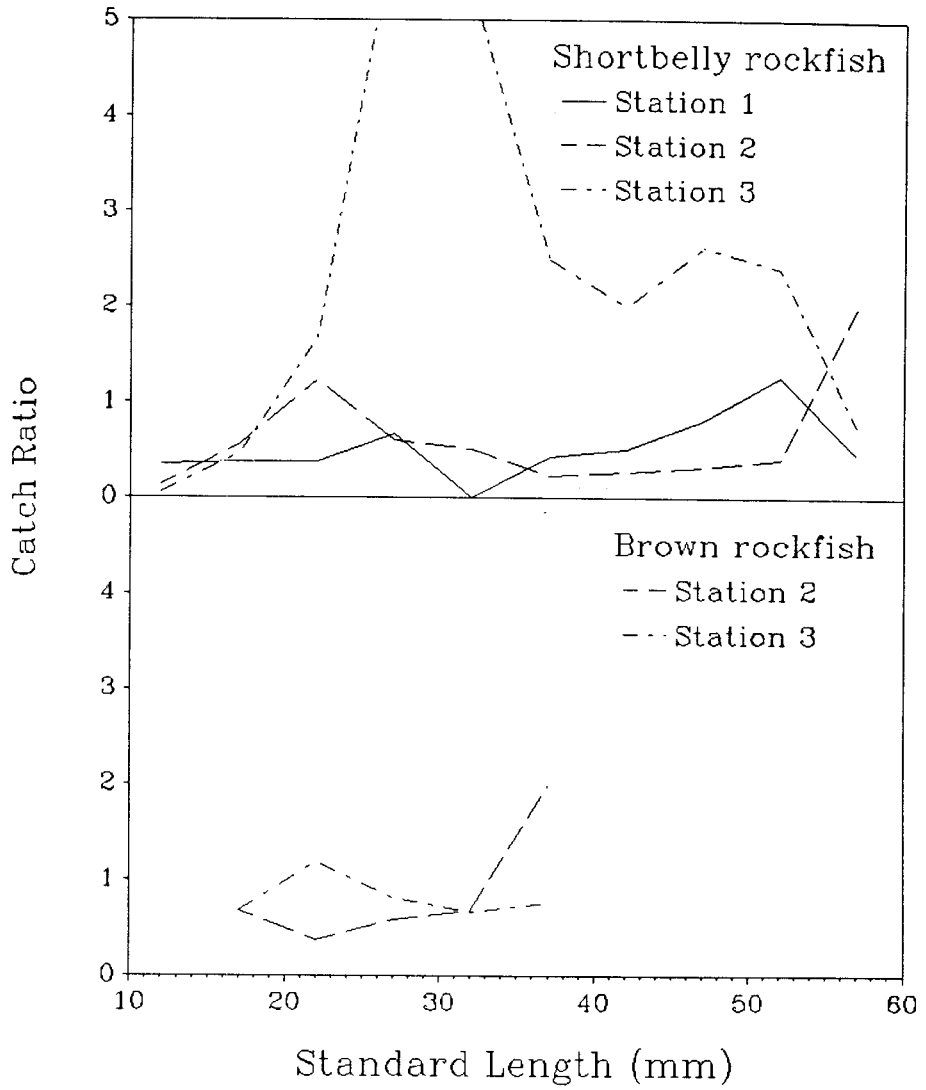

Figure 5. Ratio of catch at length (pooled over 5-mm intervals) collected in trawls using liners with two different mesh sizes.

Estimation of Abundance

As described in last year's report (Ralston, 1993), pelagic juvenile rockfish abundance indices are now adjusted to account for interannual differences in size structure (Fig. 2). After truncating the data to only include fish greater than or equal to 25 mm SL (the smallest size of fully vulnerable fish), additional adjustments were performed in a two-step process. First, fish ages were predicted from length measurements using inverse growth curves estimated for each of the 15 primary species of rockfish sampled during the 11-year period from 1983-93, amounting to 165 species-year combinations. Specifically, the predicted age of

species "s" in year "y" at standard length "l" is $\hat{\tau}_{syl} = \alpha_{sy} + \beta_{sy}l$, where the α_{sy} and β_{sy} were estimated by least-squares regressions in the 45 cases where direct age data were available from counts of daily increments (e.g., Woodbury and Ralston, 1991). If otolith data were unavailable in a particular year, the growth parameters were estimated from analyses of covariance of the otolith data, assuming a common slope (days/mm) and either (1) the mean of interannual intercepts (within species) or (2) the mean of within-year interspecific intercepts for those species where no otolith data were available at all.

For each haul conducted and each species sampled (subscripts not included), abundances of fish of different ages were then adjusted to a common age using an exponential model with a constant mortality rate (Z), i.e.,

$$N_l^* = N_l \exp[-Z(\tau^* - \hat{\tau}_{syl})]$$

where N_l^* is the adjusted number of individuals of length "l", N_l is the unadjusted number, and τ^* is the common age to which abundances were adjusted. In all calculations, τ^* was set equal to 100 days, which is representative of the midrange of pelagic juvenile rockfish ages (Woodbury and Ralston, 1991), and Z was fixed at 0.04 d^{-1}. This latter figure was based on estimates of mortality rate for larval shortbelly rockfish (S. jordani; unpublished data), settled juvenile blue rockfish (S. mystinus; Adams and Howard, In review), pelagic juvenile cod and northern anchovy (Bradford, 1992), and Pacific whiting (Hollowed, 1992). The N_l^* were then summed over all lengths that occurred within each haul, yielding a haul-specific catch of each rockfish species sampled, adjusted for variable length structure.

As in years past, final calculation of abundance statistics from our midwater trawl surveys is based upon simple logarithmic transformation of the data, i.e., $y_{jk} = \log_e[x_{jk} + 0.1]$, where x_{jk} is the length-adjusted catch taken in haul j = 1 to N_k located in stratum k = 1 to 7. We estimate the stratum means and variances according to

$$\overline{y}_k = \frac{1}{N_k} \sum_{j=1}^{N_k} y_{jk}$$

$$s_k^2 = \frac{1}{N_k - 1} \sum_{j=1}^{N_k} (y_{jk} - \overline{y}_k)^2 \quad .$$

The equally weighted stratified mean ($\overline{y}_{str}$) is then used as a sweep-specific index of abundance. This statistic and its squared standard error are defined as

$$\overline{y}_{str} = \frac{1}{7} \sum_{k=1}^{7} \overline{y}_k$$

$$s^2_{\overline{y}_{str}} = \frac{1}{7} \sum_{k=1}^{7} \frac{s_k^2}{N_k} \quad .$$

We report all indices, their standard errors and 95% confidence intervals, and back-transformations of the indices in Table 3. Note that abundance statistics have been developed for each of the fifteen most commonly caught rockfish species taken during each sweep completed since 1983. Shown also are indices for the total catch of juvenile rockfish, and indices for two sets of species that tend to fluctuate in synchrony, i.e., the Sebastes entomelas PCA group and the S. jordani PCA group (Hobson, 1989; Ralston, 1990). (S. Ralston)

Annual Trends in the Abundance of Pelagic Juveniles

As in past years, the maximum value of the stratified mean index, taken from sweeps conducted during the May-June cruise, was used as an annual estimate of the relative abundance of pelagic juvenile rockfish. Results show that 1993 abundances of the 15 most commonly sampled Sebastes spp. were invariably higher than the 1992 El Niño year, with the notable exception of S. hopkinsi (Fig. 6). As has been the case since the inception of these surveys, catches of S. jordani outnumbered those of other species (Table 2).

To better compare and contrast the annual abundance indices (I_{sy}) of the various species (s) in each year (y), the long-term (11 yr) means (μ_s) and standard deviations (σ_s) were calculated. From these, species-specific standard scores were derived for each year from 1983 to 1993 according to: $Z_{sy} = (I_{sy}-\mu_s)/\sigma_s$. Standard scores were calculated for the ten most abundant species occurring in our trawl samples (i.e., S. jordani, S. entomelas, S. goodei, S. flavidus, S. mystinus, S. melanops, S. paucispinis, S. pinniger, S. hopkinsi, and S. saxicola). Of the five species excluded, one (S. auriculatus) correlates poorly with the trends of other species (see Fig. 6) and four are uncommon (S. wilsoni, S. levis, S. rufus, and S. crameri). Results are plotted against survey year in Figure 7.

Note that for this primary subset of ten species, El Niño years (1983, 1992, and to some degree 1986) result in very much reduced levels of abundance. Conversely, 1987 and 1988 were very strong years for virtually all of these species. Data from 1991 suggest high levels of abundance, although they were especially high for northerly distributed species such as S. entomelas, S. flavidus, S. melanops, and S. pinniger (Fig. 6). Data collected from this most recent year (DSJ-9307) indicate a rebound from the poor catches of 1992, although 8 of 10 species remained below

Table 3.--Annual sweep-specific indices of abundance for 15 of the most common species of YOY Sebastes collected. Species/sweep combinations wherein a species was not collected at sizes > 25 mm SL at any of the standard stations are not listed. Shown are the adjusted index (on $\log_e$ scale), its standard error (SE), a 95% confidence interval for the estimate, and a back-transformation of the index that has been corrected for first order bias.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
			Sebastes auriculatus (brown rockfish)			
8401	1	-1.41	0.20	-1.86	-0.96	0.15
8608	1	-0.83	0.19	-1.24	-0.41	0.35
8608	2	-1.37	0.23	-1.86	-0.88	0.16
8608	3	-2.00	0.13	-2.31	-1.69	0.04
8703	1	-2.08	0.12	-2.35	-1.81	0.03
8705	1	-2.19	0.08	-2.38	-2.01	0.01
8705	2	-2.23	0.07	-2.43	-2.03	0.01
8804	1	-1.93	0.13	-2.23	-1.62	0.05
8904	1	-2.21	0.06	-2.37	-2.05	0.01
9005	1	-2.08	0.11	-2.33	-1.84	0.03
9005	2	-2.21	0.07	-2.38	-2.04	0.01
9105	1	-1.89	0.11	-2.15	-1.63	0.05
9105	2	-1.53	0.19	-1.99	-1.07	0.12
9105	3	-1.45	0.28	-2.11	-0.80	0.14
9206	3	-2.24	0.07	-2.42	-2.05	0.01
9307	1	-1.87	0.11	-2.09	-1.64	0.06
9307	2	-0.79	0.30	-1.42	-0.15	0.38
9307	3	-0.74	0.24	-1.29	-0.19	0.39
			Sebastes crameri (darkblotched rockfish)			
8401	1	-2.08	0.16	-2.47	-1.68	0.03
8505	1	-2.20	0.11	-2.49	-1.90	0.01
8703	1	-2.16	0.10	-2.40	-1.91	0.02
8705	1	-2.10	0.13	-2.41	-1.80	0.02
8705	2	-2.25	0.06	-2.40	-2.09	0.01
8804	1	-1.91	0.12	-2.19	-1.62	0.05
8806	1	-2.11	0.14	-2.43	-1.79	0.02
8806	2	-2.23	0.07	-2.42	-2.04	0.01
9005	1	-2.25	0.05	-2.40	-2.10	0.01
9105	1	-2.23	0.07	-2.42	-2.05	0.01
9105	2	-2.06	0.14	-2.37	-1.74	0.03
9105	3	-2.24	0.06	-2.41	-2.07	0.01
9307	1	-2.00	0.12	-2.27	-1.73	0.04
9307	2	-2.23	0.07	-2.41	-2.05	0.01

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
			Sebastes entomelas (widow rockfish)			
8301	1	-2.20	0.10	-2.49	-1.91	0.01
8401	1	-0.45	0.60	-2.18	1.27	0.66
8505	1	1.71	0.58	0.22	3.19	6.43
8608	1	-1.92	0.17	-2.28	-1.55	0.05
8608	2	-2.13	0.12	-2.41	-1.86	0.02
8703	1	-1.92	0.15	-2.26	-1.58	0.05
8705	1	0.34	0.36	-0.41	1.09	1.40
8705	2	1.15	0.36	0.40	1.89	3.27
8705	3	-1.72	0.22	-2.21	-1.23	0.08
8804	1	-1.32	0.31	-2.28	-0.36	0.18
8806	1	-0.26	0.34	-0.97	0.45	0.72
8806	2	0.50	0.29	-0.11	1.11	1.62
8806	3	-1.77	0.21	-2.25	-1.29	0.07
8904	1	-2.22	0.08	-2.44	-2.01	0.01
8904	2	-1.49	0.24	-2.06	-0.92	0.13
8904	3	-2.14	0.12	-2.42	-1.85	0.02
9005	1	-1.83	0.23	-2.39	-1.28	0.06
9005	2	-1.79	0.18	-2.21	-1.37	0.07
9005	3	-2.12	0.10	-2.35	-1.89	0.02
9105	1	-2.20	0.07	-2.37	-2.03	0.01
9105	2	-1.26	0.26	-1.81	-0.71	0.19
9105	3	0.78	0.39	-0.07	1.62	2.25
9307	1	-1.57	0.17	-1.94	-1.21	0.11
9307	2	-0.85	0.30	-1.48	-0.23	0.35
9307	3	-1.43	0.29	-2.07	-0.78	0.15
			Sebastes flavidus (yellowtail rockfish)			
8301	1	-2.12	0.12	-2.46	-1.78	0.02
8401	1	-0.63	0.53	-2.04	0.77	0.51
8505	1	-0.11	0.34	-0.81	0.59	0.85
8608	1	-1.93	0.15	-2.28	-1.57	0.05
8608	2	-1.81	0.15	-2.16	-1.45	0.07
8608	3	-2.13	0.13	-2.53	-1.74	0.02
8705	1	-1.64	0.25	-2.16	-1.13	0.10
8705	2	-0.89	0.27	-1.46	-0.33	0.33
8705	3	-1.55	0.25	-2.08	-1.03	0.12
8804	1	-2.12	0.13	-2.43	-1.81	0.02
8806	1	-0.68	0.32	-1.35	-0.01	0.43
8806	2	-1.32	0.25	-1.85	-0.79	0.18
8904	1	-2.06	0.13	-2.38	-1.74	0.03
8904	2	-1.68	0.19	-2.09	-1.27	0.09
8904	3	-1.65	0.22	-2.13	-1.18	0.10

