SOUTHWEST FISHERIES CENTER

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PROGRESS IN ROCKFISH RECRUITMENT STUDIES

By

Staff of the Tiburon Laboratory

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Southwest Fisheries Center Administrative Report T-90-02

PROGRESS IN ROCKFISH RECRUITMENT STUDIES

Staff of the Tiburon Laboratory

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INTRODUCTION

This is the sixth in a series of annual reports on studies at the Southwest Fisheries Center's Tiburon Laboratory concerning recruitment of Pacific coast rockfishes (genus Sebastes). It summarizes work accomplished during the period from March 1989 to February 1990 by the Laboratory's three research Investigations, i.e., Groundfish Analysis, Groundfish Communities, and Groundfish Physiological Ecology. The first of these investigations primarily studies the pelagic stage of young-of-the-year (YOY) juveniles sampled directly from the environment by midwater trawl. The second investigation samples pelagic YOY from the gut-contents of predators and assesses the abundance of post-pelagic YOY with underwater visual counts. The third considers physiological factors affecting the condition of adults and their reproductive output. Objectives, methods, and previous results have been presented in earlier versions of this series (Lenarz and Moreland 1985, Hobson et al. 1986, Larson 1987, Whipple 1988, and Hobson 1989).

STUDIES OF PELAGIC JUVENILES

The juveniles of Sebastes spp. school in the coastal pelagic environment for several months following parturition (larval extrusion). During this time they are sampled by midwater trawl and from the gut-contents of predators.

Progress in Midwater Trawl Assessments

Beginning in 1983 the Groundfish Analysis Task at the Tiburon Laboratory has fielded annual surveys designed to estimate the abundance of pelagic YOY rockfishes (Table 1). All cruises thus far have been conducted aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel DAVID STARR JORDAN between April and June, a time when the pelagic stage YOY of most commercial rockfish species are typically available to the sampling gear. These surveys use a standard 26 x 26 m modified Stauffer midwater trawl, with a cod-end liner of 9.53 mm (3/8") 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 Pt. in the south (Fig. 1). As part of the survey design the study area is subdivided into seven geographical strata, each composed of 5-6 standard stations.

During 1989, three complete sweeps were successfully made in May-June as part of cruise DS-89-04; there was no April cruise. 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. At certain stations standard trawls were made at 10, 30, and 100 m depth to provide information concerning the vertical distribution of pelagic YOY rockfishes (see Hobson 1989). Supplemental CTD data were also gathered during the day along

Table 1.--Summary of midwater trawl surveys conducted by the Groundfish Analysis Investigation for pelagic YOY rockfishes off the central California coast (1983-89).

Cruise	Sweep	Dates	Number of Standard Trawls
8301	1	June 8 -- June 23, 1983	20
8401	1	June 12 -- June 27, 1984	24
8505	1	June 5 -- June 30, 1985	28
8608	1	June 3 -- June 11, 1986	33
8608	2	June 11 -- June 18, 1986	28
8608	3	June 20 -- June 25, 1986	28
8703	1	April 10 -- April 20, 1987	33
8705	1	May 23 -- June 1, 1987	32
8705	2	June 2 -- June 11, 1987	34
8705	3	June 12 -- June 21, 1987	33
8804	1	April 16 -- April 22, 1988	27
8806	1	May 22 -- May 31, 1988	33
8806	2	June 2 -- June 10, 1988	34
8806	3	June 11 -- June 18, 1988	31
8904	1	May 14 -- May 21, 1989	31
8904	2	May 24 -- June 3, 1989	32
8904	3	June 4 -- June 13, 1989	31