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
9005	1	-2.03	0.13	-2.32	-1.73	0.03
9005	2	-1.74	0.22	-2.45	-1.02	0.08
9005	3	-2.08	0.13	-2.37	-1.79	0.03
9105	1	-1.91	0.17	-2.27	-1.56	0.05
9105	2	-1.00	0.27	-1.56	-0.44	0.28
9105	3	0.19	0.32	-0.48	0.86	1.17
9206	3	-2.24	0.06	-2.41	-2.06	0.01
9307	1	-1.91	0.17	-2.27	-1.56	0.05
9307	2	-1.61	0.22	-2.08	-1.13	0.11
9307	3	-1.42	0.29	-2.08	-0.75	0.15
		Sebastes goodei (chilipepper)				
8401	1	-0.48	0.44	-1.63	0.67	0.58
8505	1	-1.80	0.13	-2.07	-1.52	0.07
8608	1	-1.76	0.14	-2.06	-1.46	0.07
8608	2	-1.93	0.15	-2.25	-1.61	0.05
8608	3	-2.11	0.10	-2.35	-1.88	0.02
8703	1	-0.49	0.30	-1.13	0.15	0.54
8705	1	1.02	0.35	0.29	1.75	2.84
8705	2	-0.35	0.38	-1.16	0.45	0.66
8705	3	-1.25	0.25	-1.82	-0.68	0.20
8804	1	2.65	0.41	1.75	3.55	15.26
8806	1	0.31	0.48	-0.69	1.31	1.43
8806	2	-1.48	0.33	-2.20	-0.76	0.14
8806	3	-1.91	0.28	-2.57	-1.25	0.05
8904	1	-1.30	0.31	-1.97	-0.62	0.19
8904	2	-2.17	0.09	-2.39	-1.95	0.01
9003	1	-2.04	0.12	-2.32	-1.76	0.03
9005	1	-1.55	0.25	-2.07	-1.02	0.12
9005	2	-1.80	0.19	-2.22	-1.39	0.07
9105	1	-2.12	0.10	-2.35	-1.89	0.02
9105	2	-1.55	0.21	-2.01	-1.09	0.12
9105	3	-0.89	0.28	-1.48	-0.30	0.33
9206	3	-1.77	0.17	-2.14	-1.39	0.07
9307	1	0.80	0.29	0.19	1.41	2.22
9307	2	0.54	0.33	-0.15	1.23	1.71
9307	3	-1.20	0.33	-1.94	-0.46	0.22
		Sebastes hopkinsi (squarespot rockfish)				
8401	1	-1.14	0.44	-2.19	-0.09	0.25
8505	1	-1.01	0.31	-1.66	-0.37	0.28
8608	1	-2.19	0.08	-2.38	-2.00	0.01
8608	2	-2.24	0.06	-2.42	-2.06	0.01
8703	1	-2.04	0.13	-2.33	-1.76	0.03

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	Upper	Back Transform
8705	1	-0.12	0.25	-0.66	0.42	0.81
8705	2	-0.69	0.34	-1.40	0.02	0.43
8705	3	-2.23	0.08	-2.44	-2.02	0.01
8804	1	-0.42	0.37	-1.21	0.36	0.60
8806	1	-0.29	0.38	-1.08	0.51	0.71
8806	2	-0.85	0.25	-1.36	-0.34	0.34
8806	3	-2.22	0.08	-2.45	-1.98	0.01
8904	1	-1.93	0.18	-2.34	-1.53	0.05
8904	2	-2.15	0.11	-2.40	-1.89	0.02
8904	3	-2.06	0.10	-2.33	-1.79	0.03
9003	1	-2.27	0.03	-2.35	-2.20	0.00
9005	1	-1.87	0.24	-2.49	-1.25	0.06
9005	3	-2.22	0.08	-2.44	-2.01	0.01
9105	2	-2.18	0.09	-2.45	-1.90	0.01
9105	3	-1.36	0.18	-1.76	-0.97	0.16
9206	3	-1.71	0.19	-2.12	-1.31	0.08
9307	1	-1.81	0.14	-2.11	-1.51	0.06
9307	2	-1.78	0.14	-2.09	-1.47	0.07
9307	3	-2.22	0.05	-2.36	-2.09	0.01
		Sebastes jordani (shortbelly rockfish)				
8301	1	-1.64	0.36	-2.49	-0.79	0.11
8401	1	1.06	0.71	-0.78	2.90	3.61
8505	1	1.33	0.50	0.24	2.42	4.19
8608	1	-0.07	0.33	-0.77	0.63	0.89
8608	2	-0.35	0.33	-1.05	0.35	0.64
8608	3	-1.65	0.23	-2.17	-1.14	0.10
8703	1	-0.94	0.28	-1.53	-0.35	0.31
8705	1	2.14	0.42	1.25	3.03	9.17
8705	2	3.46	0.47	2.47	4.46	35.66
8705	3	0.14	0.40	-0.70	0.98	1.14
8804	1	2.30	0.52	0.94	3.65	11.29
8806	1	3.16	0.52	2.04	4.27	26.83
8806	2	2.29	0.42	1.39	3.18	10.64
8806	3	1.60	0.52	0.50	2.69	5.53
8904	1	1.61	0.33	0.93	2.29	5.19
8904	2	1.25	0.38	0.46	2.03	3.64
8904	3	-0.07	0.40	-0.91	0.77	0.91
9003	1	-1.91	0.15	-2.25	-1.56	0.05
9005	1	-0.16	0.40	-1.03	0.72	0.83
9005	2	-0.79	0.31	-1.43	-0.15	0.38
9005	3	-1.88	0.19	-2.31	-1.46	0.05
9105	1	-1.55	0.23	-2.05	-1.05	0.12
9105	2	-0.72	0.26	-1.27	-0.16	0.41
9105	3	1.54	0.34	0.83	2.24	4.82

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
9206	3	-0.64	0.36	-1.54	0.25	0.46
9307	1	0.22	0.23	-0.26	0.71	1.18
9307	2	0.56	0.36	-0.20	1.32	1.77
9307	3	-0.62	0.38	-1.60	0.37	0.48
		Sebastes levis (cowcod)				
8505	1	-2.11	0.14	-2.45	-1.76	0.02
8608	1	-2.26	0.04	-2.38	-2.15	0.00
8703	1	-2.11	0.14	-2.44	-1.78	0.02
8705	1	-1.79	0.18	-2.19	-1.39	0.07
8705	2	-2.21	0.09	-2.47	-1.95	0.01
8705	3	-2.05	0.12	-2.32	-1.78	0.03
8804	1	-1.53	0.23	-2.02	-1.03	0.12
8806	1	-2.22	0.09	-2.44	-1.99	0.01
8904	2	-2.21	0.10	-2.47	-1.94	0.01
9307	1	-2.19	0.07	-2.38	-2.01	0.01
9307	2	-2.15	0.11	-2.40	-1.89	0.02
		Sebastes melanops (black rockfish)				
8505	1	-1.75	0.26	-2.40	-1.09	0.08
8608	1	-2.26	0.05	-2.39	-2.12	0.00
8705	1	-1.96	0.14	-2.26	-1.65	0.04
8705	2	-1.67	0.20	-2.10	-1.23	0.09
8705	3	-2.18	0.09	-2.41	-1.94	0.01
8806	1	-2.08	0.12	-2.37	-1.80	0.03
8806	2	-1.72	0.20	-2.14	-1.30	0.08
8904	2	-2.07	0.12	-2.36	-1.78	0.03
8904	3	-2.16	0.14	-2.76	-1.57	0.02
9005	1	-2.21	0.07	-2.36	-2.05	0.01
9005	2	-2.16	0.11	-2.51	-1.81	0.02
9105	1	-2.21	0.09	-2.51	-1.91	0.01
9105	2	-2.16	0.10	-2.42	-1.90	0.02
9105	3	-1.41	0.24	-1.92	-0.90	0.15
9307	1	-2.21	0.06	-2.37	-2.04	0.01
9307	2	-2.21	0.06	-2.36	-2.07	0.01
9307	3	-2.12	0.14	-2.59	-1.65	0.02
		Sebastes mystinus (blue rockfish)				
8505	1	-0.21	0.31	-0.86	0.45	0.75
8608	1	-2.03	0.15	-2.37	-1.69	0.03
8703	1	-1.95	0.17	-2.34	-1.56	0.04
8705	1	0.82	0.38	0.03	1.60	2.33
8705	2	-0.02	0.42	-0.90	0.87	0.97

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	Upper	Back Transform
8804	1	0.12	0.34	-0.62	0.86	1.09
8806	1	1.08	0.35	0.35	1.80	3.03
8806	2	0.50	0.26	-0.05	1.05	1.60
8806	3	-2.13	0.12	-2.42	-1.84	0.02
8904	1	-1.11	0.31	-1.77	-0.44	0.25
8904	2	-0.81	0.31	-1.48	-0.13	0.37
8904	3	-1.89	0.20	-2.32	-1.45	0.05
9005	1	-1.31	0.28	-1.89	-0.73	0.18
9005	2	-1.51	0.27	-2.09	-0.94	0.13
9005	3	-2.25	0.05	-2.40	-2.10	0.01
9105	1	-1.99	0.19	-2.41	-1.56	0.04
9105	2	-0.85	0.25	-1.39	-0.31	0.34
9105	3	-0.38	0.35	-1.11	0.36	0.63
9206	3	-2.23	0.07	-2.43	-2.02	0.01
9307	1	-1.59	0.22	-2.05	-1.14	0.11
9307	2	-1.36	0.28	-1.96	-0.76	0.17
		Sebastes paucispinis (bocaccio)				
8401	1	-0.38	0.45	-2.00	1.23	0.66
8505	1	-1.93	0.09	-2.14	-1.71	0.05
8608	1	-1.33	0.25	-1.89	-0.78	0.17
8608	2	-1.70	0.16	-2.04	-1.35	0.09
8608	3	-2.20	0.10	-2.49	-1.91	0.01
8703	1	-1.85	0.17	-2.26	-1.43	0.06
8705	1	-1.07	0.33	-1.76	-0.38	0.26
8705	2	-0.94	0.31	-1.59	-0.29	0.31
8705	3	-1.82	0.19	-2.23	-1.41	0.06
8804	1	-0.31	0.25	-0.84	0.22	0.65
8806	1	-0.73	0.31	-1.37	-0.09	0.41
8806	2	-1.44	0.30	-2.09	-0.79	0.15
8806	3	-2.12	0.19	-2.63	-1.60	0.02
8904	1	-1.71	0.22	-2.17	-1.24	0.09
8904	2	-1.80	0.22	-2.31	-1.30	0.07
9005	1	-1.56	0.24	-2.08	-1.04	0.12
9005	2	-2.07	0.16	-2.49	-1.66	0.03
9105	1	-1.84	0.14	-2.16	-1.52	0.06
9105	2	-1.56	0.20	-2.00	-1.12	0.11
9105	3	-1.12	0.30	-1.74	-0.49	0.24
9307	1	-1.74	0.18	-2.12	-1.35	0.08
9307	2	-1.97	0.17	-2.38	-1.56	0.04
9307	3	-2.24	0.06	-2.42	-2.06	0.01