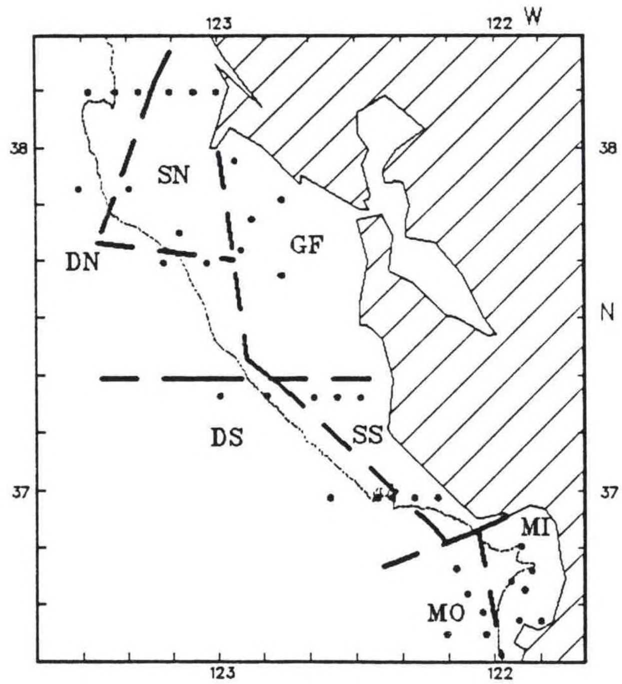


Fig. 1.--Map of the rockfish recruitment survey area showing standard stations occupied. Geographical groupings designate spatial strata (DN = deep north, SN = shallow north, GF = Gulf of Farallons, DS = deep south, SS = shallow south, MO = Monterey outside, MI = Monterey inside). The fine dotted line delineates the 183 m (100 fathom) isobath.

tracklines that criss-crossed the entire study area. As in previous years, data from this cruise were compiled, edited, and added to a mid-water trawl data base.

Improvements in Data Base Management

During the year a number of improvements were made to the midwater trawl data base. As in the past, cruise data from the recruitment surveys are stored in four different dBase III file structures: organism files have information concerning the quantities of all species (fish and invertebrates) caught while trawling; meteorological files contain information about the weather and oceanographic conditions occurring at the time of sampling; position files include depth sampled, latitude, longitude, time, and other collection data; length files record the standard lengths (SL) of individually measured YOY rockfish. A new system for editing these files was devised and instituted this year to improve the overall quality of the data.

Nine SAS programs were written to edit the data and to detect logical errors. For example, individual programs were written to check for out of range and duplicate data in each of the four different types of dBase files. Additionally, programs were written to insure that all of the variables held in common among these files are in agreement and that size-frequency catch expansions are done correctly. These editing procedures were eventually applied to all files in the midwater trawl data base (1983-89). As a result a number of errors were detected and corrected. Edit checking has now become a routine part of post cruise data processing. (C. Reilly and S. Ralston).

Estimates of 1989 Year-Class Strength

One of the most significant analytical changes that occurred during the last year is that a new statistic was instituted for indexing the abundance of pelagic YOY rockfishes. In the past, abundance within a stratum (α_j, j = 1,...,7; Fig. 1) was measured as the average of the logarithm of catches + 1 within the stratum, that is:

$$\alpha_j = [\sum_{i=1}^{n} \log_e(X_{ij}+1)]/n$$

where the X_{ij} are catches from the i = 1,...,n hauls conducted in stratum j. Sweep-specific estimates of abundance over the entire study area were then calculated using standard methods for calculating a stratified mean and the variance of the estimate (i.e., the unweighted mean of the α_j, see Snedecor and Cochran 1967). These calculations require that a mean and variance be estimated for each stratum.

Under new procedures that have been implemented we estimate these quantities by iterative solution of the equations given by Pennington (1983, 1986), assuming that the observations for each stratum follow the Δ-distribution. Observations from this distribution have a finite probability of being zero, while the distribution of non-zero values is lognormal. This distribution has appeal because zero counts are common in our data. In addition, our non-zero tows are skewed to the right as in the lognormal distribution. Pennington (1983) showed that when observations come from the Δ-distribution, the estimators he proposed are the most efficient, and can substantially outperform the arithmetic average. Although the data from the juvenile surveys show some characteristics of the Δ-distribution, certain recent (and preliminary) analyses indicate that the data may evidence minor, but statistically significant, departures from the theoretical distribution. We are currently investigating the sensitivity of Pennington's method to mild departures from the Δ-distribution.

Confidence intervals about the means for each sweep are now calculated assuming that errors are distributed lognormally. First the mean ($\hat{\mu}_\eta$) and variance ($\hat{\sigma}^2_\eta$) of an equivalent normal distribution are derived from the lognormal mean ($\hat{\mu}_\ell$) and variance ($\hat{\sigma}^2_\ell$) calculated from the Δ-distribution as described above (see stratified mean catch per tow and standard error [squared] statistics presented in Table 2). Law and Kelton (1982) show that:

$$\hat{\mu}_\eta = \log_e[\hat{\mu}^2_\ell/\sqrt{(\hat{\sigma}^2_\ell + \hat{\mu}^2_\ell)}] \quad \text{and,}$$

$$\hat{\sigma}^2_\eta = \log_e[(\hat{\sigma}^2_\ell + \hat{\mu}^2_\ell)/\hat{\mu}^2_\ell]$$

We then calculate the confidence limits for $\hat{\mu}_\eta$ as $\hat{\mu}_\eta \pm 1.96\hat{\sigma}_\eta$ and then transform these to the confidence limits for $\hat{\mu}_\ell$ by taking antilogarithms.