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
			Sebastes pinniger (canary rockfish)			
8401	1	-0.60	0.52	-2.03	0.84	0.53
8505	1	-1.86	0.14	-2.20	-1.51	0.06
8608	1	-1.52	0.13	-1.82	-1.22	0.12
8608	2	-2.04	0.12	-2.32	-1.77	0.03
8608	3	-2.23	0.07	-2.54	-1.93	0.01
8703	1	-1.95	0.16	-2.29	-1.61	0.04
8705	1	-1.81	0.15	-2.14	-1.49	0.07
8705	2	-1.37	0.16	-1.72	-1.02	0.16
8705	3	-1.88	0.17	-2.26	-1.51	0.05
8804	1	-1.95	0.15	-2.31	-1.59	0.04
8806	1	-0.13	0.27	-0.69	0.44	0.81
8806	2	-1.44	0.22	-1.93	-0.95	0.14
8806	3	-2.10	0.13	-2.45	-1.75	0.02
8904	1	-1.78	0.16	-2.18	-1.39	0.07
8904	2	-1.66	0.15	-1.99	-1.33	0.09
8904	3	-2.09	0.08	-2.28	-1.89	0.02
9005	1	-2.13	0.11	-2.44	-1.83	0.02
9005	2	-2.15	0.11	-2.43	-1.86	0.02
9005	3	-2.24	0.07	-2.52	-1.95	0.01
9105	1	-1.67	0.16	-2.01	-1.34	0.09
9105	2	-0.41	0.27	-0.99	0.16	0.59
9105	3	0.34	0.27	-0.23	0.90	1.35
9307	1	-2.15	0.09	-2.35	-1.95	0.02
9307	2	-2.15	0.08	-2.34	-1.96	0.02
9307	3	-2.25	0.05	-2.39	-2.11	0.01
			Sebastes rufus (bank rockfish)			
8705	1	-1.77	0.19	-2.18	-1.37	0.07
8705	2	-1.89	0.18	-2.27	-1.50	0.05
8705	3	-2.23	0.07	-2.41	-2.06	0.01
8804	1	-1.62	0.28	-2.30	-0.93	0.11
8806	2	-2.12	0.11	-2.41	-1.83	0.02
9307	2	-1.92	0.15	-2.25	-1.59	0.05
			Sebastes saxicola (stripetail rockfish)			
8401	1	-1.42	0.34	-2.47	-0.37	0.16
8505	1	-1.80	0.17	-2.18	-1.42	0.07
8608	1	-2.25	0.06	-2.40	-2.09	0.01
8703	1	-1.44	0.17	-1.79	-1.09	0.14
8705	1	-0.47	0.24	-0.97	0.03	0.54
8705	2	-1.76	0.16	-2.09	-1.43	0.07

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of Sebastes.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
8705	3	-2.24	0.06	-2.40	-2.08	0.01
8804	1	-0.07	0.27	-0.66	0.53	0.87
8806	1	-1.12	0.25	-1.64	-0.59	0.24
8806	2	-1.95	0.13	-2.23	-1.68	0.04
8904	1	-1.99	0.13	-2.28	-1.70	0.04
9003	1	-2.26	0.04	-2.37	-2.16	0.00
9005	1	-1.83	0.17	-2.20	-1.45	0.06
9005	2	-2.25	0.05	-2.39	-2.11	0.01
9105	1	-2.05	0.10	-2.27	-1.82	0.03
9105	2	-1.15	0.22	-1.61	-0.68	0.23
9105	3	-1.38	0.21	-1.82	-0.93	0.16
9206	3	-2.24	0.07	-2.42	-2.05	0.01
9307	1	-0.89	0.24	-1.39	-0.38	0.33
9307	2	-0.36	0.29	-0.97	0.25	0.62
		Sebastes wilsoni (pygmy rockfish)				
8401	1	-2.08	0.17	-3.09	-1.06	0.03
8505	1	-2.23	0.07	-2.43	-2.03	0.01
8608	1	-2.26	0.04	-2.38	-2.14	0.00
8703	1	-1.84	0.14	-2.16	-1.52	0.06
8705	1	-2.17	0.10	-2.40	-1.93	0.02
8705	2	-2.09	0.13	-2.37	-1.81	0.02
8804	1	-0.42	0.35	-1.51	0.66	0.60
8806	1	-1.97	0.14	-2.27	-1.67	0.04
8806	2	-2.25	0.05	-2.38	-2.12	0.01
8806	3	-2.24	0.06	-2.41	-2.08	0.01
8904	1	-2.04	0.12	-2.33	-1.76	0.03
8904	2	-2.25	0.05	-2.40	-2.10	0.01
8904	3	-2.19	0.08	-2.39	-1.99	0.01
9005	1	-2.04	0.09	-2.23	-1.84	0.03
9005	2	-2.26	0.04	-2.37	-2.15	0.00
9105	1	-2.13	0.10	-2.37	-1.88	0.02
9105	2	-1.70	0.17	-2.06	-1.34	0.08
9105	3	-1.81	0.14	-2.11	-1.52	0.06
9307	1	-2.21	0.07	-2.36	-2.05	0.01
		PCA "entomelas" Group				
8301	1	-2.11	0.13	-2.48	-1.73	0.02
8401	1	0.36	0.69	-1.47	2.19	1.71
8505	1	2.31	0.57	0.92	3.70	11.79
8608	1	-1.46	0.25	-1.98	-0.95	0.14
8608	2	-1.62	0.18	-2.03	-1.22	0.10
8608	3	-2.13	0.13	-2.53	-1.74	0.02
8703	1	-1.64	0.22	-2.11	-1.17	0.10

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of *Sebastes*.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
8705	1	2.22	0.29	1.60	2.84	9.47
8705	2	2.12	0.35	1.38	2.87	8.80
8705	3	-1.10	0.28	-1.70	-0.50	0.25
8804	1	1.05	0.41	0.17	1.93	3.01
8806	1	2.16	0.35	1.44	2.88	9.13
8806	2	1.56	0.33	0.86	2.25	4.91
8806	3	-1.57	0.25	-2.11	-1.04	0.11
8904	1	-0.75	0.32	-1.43	-0.07	0.40
8904	2	-0.08	0.32	-0.79	0.64	0.87
8904	3	-1.03	0.29	-1.65	-0.42	0.27
9003	1	-2.27	0.03	-2.35	-2.20	0.00
9005	1	-0.96	0.33	-1.67	-0.26	0.30
9005	2	-0.87	0.32	-1.59	-0.16	0.34
9005	3	-1.77	0.16	-2.12	-1.42	0.07
9105	1	-1.69	0.23	-2.19	-1.20	0.09
9105	2	0.05	0.34	-0.66	0.76	1.02
9105	3	1.68	0.34	0.97	2.39	5.60
9206	3	-1.68	0.19	-2.10	-1.27	0.09
9307	1	-0.72	0.22	-1.19	-0.25	0.40
9307	2	0.28	0.30	-0.35	0.91	1.29
9307	3	-1.06	0.34	-1.83	-0.29	0.27
			PCA "*jordani*" Group			
8301	1	-1.64	0.36	-2.49	-0.79	0.11
8401	1	2.04	0.70	-0.09	4.17	9.75
8505	1	1.45	0.49	0.36	2.53	4.70
8608	1	0.71	0.29	0.08	1.33	2.01
8608	2	0.04	0.34	-0.69	0.77	1.00
8608	3	-1.41	0.26	-1.98	-0.85	0.15
8703	1	0.29	0.31	-0.35	0.94	1.31
8705	1	3.47	0.28	2.87	4.07	33.28
8705	2	3.93	0.39	3.10	4.75	54.64
8705	3	0.66	0.39	-0.16	1.47	1.98
8804	1	3.67	0.42	2.50	4.83	42.55
8806	1	3.80	0.44	2.85	4.75	49.12
8806	2	2.58	0.41	1.73	3.43	14.24
8806	3	1.67	0.52	0.57	2.78	6.01
8904	1	1.96	0.32	1.29	2.64	7.39
8904	2	1.30	0.38	0.52	2.09	3.85
8904	3	0.10	0.39	-0.73	0.93	1.09
9003	1	-1.73	0.18	-2.14	-1.33	0.08
9005	1	0.58	0.35	-0.21	1.36	1.79
9005	2	-0.55	0.33	-1.25	0.15	0.51
9005	3	-1.82	0.20	-2.26	-1.38	0.07
9105	1	-0.70	0.25	-1.23	-0.18	0.41

Table 3 (cont.).--Annual sweep-specific indices of abundance for each of the 15 most commonly collected species of *Sebastes*.

Cruise	Sweep	Index	SE	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Back Transform
9105	2	1.00	0.27	0.45	1.55	2.71
9105	3	2.24	0.31	1.61	2.87	9.78
9206	3	-0.44	0.37	-1.34	0.45	0.59
9307	1	1.58	0.22	1.12	2.04	4.87
9307	2	2.14	0.35	1.41	2.87	8.93
9307	3	0.50	0.41	-0.51	1.51	1.69
			Total *Sebastes* spp.			
8301	1	-1.57	0.36	-2.42	-0.71	0.12
8401	1	2.43	0.74	0.13	4.73	14.85
8505	1	3.06	0.57	1.75	4.37	24.88
8608	1	0.88	0.29	0.26	1.50	2.41
8608	2	0.26	0.33	-0.43	0.95	1.27
8608	3	-1.30	0.29	-1.92	-0.68	0.18
8703	1	0.57	0.29	-0.04	1.17	1.74
8705	1	3.93	0.26	3.35	4.51	52.70
8705	2	4.25	0.39	3.42	5.08	75.80
8705	3	1.07	0.38	0.27	1.87	3.04
8804	1	3.88	0.40	2.82	4.95	52.68
8806	1	4.29	0.38	3.48	5.11	78.63
8806	2	3.34	0.34	2.63	4.05	29.88
8806	3	1.91	0.50	0.86	2.97	7.59
8904	1	2.16	0.32	1.49	2.83	9.02
8904	2	1.87	0.34	1.16	2.59	6.79
8904	3	0.45	0.41	-0.43	1.33	1.61
9003	1	-1.72	0.18	-2.13	-1.32	0.08
9005	1	0.88	0.33	0.15	1.62	2.46
9005	2	0.04	0.35	-0.68	0.77	1.01
9005	3	-1.36	0.23	-1.85	-0.86	0.16
9105	1	-0.32	0.28	-0.92	0.27	0.65
9105	2	1.50	0.30	0.87	2.13	4.59
9105	3	3.00	0.29	2.40	3.61	20.90
9206	3	-0.38	0.38	-1.28	0.52	0.64
9307	1	1.78	0.22	1.31	2.24	5.97
9307	2	2.46	0.31	1.81	3.11	12.17
9307	3	0.75	0.45	-0.31	1.81	2.23

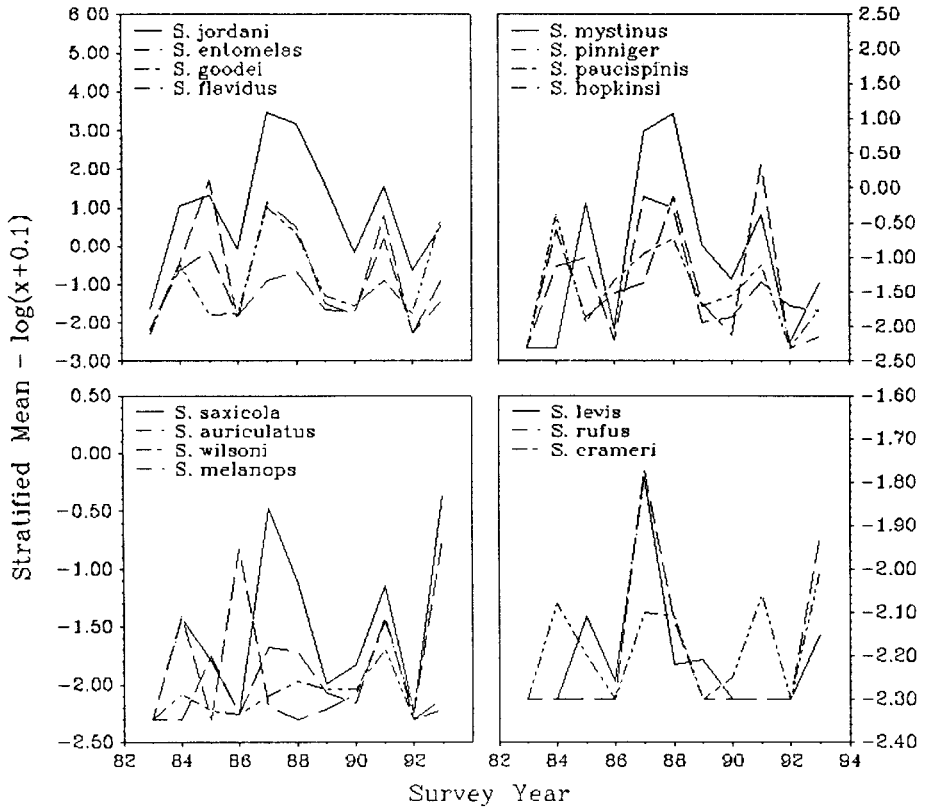

Figure 6. Annual (1983-93) estimates of pelagic juvenile relative abundance for species of Sebastes taken by midwater trawl.

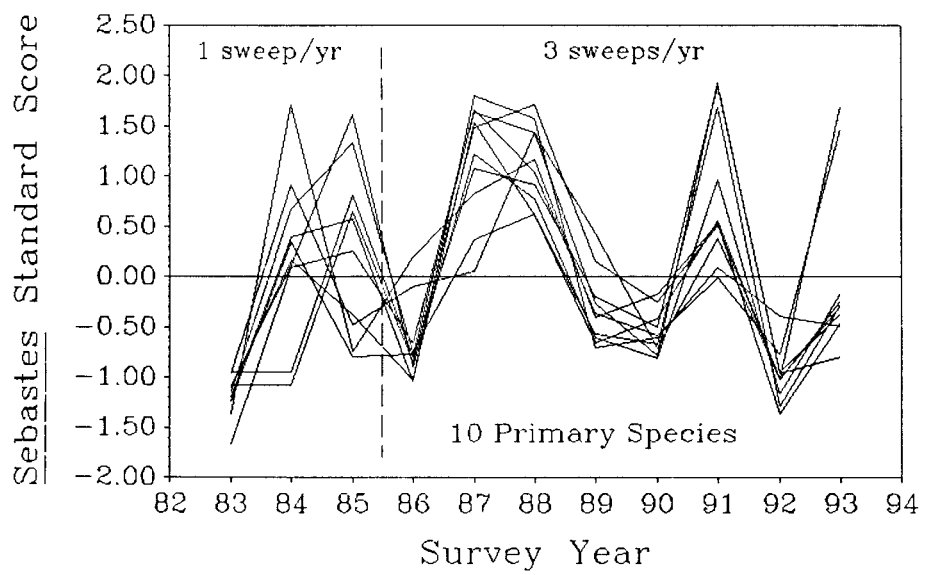

Figure 7. Normalized relative abundance trends for each of the ten most commonly caught species of pelagic juvenile rockfish.

their long-term means. Three species were unusually abundant however, i.e., chilipepper (S. goodei), stripetail rockfish (S. saxicola), and brown rockfish (S. auriculatus).

There is extensive covariation in pelagic juvenile abundance patterns among the ten species of rockfish plotted in the figure, particularly after 1986 when multiple sweeps were conducted each year. For example, of the 45 possible pairwise combinations among the species, the correlation coefficients between recruitment time series are positive in all cases ($\hat{\rho}$ = 0.22-0.97). Likewise, principal components analysis of these data (species as variables, years as cases) revealed that the first component accounted for 75% of the variation among the ten species-specific time series (λ_1 = 7.48) and the second component accounted for an additional 14% (λ_2 = 1.38). When annual scores on the first two principal components are plotted (Fig. 8), the strength of the 1987, 1988, and 1991 year-classes is revealed, as is the weakness of year-classes associated with El Niño conditions (1986 and, especially, 1992). Overall levels of pelagic juvenile rockfish abundance were intermediate in 1993. (S. Ralston)

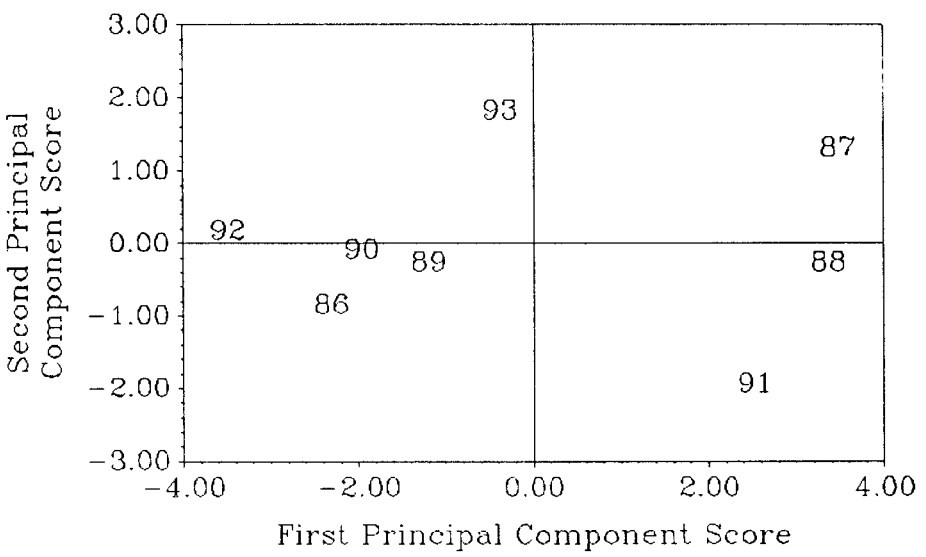

Figure 8. Yearly scores of pelagic YOY abundance plotted on the first two principal components.

Distributional Patterns of Late Larval and Early Juvenile Groundfish

From February 23-March 6, 1992, and from March 2-13, 1993, the Groundfish Analysis Investigation fielded cruises aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel David Starr Jordan to sample late larval and early pelagic

juvenile fish, in particular rockfish, Pacific whiting, and sanddabs. A series of stations located between Salt Point and Cypress Point were sampled using Methot's Frame trawl with a modified Isaacs-Kidd depressor. The Methot Isaacs-Kidd (MIK) trawl had a 5-m^2 opening with a 2-mm stretched mesh and a 0.505 mm codend. Oblique tows were conducted at night for a duration of 20-30 minutes. Average maximum depth of tows determined by an attached TDR was approximately 70 m during 1992 and about 80 m during 1993. During 1992 a CTD cast was done at each station with additional CTDs dropped during the day. In 1993 CTD casts were done at every other station with additional CTDs dropped during the day throughout the survey area. CTD data were used to develop horizontal contours of temperature and salinity at depth. All rockfish, Pacific whiting, and sanddabs were sorted from the catch and enumerated. Shortbelly rockfish were enumerated separately from the other rockfish species; sanddabs were separated by species to Pacific and speckled sanddabs. All abundances were adjusted to number/10,000 m^3 water filtered.

Surface temperatures recorded by the CTD were very similar to those recorded by the Half Moon Bay weather buoy. Together these data show that February/March sea surface temperatures of both 1992 and 1993 were ~2.0°C warmer than in the previous four years. Contour plots of the 1992 CTD data revealed a frontal gradient about 150 km offshore, with warmer, more saline water on the nearshore side, and colder, less saline water offshore (see Fig. 1, upper panel). During 1993, temperatures had decreased slightly relative to 1992. While 13°C water temperatures were found ~150 km offshore at 30-m depth throughout the survey area in 1992, equivalent temperatures in 1993 were restricted to the nearshore Monterey Bay area and in the region to the south, as well as offshore of Monterey Bay in association with an eddy-like feature, which was more evident in the salinity and density contours. This feature was prominent at the surface, 30 m, and 60 m. In addition, instead of a temperature front, there was a nearshore salinity front at 30 m (Fig. 1, lower panel).

Analysis of the catch data showed that all species were more abundant in 1992 than in 1993 (Fig. 9). In both years the spatial distribution of "other" rockfish was similar to shortbelly rockfish. Likewise, the patterns of speckled and Pacific sanddabs were similar. In 1992, shortbelly rockfish, Pacific sanddabs, and Pacific whiting were all distributed differently, while in 1993 they were similar (Figs. 10 and 11). Shortbelly rockfish were abundant on the nearshore side of the frontal gradient, in association with warmer, more saline waters of the survey area in 1992 (Fig. 10). Pacific sanddabs were most abundant along the frontal gradient, but unlike shortbelly rockfish, they were also fairly abundant on the offshore side of the front in colder, less saline waters (Fig. 10). In contrast, Pacific whiting, which are scaled differently (see Fig. 9), were abundant only in warm water on the nearshore side of the front in the southern region of the survey (Fig. 10).

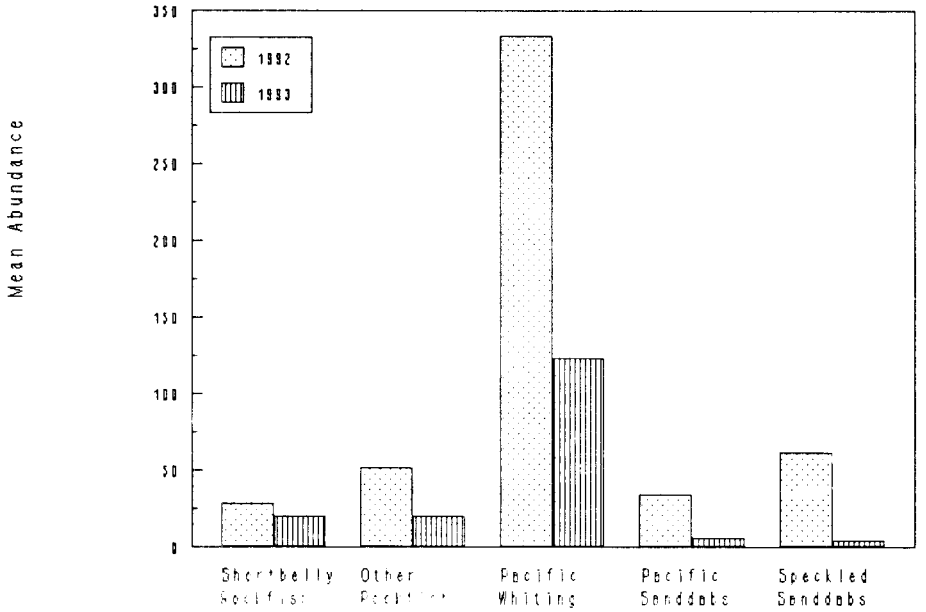

Figure 9. Mean abundance (#/10,000 m^3) for 1992 and 1993.

In 1993 shortbelly rockfish were abundant within the nearshore salinity front and within the eddy-like feature located offshore of Monterey Bay (Fig. 11). Sanddab abundances were much reduced in 1993 (Figs. 9 and 11). However, the largest catches, like shortbelly rockfish, were found in areas of high salinity water and in the eddy off Monterey Bay (Fig. 11). Similar to 1992, Pacific whiting were most abundant in the nearshore Monterey Bay area in relatively warm, high salinity water. Moderate catches of Pacific whiting were taken on the nearshore side of the salinity front and within the eddy (Fig. 11).

Correlation analysis of $\log_e$-transformed adjusted abundance (#/10,000 m^3 + 1) with temperature, salinity, and density at 30 m indicated that in 1992 temperature was most often correlated with abundance patterns, but in 1993 salinity and density were more often correlated with abundance (Table 4). These results are consistent with the observation that catches were generally associated with the offshore temperature gradient in 1992 and with the nearshore salinity front and eddy-like feature in 1993 (Figs. 10 and 11). (K. Sakuma)

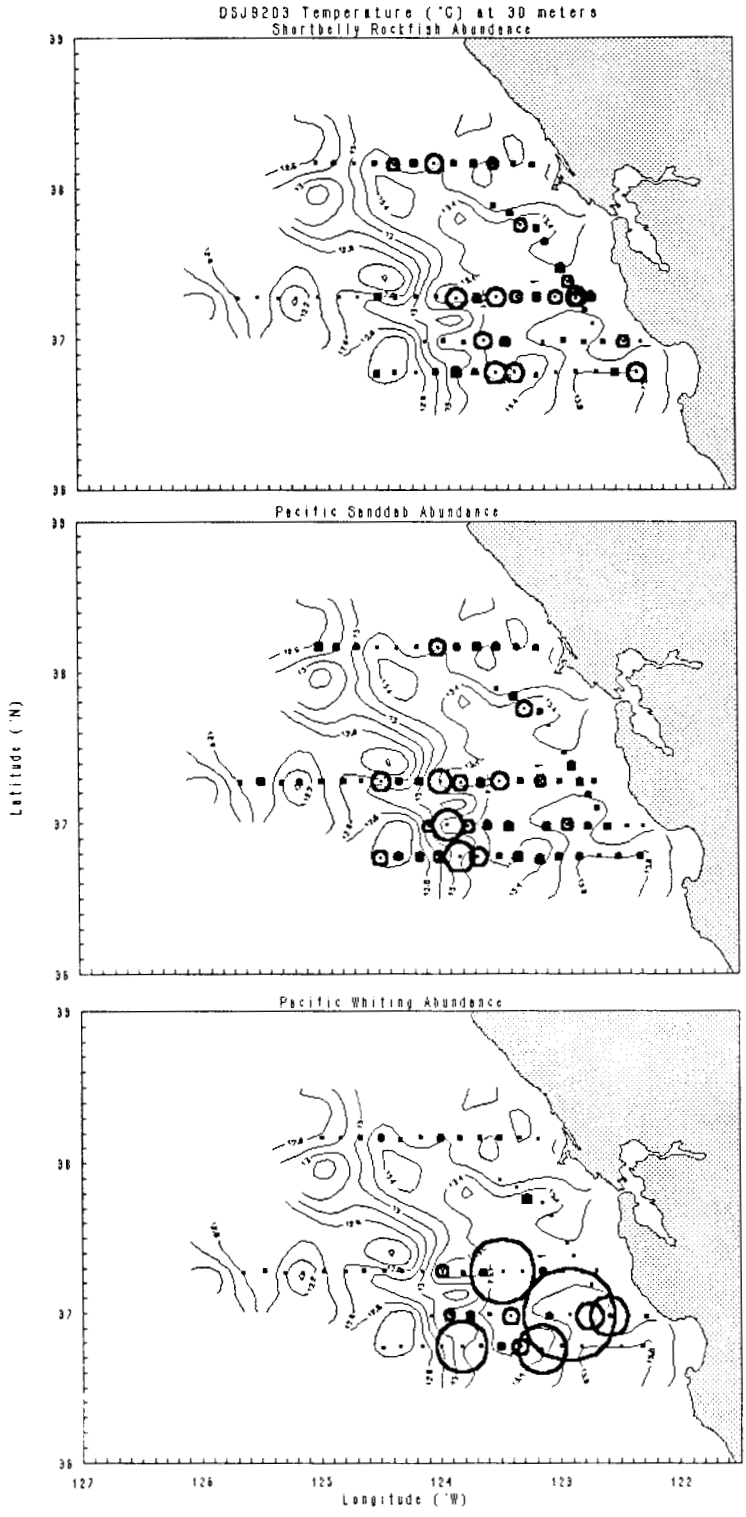

Figure 10. Distribution of shortbelly rockfish, Pacific sanddabs, and Pacific whiting in 1992. The size of the circular symbols are proportional to catch sizes.