Revised estimates of the stratified mean catch per tow (with error statistics) for each of the 15 most commonly caught rockfish species were then recalculated for each sweep completed since 1983 using these new procedures (Table 2). In addition, the combined average catch rate (by sweep) of all pelagic YOY _Sebastes_ spp. is included in the table. These data provide the basis for present and future determinations of pelagic juvenile abundance along the central California coast and, by inference, year-class strength.

The sequential nature of repetitive sampling by sweeps reveals patterns of within season fluctuation in catch rates of pelagic YOY rockfishes. For example, shortbelly rockfish (_S. jordani_) are caught in the greatest quantities during the first half of June (Fig. 2). In contrast, catch rates of chilipepper rockfish (_S. goodei_) often peak somewhat earlier in the year, usually in April or May. These seasonal variations are likely due to a number of factors. Although parturition of most species occurs from December-March, rockfish larvae and small juveniles (< 20 mm SL) are not sampled effectively by the 9.53 mm cod-end mesh trawl. Once the fish have grown to a size that is fully vulnerable to the trawl, their numbers decline due to the combined effects of mortality and emigration (i.e., settlement to benthic or nearshore habitats).

Table 2.--Estimates of the stratified mean catch of pelagic YOY rockfishes per 15 minute haul. Means are based on nighttime trawls conducted at specific stations (see Fig. 1). Sweeps wherein a species was not caught are not reported.

Species	Cruise	Sweep	Stratified Mean Catch per Tow	Standard Error	95% Confidence Interval Bounds	
					Lower	Upper
_S_. _auriculatus_	8401	1	0.8529	0.2279	0.493	1.379
_S_. _auriculatus_	8608	1	6.6815	2.4947	3.083	12.707
_S_. _auriculatus_	8608	2	4.7585	1.7228	2.249	8.901
_S_. _auriculatus_	8608	3	0.7675	0.4666	0.219	1.969
_S_. _auriculatus_	8703	1	0.5127	0.1657	0.263	0.905
_S_. _auriculatus_	8705	1	0.0286	0.0286	0.004	0.103
_S_. _auriculatus_	8705	2	0.1429	0.0756	0.048	0.334
_S_. _auriculatus_	8705	3	0.0857	0.0452	0.029	0.200
_S_. _auriculatus_	8804	1	0.6459	0.2131	0.327	1.152
_S_. _auriculatus_	8904	1	0.0857	0.0571	0.022	0.234
_S_. _crameri_	8401	1	0.0357	0.0357	0.005	0.129
_S_. _crameri_	8703	1	0.2000	0.1178	0.059	0.502
_S_. _crameri_	8705	1	0.1214	0.0732	0.035	0.310
_S_. _crameri_	8705	3	0.0286	0.0286	0.004	0.103
_S_. _crameri_	8804	1	0.1421	0.0427	0.077	0.242
_S_. _crameri_	8806	1	0.1357	0.1109	0.026	0.427
_S_. _entomelas_	8301	1	0.1333	0.1333	0.018	0.482
_S_. _entomelas_	8401	1	2.1362	0.9300	0.866	4.432
_S_. _entomelas_	8505	1	11.8881	5.9628	4.199	26.892
_S_. _entomelas_	8608	1	0.2571	0.1355	0.086	0.600
_S_. _entomelas_	8608	2	0.0571	0.0404	0.013	0.163
_S_. _entomelas_	8703	1	0.5295	0.3451	0.138	1.424
_S_. _entomelas_	8705	1	4.2766	1.2340	2.361	7.152
_S_. _entomelas_	8705	2	6.6306	1.4305	4.267	9.845
_S_. _entomelas_	8705	3	0.3143	0.1604	0.109	0.719
_S_. _entomelas_	8804	1	0.5404	0.1756	0.276	0.956
_S_. _entomelas_	8806	1	2.7864	1.0589	1.268	5.350
_S_. _entomelas_	8806	2	3.4485	0.8233	2.114	5.321
_S_. _entomelas_	8806	3	0.2095	0.0846	0.091	0.416
_S_. _entomelas_	8904	1	0.0286	0.0286	0.004	0.103
_S_. _entomelas_	8904	2	0.2881	0.1010	0.139	0.530
_S_. _entomelas_	8904	3	0.0643	0.0457	0.015	0.184
_S_. _flavidus_	8301	1	0.2667	0.2273	0.048	0.864
_S_. _flavidus_	8401	1	2.6925	1.1098	1.145	5.411
_S_. _flavidus_	8505	1	3.1458	1.6530	1.058	7.330
_S_. _flavidus_	8608	1	0.2556	0.1320	0.088	0.589
_S_. _flavidus_	8608	2	0.3714	0.1565	0.155	0.756
_S_. _flavidus_	8608	3	0.1127	0.0690	0.032	0.291
_S_. _flavidus_	8705	1	0.2857	0.1429	0.101	0.645
_S_. _flavidus_	8705	2	1.3252	0.4291	0.679	2.341
_S_. _flavidus_	8705	3	0.5643	0.2149	0.256	1.085
_S_. _flavidus_	8804	1	0.0357	0.0357	0.005	0.129
_S_. _flavidus_	8806	1	1.4896	0.4241	0.829	2.476
_S_. _flavidus_	8806	2	0.5502	0.1575	0.305	0.917