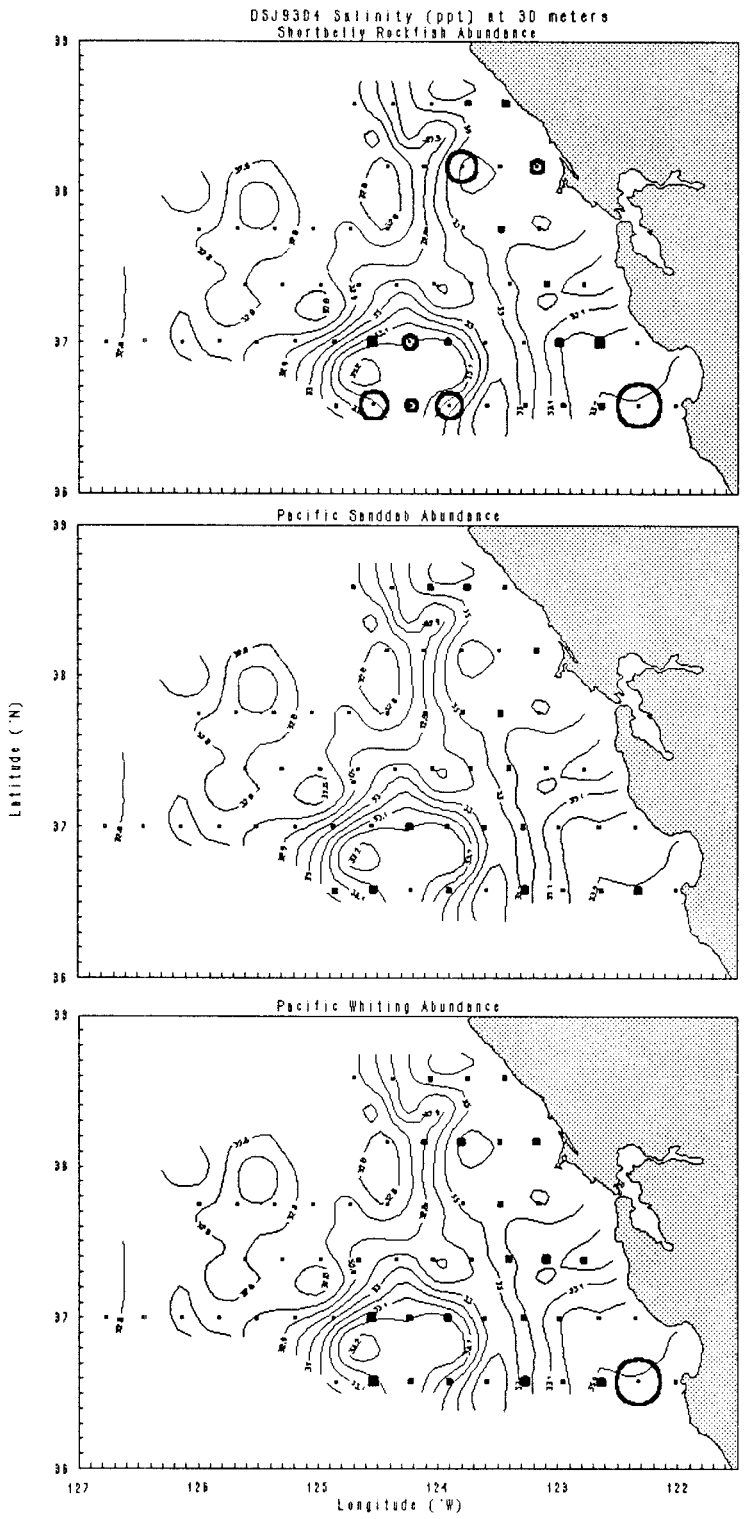

Figure 11. Distribution of shortbelly rockfish, Pacific sanddabs, and Pacific whiting in 1993. The size of the circular symbols are proportional to catch sizes.

Spearman Rank Correlation Coefficients

P > 0.05 P < 0.05

1992 (N=67)	Temperature	Salinity	Density
Shortbelly Rockfish	0.303	0.346	0.203
Pacific Sanddabs	0.052	-0.228	-0.300
Pacific Whiting	0.331	0.093	-0.107
1993 (N=55)			
Shortbelly Rockfish	0.300	0.735	0.584
Pacific Sanddabs	0.050	0.461	0.485
Pacific Whiting	0.209	0.730	0.613

Table 4.--Correlation analysis of groundfish abundance with temperature, salinity, and density at 30-m depth.

Environmental Databases Established

In May 1993, the establishment of long term oceanographic and atmospheric databases was initiated. Data sets were set up using environmental information from the central and northern California coast. The data were collected from various NOAA agencies, as well as other environmental research facilities, including: the National Ocean Service, the National Weather Service, the National Environmental Satellite Data and Information Service, the NMFS Pacific Fisheries Environmental Group, the CoastWatch Program Division of the NMFS La Jolla Laboratory, the Naval Postgraduate School, NASA's Goddard Space Flight Center, and Scripps Institute of Oceanography. The data are stored in standardized formats on one of the Investigation's SPARC workstations, which facilitates data distribution to all Laboratory research groups over the local area network (LAN). The various databases are updated on a monthly basis and will be continously managed. Data that are currently maintained on the LAN include: Bakun's upwelling indices for the California coast, monthly upwelling anomalies, monthly sea level anomalies at the San Francisco tide gauge, the Northeast Pacific Atmospheric Pressure Index, National Weather Service weather buoy data for selected offshore buoys, salinity and sea temperature data from the Scripps Shore Stations monitoring program, and Sea Surface Temperature data from AVHRR satellite imagery. (K. Baltz)

Progress in Estimating Year-Class Strength from the Composition of Predator Diet

The relative abundance of rockfish recruits in the pelagic environment from May to July has been estimated each year since 1980 based on their occurrences in the diet of the king salmon, (Oncorhynchus tshawytscha). During all these years, the numbers of rockfish recruits among the stomach contents of this major coastal predator have closely followed their numbers in the environment. King salmon sampled from the recreational fishery during the 1993 season contained a mean of 2.54 rockfish recruits, which is relatively high compared to previous years (Table 5).

Closer examination, however, reveals an unusual pattern of predation by king salmon on rockfish recruits during 1993. The recruits were consumed during two distinct periods, which has not happened before. The first period of predation began on 26 April--which is earlier than usual--and continued until 14 May. During this time, a mean of 0.45 recruits was recovered from the stomach contents of all salmon sampled. The species composition was as follows: stripetail rockfish (Sebastes saxicola), 36%; shortbelly rockfish (S. jordani), 18%; yellowtail-black (S. flavidus-S. melanops) complex, 22%; unidentified non-shortbelly rockfish complex, 22%. There were no juvenile rockfishes in salmon that were examined over the next seven weeks, but on 8 July they reappeared among the stomach contents in larger numbers than before. This second period of predation lasted just four days, but salmon sampled during that time contained a mean of 6.15 recruits, with over 90% being shortbellies. This brief but intensive period of predation during early July is the major basis for the relatively high values for 1993 in Table 5. (P. Adams and K. Silberberg).

Table 5.--Mean number of first year juvenile rockfishes (Genus *Sebastes*) in the stomach contents of king salmon (*Oncorhynchus tshawytscha*) from the Gulf of the Farallones, 1983-1993 (N = the number of stomachs from collections which contained rockfish).

Year	N	All Species	*S. jordani*	*S. entomelas*
1980	144	0.88	0.35	-
1981	406	2.98	1.11	-
1982	374	2.20	0.79	-
1983	-	-	-	-
1984	456	1.26	0.43	0.01
1985	506	2.64	0.86	0.07
1986	141	0.75	0.10	0.02
1987	883	2.71	1.72	0.06
1988	993	4.07	2.28	0.03
1989	517	5.97	4.47	0.01
1990	153	0.31	0.23	0.01
1991	637	0.93	0.14	0.11
1992	-	-	-	-
1993	457	2.56	2.09	-

Progress in Studies of Physiological Condition of Juvenile Yellowtail Rockfish

Physiological condition is an important factor modulating growth and survival of juvenile fish. The ability to distinguish variation in juvenile physiological condition along with associated environmental, abundance, and distribution data will enhance the determination of year-class strength.
In 1989, a project was initiated to assess the physiological condition of juvenile rockfish. Yellowtail rockfish were selected in order to relate estimates of juvenile year-class strength to adult yellowtail rockfish condition and reproductive success. The main objective was to determine interannual variation in physiological condition of juveniles and the relationship to environmental and abundance data. Initially, only juveniles from Cordell Bank and surrounding areas were analyzed to compare to adult population studies. Due to great difficulty in obtaining an adequate sample size, juveniles were collected and analyzed from an expanded area including Point Reyes south to Monterey Bay.

A number of analyses were used to assess juvenile condition including wet weight, length, total protein, total lipid, energetic lipids (triacylglycerols [TAG], esters, free fatty acids), polar lipids (cholesterol, phospholipids), and nucleic acid ratios (Table 6). Wet weight and length data were measured and completed for all years. Ages were not available; thus, differences attributable to age variation were accounted for by using length as a covariate. Using analysis of covariance, we found a significant difference ($P < 0.05$) among years in wet weight. Duncan's multiple contrast test revealed juveniles were largest, weighing more per unit length, in 1993 than in previous years. Juvenile weights in 1989, 1990, and 1991 were not significantly different.

Comparisons of physiological variables were limited due to small sample sizes, but data were available for some years to make contrasts. Total lipid quantities in 1989 and 1990 were not significantly different ($P > 0.05$), but there was a significant difference ($P < 0.001$) in TAG, the main energetic lipid. The polar lipids, which contribute mainly to cell membranes, made up 85% of the total lipid content and were not significantly different. Polar lipids are less likely than TAG to show substantial changes within a species on spatial or temporal bases. TAG are an important source of fuel and can fluctuate significantly depending on available nutrients. On the other hand, RNA/DNA ratios are a more sensitive measure of recent growth than lipid class composition. RNA/DNA ratios were also significantly different in 1989 and 1990, with a lower value in 1990 corresponding to the lower energetic lipid value. Thus, it would appear that juveniles in 1990 were less fit than those in 1989. Although both are measures of physiological condition, limited resources have restricted us to lipid class separations

which provide a more synoptic measure of long-term condition than the instantaneous measure of RNA/DNA ratios. Protein concentration was measured in two years with a significant difference ($P < 0.05$) between years. This difference might not be real because only white muscle was analyzed in 1989 as opposed to whole fish in 1991.

When the study area was expanded, there were still insufficient numbers of juvenile yellowtail rockfish to determine interannual variations in condition. Perhaps the most important contribution to date is that various methods were developed and tested. The juvenile yellowtail rockfish results support the contention that the best protocol to measure condition must include a combination of analyses. In 1993, our focus was switched to reproductive studies of shortbelly rockfish (*S. jordani*). This allows a much better opportunity to evaluate not only juvenile condition but also all early-life stages in relation to maternal and environmental factors. A number of reasons indicate the assessment of shortbelly rockfish early-life stages may provide a better model than yellowtail rockfish to determine linkages between physiological condition and maternal and/or environmental variables. These reasons include the following: all early-life stages from larvae to juveniles can be identified, shortbelly rockfish are much more abundant, and ship time is available to increase the temporal coverage from parturition through juvenile stages.
(E. Norton and B. MacFarlane)

STUDIES OF POST-PELAGIC JUVENILES

Progress in Visual Assessments of Juvenile Rockfishes in Near-Shore Habitats

Two species, *Sebastes mystinus* and *S. flavidus*, continued to dominate among rockfish recruits in most near-shore habitats off northern California. Recruits of a third, *S. melanops*, are numerous in certain surroundings close inshore, but these places have been inadequately represented in the assessments, so data representing that species are omitted here. Based on counts by D. Howard at sites along the Sonoma and Mendocino coasts, it was evident that while 1993 was a poor year for recruitment of *S. flavidus* throughout the region, and for *S. mystinus* in Sonoma,the latter recruited moderately well in Mendocino (Table 7). This is one of the few years that recruitment of *S. mystinus* has been stronger off Mendocino than off Sonoma. (E. Hobson, J. Chess, D. Howard).