Table 2.--continued.

Species	Cruise	Sweep	Stratified Mean Catch per Tow	Standard Error	95% Confidence Interval Bounds Lower	Upper
S. flavidus	8904	1	0.1214	0.0674	0.038	0.293
S. flavidus	8904	2	0.4547	0.1719	0.208	0.871
S. flavidus	8904	3	0.3762	0.1410	0.173	0.717
S. goodei	8401	1	2.0447	0.7555	0.951	3.867
S. goodei	8608	1	0.7685	0.2341	0.410	1.318
S. goodei	8608	2	0.6165	0.2441	0.271	1.211
S. goodei	8608	3	0.1667	0.1080	0.044	0.446
S. goodei	8703	1	37.0484	24.6488	9.416	101.040
S. goodei	8705	1	6.9907	1.8183	4.098	11.171
S. goodei	8705	2	6.5946	3.2612	2.363	14.785
S. goodei	8705	3	1.3948	0.6461	0.533	3.003
S. goodei	8804	1	65.8335	27.0222	28.103	131.984
S. goodei	8806	1	114.7360	93.2933	22.034	359.667
S. goodei	8806	2	27.9224	27.7534	3.901	100.539
S. goodei	8806	3	12.3500	12.3143	1.716	44.564
S. goodei	8904	1	0.6855	0.2328	0.340	1.240
S. goodei	8904	2	0.0571	0.0350	0.016	0.147
S. hopkinsi	8401	1	1.1285	0.6506	0.342	2.794
S. hopkinsi	8505	1	0.5714	0.3455	0.164	1.460
S. hopkinsi	8608	1	0.0857	0.0639	0.019	0.253
S. hopkinsi	8608	2	0.0286	0.0286	0.004	0.103
S. hopkinsi	8703	1	0.1786	0.0992	0.056	0.431
S. hopkinsi	8705	1	3.4505	0.7186	2.256	5.059
S. hopkinsi	8705	2	1.5035	0.6558	0.608	3.123
S. hopkinsi	8705	3	0.0286	0.0286	0.004	0.103
S. hopkinsi	8804	1	6.7974	4.9307	1.538	19.679
S. hopkinsi	8806	1	9.6699	8.5674	1.628	32.177
S. hopkinsi	8806	2	1.0290	0.3658	0.493	1.907
S. hopkinsi	8806	3	0.0286	0.0286	0.004	0.103
S. hopkinsi	8904	1	0.0929	0.0539	0.028	0.231
S. hopkinsi	8904	2	0.0643	0.0457	0.015	0.184
S. hopkinsi	8904	3	0.0857	0.0350	0.037	0.171
S. jordani	8301	1	6.0444	5.7794	0.900	21.197
S. jordani	8401	1	26.7335	8.5849	13.774	47.034
S. jordani	8505	1	13.4954	7.5782	4.217	32.833
S. jordani	8608	1	308.4770	253.0471	58.463	972.952
S. jordani	8608	2	62.2260	33.4587	20.411	147.160
S. jordani	8608	3	4.1443	2.5967	1.137	10.849
S. jordani	8703	1	16.1716	8.5596	5.396	37.858
S. jordani	8705	1	61.2476	12.6943	40.122	89.646
S. jordani	8705	2	116.7771	35.4648	62.426	200.001
S. jordani	8705	3	17.9984	9.1421	6.275	41.039
S. jordani	8804	1	50.9777	17.6086	24.953	93.043
S. jordani	8806	1	1349.6236	1258.0400	209.551	4651.062
S. jordani	8806	2	55.9656	24.1033	22.901	115.371
S. jordani	8806	3	55.8912	31.7436	17.241	136.998
S. jordani	8904	1	11.6913	3.3251	6.510	19.425

Table 2.--continued.