Table 6.--Yearly mean ± SD (n in parentheses) for wet weight, length, protein, lipid, lipid classes, and RNA/DNA ratio condition factors for juvenile yellowtail rockfish (*Sebastes flavidus*).

CONDITION VARIABLE	1989	1990	1991	1992	1993
Wet weight (g)	1.06±0.03 (49)	0.72±0.33 (26)	1.11±0.40 (216)	0.52±0.23 (5)	1.51±0.43 (80)
Length (mm)	39.0±4.1 (50)	34.9±4.2 (26)	40.4±4.8 (216)	30.9±5.0 (5)	42.3±4.6 (80)
Protein (mg/g)	191.6±52.6 (17)	--	145.7±15.8 (50)	--	--
Lipid (mg/g)	72.2±10.0 (19)	68.0±8.4 (10)	--	--	--
Triacylglycerols (mg/g)	12.29±7.83 (19)	5.79±3.78 (10)	--	--	--
Polar lipids (mg/g)	57.63±9.19 (19)	60.38±08.02 (10)	--	--	--
RNA/DNA ratio	10.6±1.7 (21)	8.2±1.0 (8)	--	--	--

Table 7.--Numbers of recruits counted near shore during August and September, 1983-1993. Values are mean number (standard error in parentheses) counted per minute. N = number of 1-min counts.

MENDOCINO

Species	1983 n=36	1984 n=57	1985 n=50	1986 n=103	1987 n=112	1988 n=62	1989 n=181	1990 n=99	1991 n=80	1992 n=120	1993 n=90
S. flavidus	0.00 (0.00)	6.58 (2.29)	115.60 (21.26)	6.01 (1.50)	102.66 (11.08)	59.47 (10.23)	1.29 (0.35)	1.93 (0.90)	8.14 (3.04)	0.09 (0.05)	0.24 (0.14)
S. mystinus	0.27 (0.09)	1.49 (0.30)	70.56 (15.32)	7.83 (1.88)	181.04 (26.19)	75.89 (10.18)	6.08 (0.94)	0.76 (0.17)	0.64 (0.16)	0.26 (0.06)	6.21 (1.40)

SONOMA

Species	1983 no data	1984 n=57	1985 n=50	1986 n=60	1987 n=56	1988 n=62	1989 n=186	1990 n=100	1991 n=79	1992 n=40	1993 n=100
S. flavidus		4.39 (1.48)	135.17 (26.00)	6.73 (2.29)	89.39 (18.42)	39.92 (7.94)	1.54 (0.42)	0.12 (0.05)	38.33 (6.40)	0.49 (0.29)	1.14 (0.78)
S. mystinus		4.89 (1.29)	117.63 (19.50)	15.27 (3.81)	328.05 (52.15)	175.06 (16.76)	7.19 (0.93)	0.66 (0.12)	13.58 (1.82)	1.01 (0.25)	2.96 (0.87)

STUDIES OF ADULTS

Progress in Studies of Adult *Sebastes mystinus*

Effects of Feeding Conditions on Physical Condition and Recruitment Success

That feeding conditions experienced by adult *S. mystinus* may influence success of recruitment has been studied since November 1987. Results presented in previous numbers of this series have consistently showed a connection between summer-fall feeding success and physical condition of adult females during the following January-February spawning season. (See earlier reports for definitions of the condition indicators.) A positive correlation between physical condition and recruitment success has been apparent for some years, but not others. For example, the year that produced the smallest number of recruits, 1992, was a year when the reproducing females were relatively in good shape (Table 5, Figure 13). This anomalous result can be explained by the prevalence that year of a major El Niño.

It has been demonstrated that physical condition is influenced by the quality as well as the quantity of items in the diet. For example, the moderate volume of material ingested during 1989 and 1990 was dominated by plant materials, only a small proportion of which is utilized as food, and as a result physical condition was relatively poor both years (Figures 12 and 13). Conversely, while the volume of materials ingested during 1992 was relatively low, the dominant items were gelatinous zooplankters and crustacea, all utilized as food, and as a result physical condition was relatively good that year (Figures 12 and 13, with mysids constituting virtually all of the "other" category in Figure 12).

Feeding circumstances and condition indicators during the past year (Figures 12 and 13) suggest that recruitment during 1994 will be on the low side of moderately successful. The unusually large number of empty guts during 1993 (Figure 12) probably is less an indicator of generally poor feeding conditions than an unusually late development of *Nereocystis* beds last summer. The sori of this large alga are the major plant material eaten by *S. mystinus* and are taken particularly when other foods are scarce. The increased incidence of empty guts during the past year, therefore, resulted because this supplemental food source was unavailable during much of the feeding season. (E. Hobson, J. Chess, D. Howard).

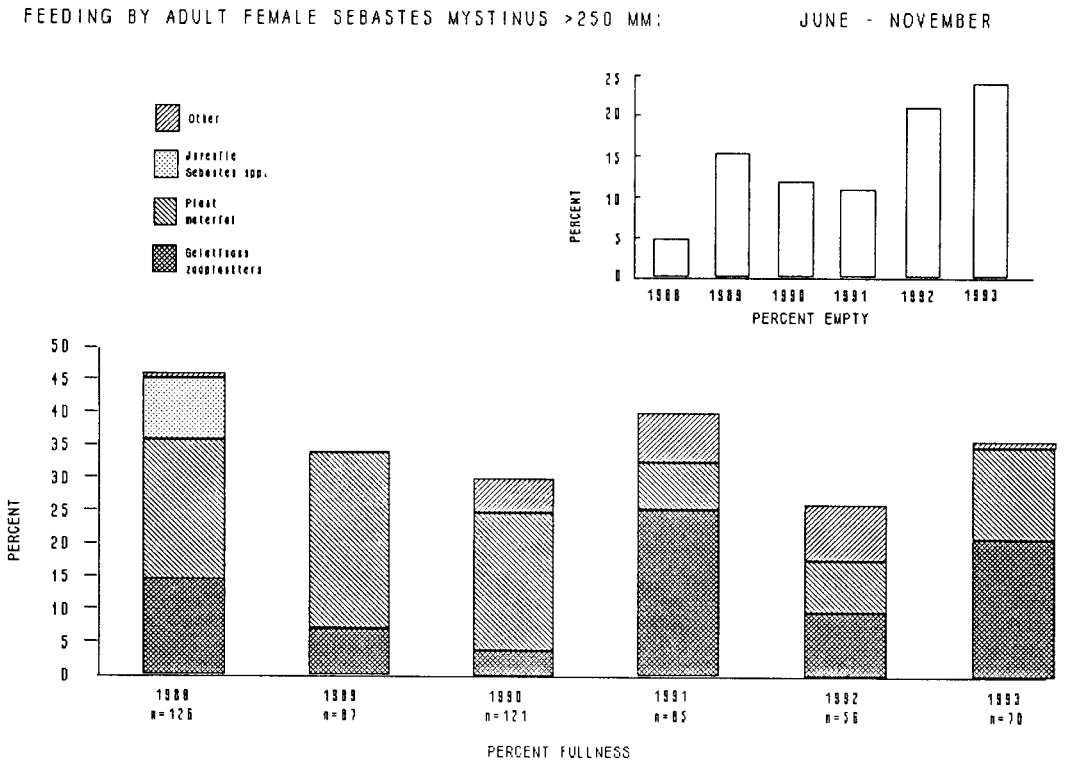

Figure 12. Feeding by adult female S. mystinus (June-November).

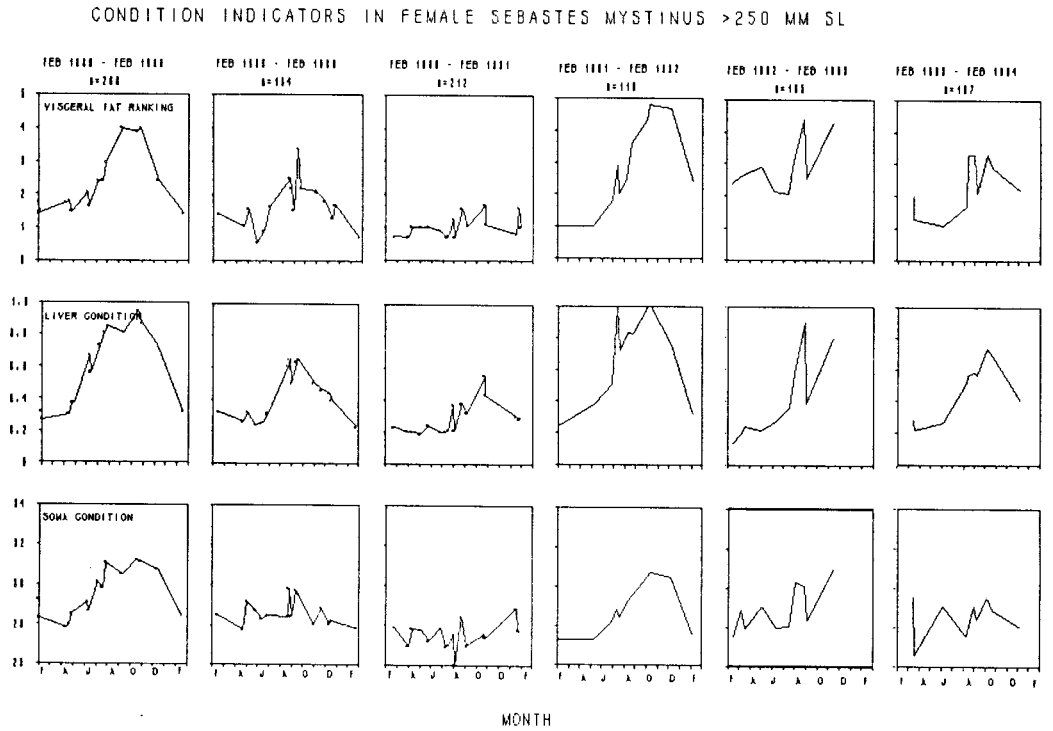

Figure 13. Condition indices in female S. mystinus > 250 mm SL.

Progress in Studies of Adult *Sebastes flavidus*

Nutritional Aspects of Rockfish Reproduction: Comparisons of Annual Dynamics

An objective of our research into factors relating to, and perhaps modulating, reproductive success is to link nutritional and environmental variables to the health and abundance of progeny. During the first three annual cycles of our investigation of yellowtail rockfish (*Sebastes flavidus*), a common pattern of energy accumulation in somatic tissues, transport to ovaries, and sequestration in ovaries became evident. A typical sequence of events occurred during the annual reproductive cycle starting in May 1987 and concluding with parturition in March 1988 (Fig. 14). Mesenteric fat increased substantially (to about 2% of total body weight) during the summer and fall upwelling season in response to abundant forage, mostly euphausiids. This energy reserve was depleted during the winter when food was scarce. Concurrent with the decline of mesenteric fat, serum lipids (triacylglycerols, phospholipids, etc.) and protein (vitellogenin, albumin, etc.) increased, presumably for transport to developing oocytes in the ovaries. In fact, ovary accumulation of lipids and protein occurred reciprocally to somatic reserve declines. We hypothesized that this course of events, in particular the acquisition of adequate fat in mesenteries and liver, was required to supply ovaries with the necessary quantities of energy and structural precursors to produce optimal numbers of healthy larvae.

The somatic-ovarian nutritional energetic profile observed from 1985 through 1988 changed during 1989. During the 1989-90 and 1990-91 annual reproductive cycles, and to a lesser degree in 1991-92, significantly less mesenteric fat and liver lipids ($P<0.0001$ for both) were accumulated during the typical time interval of upwelling (April-October). The reproductive cycle of 1990-91 illustrates the magnitude of decline in mesenteric fat accumulation (Fig. 14). However, even though much less energy was acquired by female soma, and significantly less lipid was transported during oocyte development ($P<0.05$), the ovaries acquired greater amounts of lipid than during 1987-88 ($P<0.05$). Moreover, lipid accumulation continued later into gestation than in previous reproductive cycles. Although serum data revealed elevated triacylglycerol concentrations during October to January, similar to earlier cycles, the source appeared to be directly from the environment and not from maternal stores. Also, from November 1990 to January 1991, mesenteric fat increased somewhat, atypical of previous patterns. This co-occurred with greater than usual upwelling intensity and euphausiid abundance in the winter of 1990-91. Thus, it appeared that yellowtail rockfish had a mechanism to incorporate nutrition directly from food into final maturation stage oocytes and embryos. If this were the case, then yellowtail rockfish are capable of matrotrophy, a process unknown in this species. Subsequent laboratory research confirmed lipids could be incorporated into embryos from maternal serum during gestation.

These results suggested that the dynamics of energy and nutrient input to ovaries of yellowtail rockfish are adaptive to variability in the time and source of nutrition. This provides the ability to benefit reproductively from food availability regardless of when it occurs during the annual cycle, unlike strictly lecithotrophic (ovoviviparous) species, as Sebastes flavidus was previously classified.