Species	Cruise	Sweep	Stratified Mean Catch per Tow	Standard Error	95% Confidence Interval Bounds Lower	Upper
S. *jordani*	8904	2	7.0167	2.2290	3.642	12.280
S. *jordani*	8904	3	16.3186	12.4700	3.432	48.987
S. *levis*	8505	1	0.0643	0.0457	0.015	0.184
S. *levis*	8608	1	0.0286	0.0286	0.004	0.103
S. *levis*	8703	1	0.0643	0.0457	0.015	0.184
S. *levis*	8705	1	0.2190	0.0938	0.090	0.450
S. *levis*	8705	3	0.1857	0.0958	0.064	0.428
S. *levis*	8804	1	0.5265	0.1595	0.282	0.901
S. *levis*	8806	1	0.0238	0.0238	0.003	0.086
S. *levis*	8904	2	0.0286	0.0286	0.004	0.103
S. *melanops*	8505	1	0.0357	0.0357	0.005	0.129
S. *melanops*	8608	1	0.0286	0.0286	0.004	0.103
S. *melanops*	8705	1	0.1429	0.0670	0.054	0.310
S. *melanops*	8705	2	0.3408	0.1443	0.142	0.696
S. *melanops*	8705	3	0.0929	0.0539	0.028	0.231
S. *melanops*	8806	1	0.0929	0.0500	0.030	0.220
S. *melanops*	8806	2	0.3974	0.1763	0.158	0.834
S. *melanops*	8904	2	0.1357	0.0741	0.044	0.324
S. *melanops*	8904	3	0.0476	0.0476	0.007	0.172
S. *mystinus*	8505	1	1.8669	1.0632	0.574	4.584
S. *mystinus*	8608	1	0.1143	0.0670	0.034	0.286
S. *mystinus*	8703	1	0.2071	0.1197	0.063	0.514
S. *mystinus*	8705	1	2.5475	0.5703	1.612	3.835
S. *mystinus*	8705	2	2.8874	1.0491	1.361	5.412
S. *mystinus*	8804	1	1.6540	0.4614	0.932	2.725
S. *mystinus*	8806	1	5.7495	2.0642	2.735	10.708
S. *mystinus*	8806	2	5.0427	0.5778	4.005	6.267
S. *mystinus*	8806	3	0.0643	0.0457	0.015	0.184
S. *mystinus*	8904	1	0.5452	0.1998	0.255	1.027
S. *mystinus*	8904	2	0.9905	0.2743	0.560	1.626
S. *mystinus*	8904	3	0.2857	0.1714	0.083	0.726
S. *paucispinis*	8401	1	7.9949	3.7699	3.005	17.403
S. *paucispinis*	8608	1	6.3648	4.9317	1.312	19.292
S. *paucispinis*	8608	2	1.1420	0.3045	0.660	1.844
S. *paucispinis*	8608	3	0.1556	0.0930	0.045	0.394
S. *paucispinis*	8703	1	0.7859	0.4765	0.224	2.012
S. *paucispinis*	8705	1	0.7886	0.2860	0.372	1.476
S. *paucispinis*	8705	2	0.9435	0.2691	0.524	1.570
S. *paucispinis*	8705	3	0.8934	0.4914	0.286	2.144
S. *paucispinis*	8804	1	0.8479	0.1407	0.605	1.155
S. *paucispinis*	8806	1	1.0961	0.2507	0.686	1.663
S. *paucispinis*	8806	2	0.3190	0.1695	0.106	0.749
S. *paucispinis*	8806	3	0.0857	0.0857	0.012	0.310
S. *paucispinis*	8904	1	0.2929	0.1274	0.119	0.607
S. *paucispinis*	8904	2	0.3333	0.1709	0.115	0.765
S. *pinniger*	8401	1	2.7325	1.1041	1.182	5.429
S. *pinniger*	8505	1	0.1786	0.1473	0.034	0.565

Table 2.--continued.

Species	Cruise	Sweep	Stratified Mean Catch per Tow	Standard Error	95% Confidence Interval Bounds	
					Lower	Upper
S. pinniger	8608	1	1.0226	0.3200	0.536	1.777
S. pinniger	8608	2	0.2857	0.1325	0.109	0.616
S. pinniger	8608	3	0.0556	0.0556	0.008	0.201
S. pinniger	8703	1	0.7214	0.3598	0.256	1.626
S. pinniger	8705	1	0.3720	0.1238	0.187	0.666
S. pinniger	8705	2	0.9186	0.2219	0.560	1.424
S. pinniger	8705	3	0.5143	0.2119	0.219	1.033
S. pinniger	8804	1	0.7391	0.2948	0.323	1.458
S. pinniger	8806	1	3.7678	1.3865	1.759	7.110
S. pinniger	8806	2	0.7951	0.3003	0.364	1.522
S. pinniger	8806	3	0.1119	0.0660	0.033	0.281
S. pinniger	8904	1	0.4409	0.1751	0.194	0.868
S. pinniger	8904	2	0.4617	0.1365	0.251	0.781
S. pinniger	8904	3	0.1929	0.0500	0.113	0.308
S. rufus	8705	1	0.2571	0.0948	0.120	0.486
S. rufus	8705	2	0.2000	0.0904	0.078	0.424
S. rufus	8705	3	0.0286	0.0286	0.004	0.103
S. rufus	8804	1	0.4357	0.2037	0.165	0.943
S. rufus	8806	2	0.0952	0.0602	0.026	0.251
S. saxicola	8401	1	0.3519	0.1232	0.171	0.647
S. saxicola	8505	1	0.1000	0.0769	0.021	0.302
S. saxicola	8608	1	0.0571	0.0404	0.013	0.163
S. saxicola	8703	1	1.2071	0.3105	0.712	1.920
S. saxicola	8705	1	6.5719	3.6032	2.110	15.740
S. saxicola	8705	2	0.3150	0.1104	0.153	0.579
S. saxicola	8705	3	0.0571	0.0571	0.008	0.207
S. saxicola	8804	1	5.5142	1.5313	3.114	9.065
S. saxicola	8806	1	0.7318	0.1731	0.451	1.125
S. saxicola	8806	2	0.1714	0.0606	0.082	0.317
S. saxicola	8904	1	0.1786	0.0811	0.070	0.380
S. wilsoni	8401	1	0.0714	0.0714	0.010	0.258
S. wilsoni	8608	1	0.0571	0.0404	0.013	0.163
S. wilsoni	8703	1	0.4500	0.1886	0.189	0.913
S. wilsoni	8705	1	0.0286	0.0286	0.004	0.103
S. wilsoni	8705	2	0.2357	0.1247	0.079	0.552
S. wilsoni	8705	3	0.0571	0.0571	0.008	0.207
S. wilsoni	8804	1	2.9343	0.8751	1.587	4.983
S. wilsoni	8806	1	0.2024	0.0813	0.088	0.401
S. wilsoni	8806	2	0.0357	0.0357	0.005	0.129
S. wilsoni	8806	3	0.0286	0.0286	0.004	0.103
S. wilsoni	8904	1	0.2714	0.1794	0.070	0.737
S. wilsoni	8904	2	0.0286	0.0286	0.004	0.103
S. wilsoni	8904	3	0.0643	0.0457	0.015	0.184
Total Sebastes	8301	1	6.5702	5.7972	1.113	21.800
Total Sebastes	8401	1	44.9833	14.7250	22.875	79.896
Total Sebastes	8505	1	31.1745	14.9903	11.492	68.683
Total Sebastes	8608	1	298.5559	224.3189	64.322	885.750

Table 2.--continued.

Species	Cruise	Sweep	Stratified Mean Catch per Tow	Standard Error	95% Confidence Interval Bounds Lower	Upper
Total *Sebastes*	8608	2	73.1108	37.2146	25.431	166.929
Total *Sebastes*	8608	3	5.5251	3.4662	1.513	14.476
Total *Sebastes*	8703	1	58.0162	33.1500	17.772	142.776
Total *Sebastes*	8705	1	88.5507	15.1383	62.584	121.734
Total *Sebastes*	8705	2	128.7842	27.8215	82.825	191.318
Total *Sebastes*	8705	3	20.2456	7.7240	9.184	38.959
Total *Sebastes*	8804	1	133.8810	38.2451	74.349	222.892
Total *Sebastes*	8806	1	1630.9266	1486.5423	262.522	5534.351
Total *Sebastes*	8806	2	78.3556	30.2646	35.193	151.808
Total *Sebastes*	8806	3	46.8264	21.7565	17.853	101.013
Total *Sebastes*	8904	1	14.6835	3.5162	8.989	22.684
Total *Sebastes*	8904	2	10.8690	3.3602	5.744	18.773
Total *Sebastes*	8904	3	16.8997	11.8912	3.988	47.904