By considering environmental variables that reflect system productivity, and thus food abundance, and maternal nutritional variables in relation to quantitative and qualitative measures of reproduction, factors that influence year-class success may be revealed. Since nutrients and energy must be transported through the circulatory system, serum nutrients were evaluated with ovarian development. Serum lipid and calcium (vitellogenin surrogate) levels related significantly to ovary lipid and protein concentrations (which are considered indicators of embryo energy status, and therefore health) (Table 8). In turn, ovary lipid levels during late yolk accumulation and embryogenic stages correlated significantly to relative fecundity (eggs/g somatic weight). Mesenteric fat and other somatic reserve depots do not appear to be necessary for ovarian development, and correlations with reproductive parameters were not statistically significant. The extent of lipid accumulation in ovaries, however, was related to the intensity of upwelling during late yolk accumulation and embryogenesis (September-March). Upwelling intensity during the summer did not correlate significantly to female nutritional or ovarian variables, suggesting greater upwelling intensity at that time was not a factor in ovarian processes during the winter.

The results of this analysis indicated associations among upwelling, a main driving force in the California Current ecosystem, maternal nutritional dynamics, and progeny energy status and production. There does not seem to be a requirement for a precise temporal supply of fuel and structural building blocks for oocyte and embryo development so long as adequate nutrients are provided before hatching. (B. MacFarlane and B. Norton)

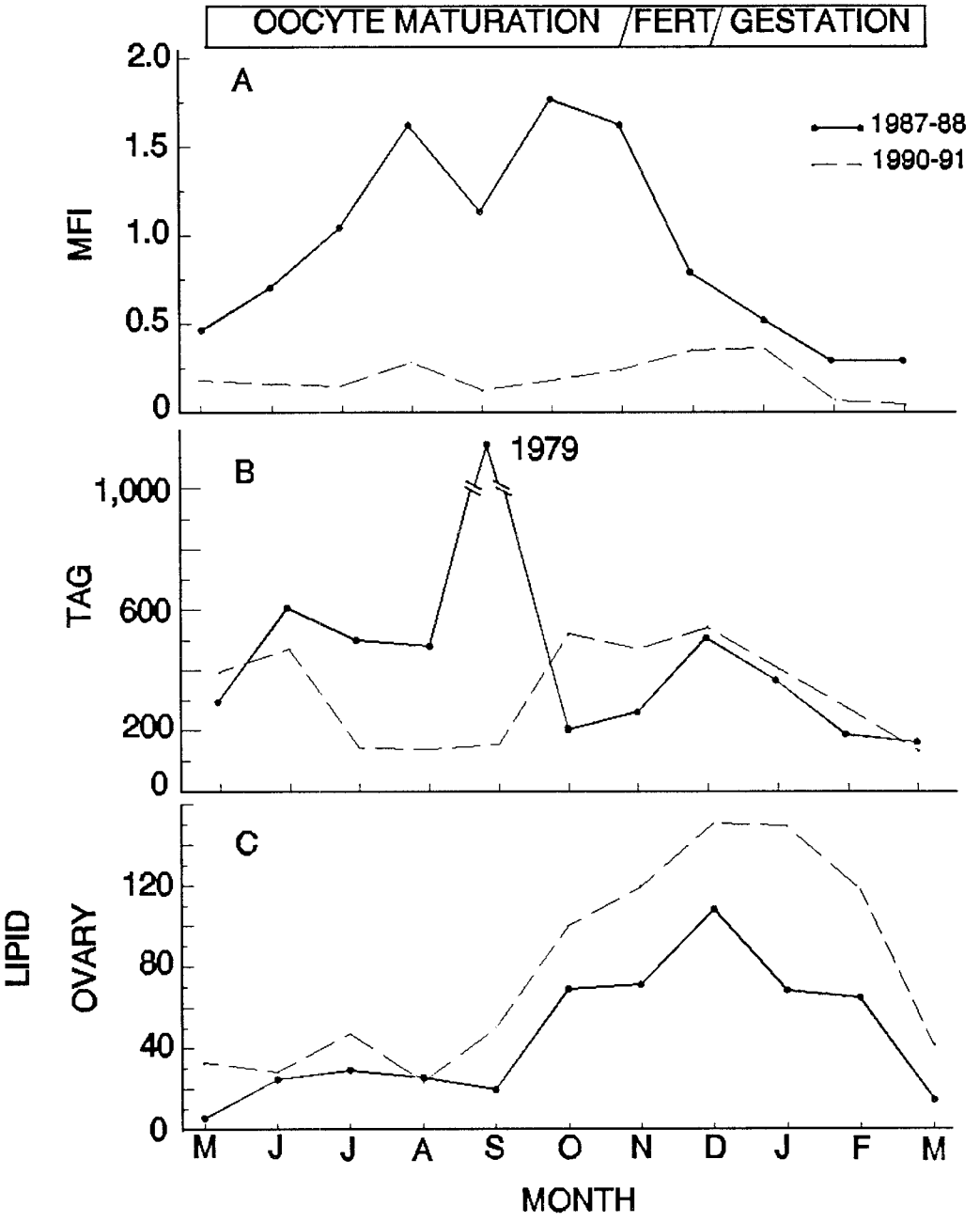

Figure 14. Changes in lipids of female yellowtail rockfish during reproductive cycles in 1987-88 and 1990-91. Temporal sequence of ovarian development during annual cycle is represented across top. (A) Mean monthly mesenteric fat indices (MFI=[weight of fat in mesenteries]/fish weight X 100); (B) Mean monthly serum triacylglycerol concentrations (TAG), in mg/dl serum; (C) Mean monthly ovary lipid concentration, in mg/g wet weight.

Table 8. Significant relationships among environmental, maternal nutritional, and ovarian reproductive variables. Correlation analysis included data from female yellowtail rockfish obtained during seven annual reproductive cycles between April 1985 and March 1992. Descriptors in parentheses denote data subset used. Brackets denote concentration.

Variables	r	P
Serum [triacylglycerols] (Sep-Mar) - Ovary [lipid] (gestation)	0.912	0.06
Serum [calcium] (vitellogenin) (Sep-Mar) - Ovary [protein] (gestation)	0.868	0.05
Serum [triacylglycerols] (yolk accumul.) - Ovary [lipid] (yolk accumul.)	0.908	0.07
Ovary [lipid] (yolk accumul.) - Relative fecundity	0.888	0.05
Ovary [lipid] (gestation) - Relative fecundity	0.909	0.06
Upwelling index (weekly mean, Sep-Jan) - Ovary [lipid] (Sep-Mar)	0.865	0.05
Upwelling index (weekly mean, Sep-Jan) - Ovary [lipid] (gestation)	0.855	0.06

Investigations of Ovary Maturation Rates in Yellowtail Rockfish

Ovary maturation stages (OMS, defined as the most advanced stage of egg or embryo development within an ovary) were determined for female yellowtail rockfish over six reproductive years of study (1986-88; 1990-92). A temporal comparison of oocyte and pre-hatching embryonic stages, revealed variations in their rates of maturation. The data were subjected to a statistical analysis in an effort to determine the extent of variation not only among reproductive months but also among reproductive years. Additionally, it presented an opportunity to search for physiological and environmental sources that might relate to the variability observed in yearly ovary maturation.

To determine the extent of variation and to test for physiological/environmental relationships, a general linear model (GLM) analysis of variance was used for this initial statistical analysis, i.e.,

OMS = repoyr repomo repoyr*repomo (covariate*repomo).

Reproductive year was considered a class variable, and the model states that ovary maturation is a function of reproductive year, month, and the year-month combination. Reproductive month was considered a continuous variable to allow the determination of slopes for each year's OMS progression. Comparisons of slopes can then be used to test differences between specific years. Since all females progress from OMS 1 to 8, the year effect is not a valid determinant of true differences among years. Variation among year-month interactions was used to analyze variability of OMS schedules among years. In addition, once the extent of this relationship was established, we wanted to determine which physiological/environmental variables, when used as covariates, decreased statisical differences (or increased P) across reproductive cycles.

Annual variations of OMS are revealed when plotted against reproductive months (Fig. 15). Reproductive cycles in yellowtail rockfish typically begin in April and end in March, when parturition of well formed larvae occurs. April through June is characterized by a relatively constant OMS, indicating the slow growth of pre-vitellogenic oocytes. Oocytes progressively increase in size as they develop through vitellogenic stages (OMS 3-4) during fall. Mature ova are ovulated and fertilized (OMS 5) followed by a 30- to 40-day intralumenal gestation of embryos (OMS 6-8) which usually occurs in January or February. Since the objective of this analysis was to determine the slopes or rates of change in developmental growth, only those months where the most rapid linear ovarian maturation occurred (July through February) were used in the statistical test. Using these ovary maturation stages, the resulting base model established a year/month interaction where P = 0.128. An attempt to explain this variability was then pursued by using physiological and environmental variables as covariates in our base model. These variables were selected on a biological basis of their known or suspected influences on oocyte development.

Results of a few of the environmental, maternal, and ovarian variables used as covariates were of interest by either having no effect, or slightly improving our model by increasing the P value of 0.128 (Table 9). Upper water temperature (P = 0.260) showed the strongest relationship. Upper water mass temperatures may regulate food productivity or availability and affect somatic energy resources transported to gonad developmental processes. This may be reflected in the improvement of our base model by mesenteric fat (P = 0.177) and gonad protein (P = 0.188). However, if the upper water mass does indeed effect the energy resource such that it has an influence on nutrient transport to the maternal system, we should have detected stronger associations from a greater array of variables.

Since sample monthly means of age were different among monthly collections, it became necessary to test for age effects. Age, however, did not show a strong relationship. This was surprising because from our own observations, larger fish, when examined, tended to be reproductively further advanced. A

regression analysis of age-OMS by month revealed significant age effects on ovary maturation ($P < 0.01$) in the months of January and February. However, since a relationship between age and ovary maturation stage was found only in January and February, when the most rapid development occurred, and not in other months, age was not a factor contributing to interannual variability.

While this initial analysis indicated differences among years, environmental and maternal variables failed to clearly demonstrate strong associations to ovarian maturation and explain the interannual variability in this yellowtail rockfish population. It would appear that the accumulation of yolk in oocytes is an event influenced to some degree by external factors, e.g., food availability, and the capacity to synthesize and transport vitellogenin to the ovaries. But rates of maturation are probably the result of hormonal regulation modulated indirectly by upper water mass processes related to ecosystem productivity. (M. Bowers and B. MacFarlane)

Table 9. Partial results of GLM ANOVA of ovary maturation stage (OMS) schedules by month. The base model reflects the year/month interaction with no covariates included. Selected covariates were tested to determine their association to temporal OMS variability.

COVARIATE	R^2	REPOYR*REPOMO TYPE III MEAN SQ.	Pr>F
None (base model)	0.620	1.826	0.128
Age	0.633	2.335	0.047
Sea Surface Temp.	0.632	8.956	0.0001
Upper Water Temp.	0.717	1.518	0.260
Lower Water Temp.	0.736	7.733	0.0008
Mesenteric Fat Index	0.638	1.600	0.177
Gonad Protein	0.835	0.889	0.188
Gonad Water	0.863	0.783	0.167

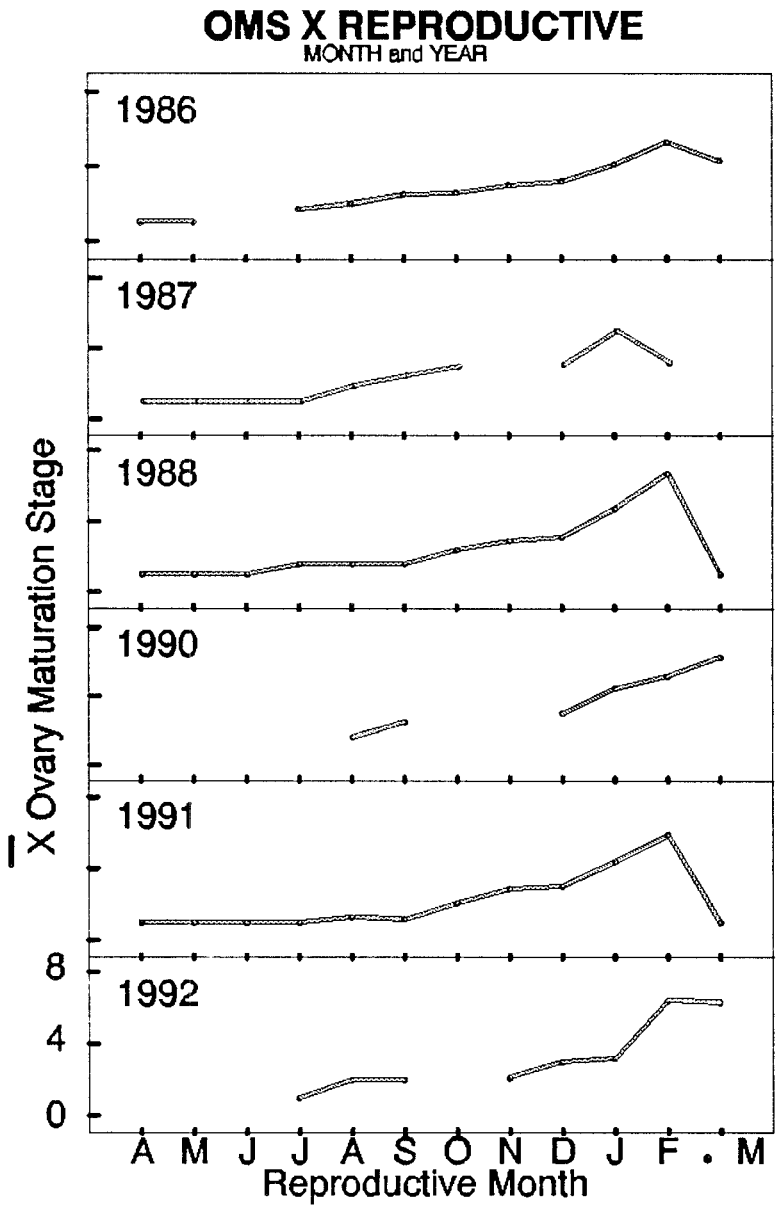

Figure 15. Ovary maturation stages (OMS) for six years of study. Year of reproduction was used to define each reproductive cycle. Reproductive years begin in April and end in the month of March. OMS 1 = pre-vitellogenic oocytes; 2 = early yolk accumulation; 3 = late yolk accumulation; 4 = migrating nucleus; 5 = ovulation/fertilization; 6 = early-celled embryo; 7 = embryonic body; 8 = eyed-larvae (pre-hatch).