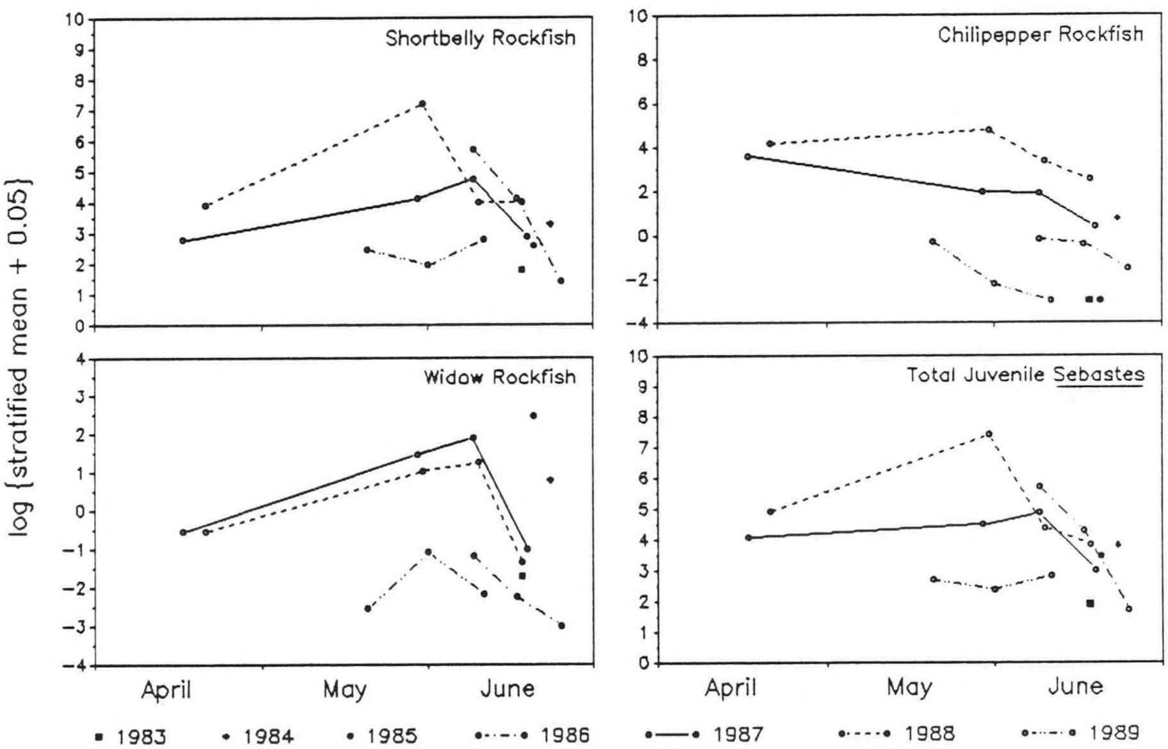


Fig. 2.--Seasonal and interannual variation in the abundance of three common rockfish species (data for all *Sebastes* spp. combined are also presented). Stratified means, based upon the Δ-distribution (see Table 2), have been transformed with natural logarithms to facilitate comparisons. Note that repeated sampling of standard stations by sweep began in 1986.

Results from 1989 indicate that catches were rather poor (Table 2; Fig. 2). Overall levels of pelagic YOY Sebastes spp. were lower than in any year except 1983, an El Niño year. During the period May 14-June 13, chilipepper catch rates appear to have declined. At the same time widow rockfish catch rates first rose and then peaked during sweep 2. Shortbelly rockfish catch rates were more or less constant during this period.

That 1989 was a poor year for pelagic YOY rockfishes is confirmed by an examination of the frequency distribution of 1989 standard scores, compiled from statistics on the 15 species considered previously (Fig. 3). Here the annual index of abundance for species i in year j (θ_{ij}) is defined as the maximum across sweeps within the year of the $\log_e$(stratified mean Δ-distribution