Temporal and Spatial Variation in Fecundity of Yellowtail Rockfish

Efficient conservation and management of yellowtail rockfish and other rockfish species depend on accurate estimates of stock abundance and recruitment. Attempts are underway to estimate spawning stock biomass of *Sebastes* species through the larval production method, a modification of the egg production method which was developed for oviparous fishes. Knowledge of fecundity at different ages and sizes is needed in this method to complete any stock assessment. Further, long-term or multiple stock assessments require an assumption that fecundity is invariant interannually and between stocks. During the past research season, a multi-year, two-stock study was completed on the variation in fecundity of the commercially important yellowtail rockfish. Gravimetrically estimated fecundities were compared between 1985 and 1991 in yellowtail rockfish from Cordell Bank, California, the southern extent of their distribution, and between 1988 and 1991 in fish from central Washington, near their center of abundance.

California yellowtail rockfish were older, smaller in weight and length, and had smaller mesenteric fat deposits and more extensive disease and parasite pathologies than Washington fish. Egg production of this comparatively fecund viviparous fish increased linearly and sigmoidally with body weight and length, and asymptotically with age. Mean absolute fecundity for California fish was 523,200 eggs for fish with an average age of 15.4 years, standard length of 37.1 cm, and somatic weight of 1207 g. Washington fish had a mean fecundity of 904,700 eggs for fish of 11.9 years, 40.8 cm, and 1689 g. Significant interannual differences were observed in fecundities of young (< age 15) fish from California while no differences were found in older California fish (> age 14) or in young or old Washington fish. Washington yellowtail rockfish had higher group fecundities because they were larger and more fecund at age. Rate-specific fecundities were significantly higher in young Washington fish. Multiple-regression predictive models of fecundity were highly correlated in young age yellowtail rockfish, less so in old age fish. Although fecundity of young fish depended on weight, length, and age, that of old fish was age dependent.

Our findings showed age-dependent inter-annual and geographic differences in reproductive effort, which suggest unique population-specific reproductive life histories. (M. Eldridge & B. Jarvis)

Metabolic Costs of Viviparity in Yellowtail Rockfish

Previous presentations in this report have documented significant temporal-spatial variation in fecundity in yellowtail rockfish and interannual variation in young-of-the-year recruitment in yellowtail and other rockfishes. Probable factors that influence these traits include varying environmental conditions that affect important physiological processes, such as

metabolism and reproduction. To estimate the extent of factor effects, one must first know the routine energetic costs associated with a particular reproductive strategy, especially one as unique as that found in Sebastes, where eggs are fertilized internally and embryos and larvae are incubated in the ovary.

This year an experimental study was completed that determined the energetic costs of viviparous reproduction in adult yellowtail rockfish during gestation by direct in vivo respirometry. Measurements also allowed us to quantify the extent of matrotrophy through comparison of metabolism in gestating and non-gestating adults and estimating embryonic and larval catabolism with measurements of endogenous energy consumption from fertilization to parturition.

The pattern of maternal oxygen consumption during gestation was such that metabolic demands did not become significantly elevated until intra-ovarian embryos had hatched and larvae were being incubated (Fig. 16). Metabolic rates of females in this latter stage of gestation were 82% higher than spent females and 101% higher than those of non-reproducing males. We determined that 0.08996 cal embryo^{-1} was consumed during gestation as compared to the change in energy content of embryos from fertilization to birth which was 0.08690 cal embryo^{-1}. The difference between the energy consumed and the energy lost during the 29-day gestation period indicated that extra embryonic sources contributed only 3.4% or 0.00306 cal embryo^{-1} of the energy utilized after fertilization (Table 10). Our observations agree with previous work which determined that embryos and larvae of S. flavidus are primarily lecithotrophic and metabolic patterns optimally position females for long-term reproductive success in unpredictable environments. (M. Eldridge)

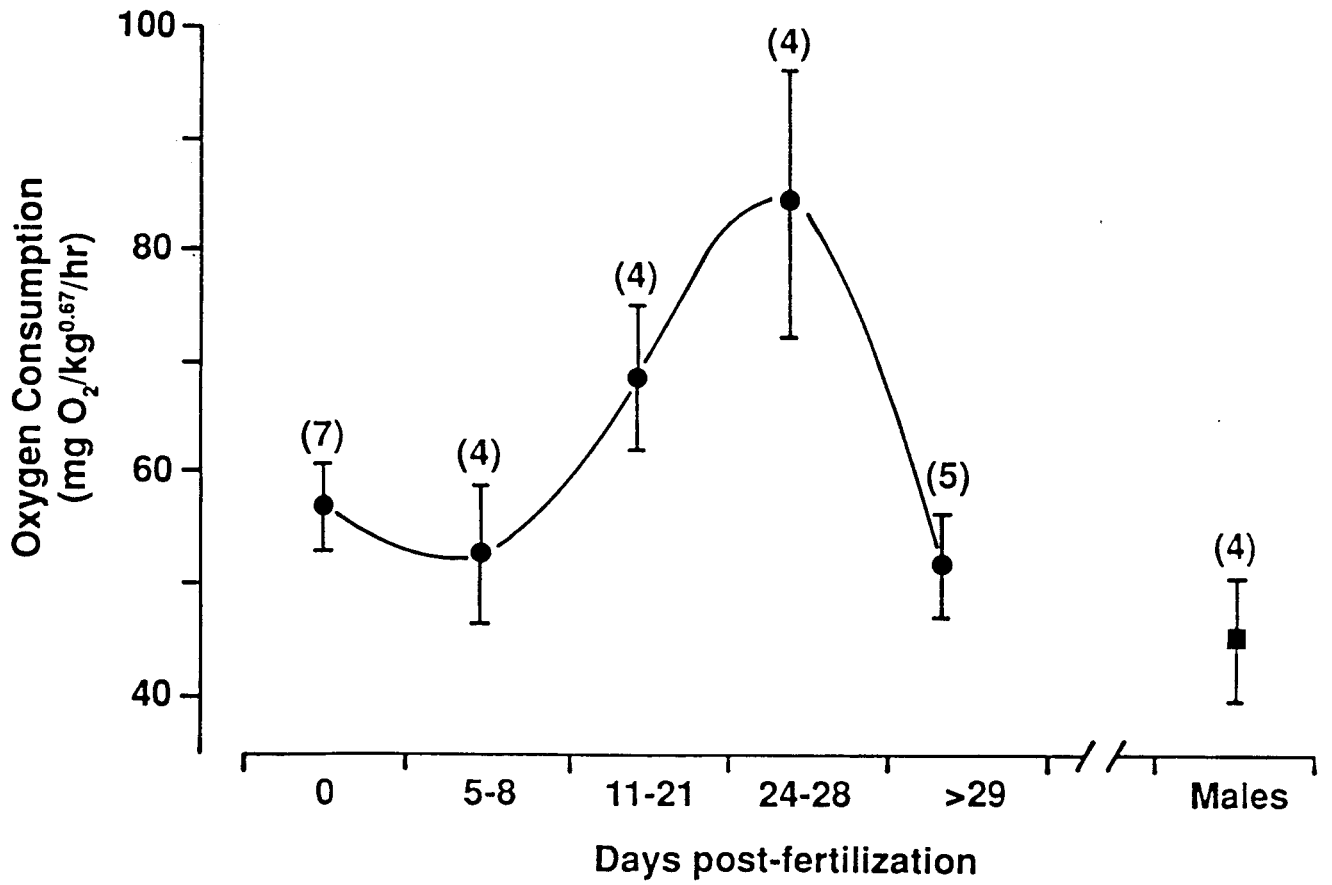

Figure 16. Sebastes flavidus resting routine metabolic rates versus days post fertilization (mean ± SE). Closed circles are gestating females, closed squares are males, and n is given in parentheses. Means are plotted in the middle of each gestational stage, and means with the same letter are not significantly different.

Table 10.--Comparison of energy requirements per embryo, change in caloric content and weight change data (dry weight for S. caurinus, ash free dry weight for all others) per embryo during gestation in four species of Sebastes where matrotrophic contribution (energy requirement from external sources) has been estimated.

Species	Calories per embryo		Energy use embryo during gestation (calories)	Energy requirement from external sources (%)	Energy change per embryo (%)	Weight change per embryo(%)	Gestation period (days)
	Fertilization	Birth					
S. caurinus[1]	1.049	0.688	0.408	11.5	-34.4	-20.6	41.5
S. melanops[2]	0.429	0.345	0.273	69.2	-19.6	-10.5	37.0
S. shlegeli[3]	1.590	1.480	1.386	92.1	-6.9	+21.9	51.5
S. flavidus[4]	0.361	0.274	0.090	3.4	-24.1	-16.0	29.0

1. Dygert and Gunderson 1991.

2. Boehlert and Yoklavich 1984.

3. Boehlert et al. 1986.

4. This study.

Progress in Studies of adult *Sebastes jordani*

Reproductive Life History of Shortbelly Rockfish

Of the 83 managed fish species in the Pacific coast groundfish fishery, 55 are rockfish species (Genus *Sebastes*). They comprise 44% of the total recent groundfish average yield, excluding whiting (13% when whiting is included). Most major west coast groundfishes are fully harvested. Only the shortbelly rockfish is classified as underutilized with an above average stock level status. Although there is no developed market for this species, the Pacific Fisheries Management Council has set a harvest guideline of 23,500 metric tons.

To compliment previous stock assessments obtained from hydroacoustic surveys, recent efforts have been made to estimate spawning biomass using the larval production method (Ralston et al., in preparation). Knowledge of the reproductive life history of the shortbelly rockfish is required to complete this assessment. Studies began in 1990 that included adult and larval surveys in central Calfornia from the Monterey Canyon area to Bodega Canyon in the north. Bongo net ichthyoplankton tows and trawls were done from a combination of chartered commercial fishing vessels and the research ship *David Starr Jordan*.

One area of emphasis in these studies is the estimation of fecundity. We are currently in the fourth year (reproductive year 1993/1994) of collection with a total of 832 fecundity specimens collected. Of these, 532 fish from the first three years have been examined and their fecundities estimated. The sampled population is representative of the general population as indicated by its full range of ages and sizes (Table 11). Ages of the fish covered the known range of the reproductive life span (Low et al., 1991) and were variable as indicated by a coefficient of variation of 75%. Nonetheless, the mean age was six years. (M. Eldridge)

Table 11. Summary of ages, standard lengths, total body wet weights, and absolute and relactive fecundities of shortbelly rockfish from reproductive seasons 1990/1991 to 1992/1993.

	Mean	SD	Minimum	Maximum
Ages (years)	6.0	4.5	1	23
Standard Length (cm)	19.8	3.8	13.0	26.5
Wet Weight (g)	132.2	73.7	29.4	297.5
Absolute Fecundity	14,067	12,275	631	77,367
Relative Fecundity	101.6	53.0	14.0	370.2

Absolute fecundity (Y) generally increased in a linear fashion with body weight (X) and fits the general linear model

$$Y = -1446 + 117.98\ X,\ r^2 = 0.71.$$

While the above relationship described how the total number of eggs increased with increasing body size, the relative fecundity (or number of eggs per unit of body weight) did not significantly change with increasing body size. Rather, the linear regression equation for this relationship was:

$$Y = 82.1 + 0.163\ X,\ r^2 = 0.20.$$

This implies that the concentration remains relatively constant throughout the reproductive life of the shortbelly rockfish, unlike patterns that were observed in yellowtail rockfish. (M. Eldridge and B. Jarvis)

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