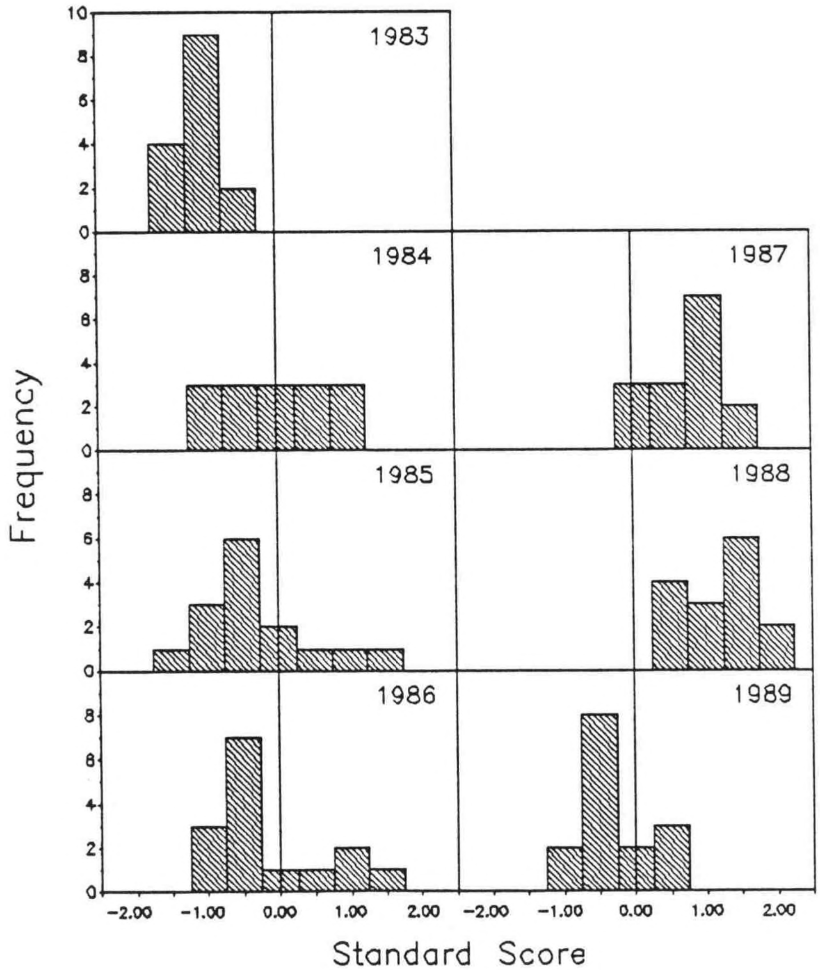


Fig. 3.--Frequency distributions by year of the relative abundance of 15 rockfish species. Annual values for a species were normalized to the long term (1983-89) mean and variance of that species.

catch per haul + 0.05}. Standard scores for each year (Z_j) were then calculated relative to each species' long-term (1983-89) mean ($\hat{\mu}_i$) and variance ($\hat{\sigma}^2{}_i$), such that:

$$Z_j = \frac{\theta_{ij} - \hat{\mu}_i}{\sqrt{\hat{\sigma}^2{}_i}}$$

Results show that catches of most species were well below their long-term means ($Z < 0$) in 1989. In contrast, the preceding two years (1987 & 1988) were both exceptionally good years vis-à-vis the 7 year time series.

Another pattern is evident in these data; levels of abundance among the 15 species tend to vary similarly from year to year. With the exception of 1986, the 7 distributions are essentially unimodal. Other than that year, there are no clear instances in which the distribution of Z_j values is split into a group lying above the long-term mean and another group lying below. One can conclude that the physical and biotic environmental conditions affecting pelagic YOY rockfishes act, to a large extent, uniformly within this set of species.

This conclusion is further verified with results from a principal components analysis of the data (Green 1978). This multivariate technique was used to quantitatively resolve patterns of covariation among rockfish species spanning the 7 available years of survey data. For this purpose, annual indices of abundance (maximum across sweeps within a year of $\log_e${stratified mean Δ-distribution catch per haul + 0.05}) were tabulated for 10 of the most commonly encountered species (S. auriculatus, S. entomelas, S. flavidus, S. goodei, S. hopkinsi, S. jordani, S. mystinus, S. paucispinis, S. pinniger, S. saxicola) in each year (1983-89). Ordination of the correlation matrix was conducted using species as variables and years as cases.

Results from this analysis (Fig. 4) show that the first principal component accounted for 57% of the variation in the data ($\lambda_1 = 5.73$); between the first and second components ($\lambda_2 = 2.57$) 83% of the variation was accounted for. It is noteworthy that the signs of all elements in the first eigenvector were positive, indicating that abundance levels of these 10 species were, in the most general sense, positively associated. Individual scores on the first component (ς_1) for each year, ranked in descending order, were: 1988 ($\varsigma_1 = 3.33$) > 1987 ($\varsigma_1 = 2.18$) > 1984 ($\varsigma_1 = 0.83$) > 1986 ($\varsigma_1 = -0.19$) > 1985 ($\varsigma_1 = -0.95$) > 1989 ($\varsigma_1 = -1.30$) > 1983 ($\varsigma_1 = -3.90$). To the extent that the abundances of these 10 species are governed by identical processes, these ς_1 values represent integrated indices of year-class strength.

These findings are quite similar to results presented one year ago (Hobson 1989). With the addition of another year of data and the implementation of a new estimation procedure (Δ-distribution) the results were not seriously affected. This shows that our prior conclusion, that abundance covaries in a positive manner among these species, is robust.

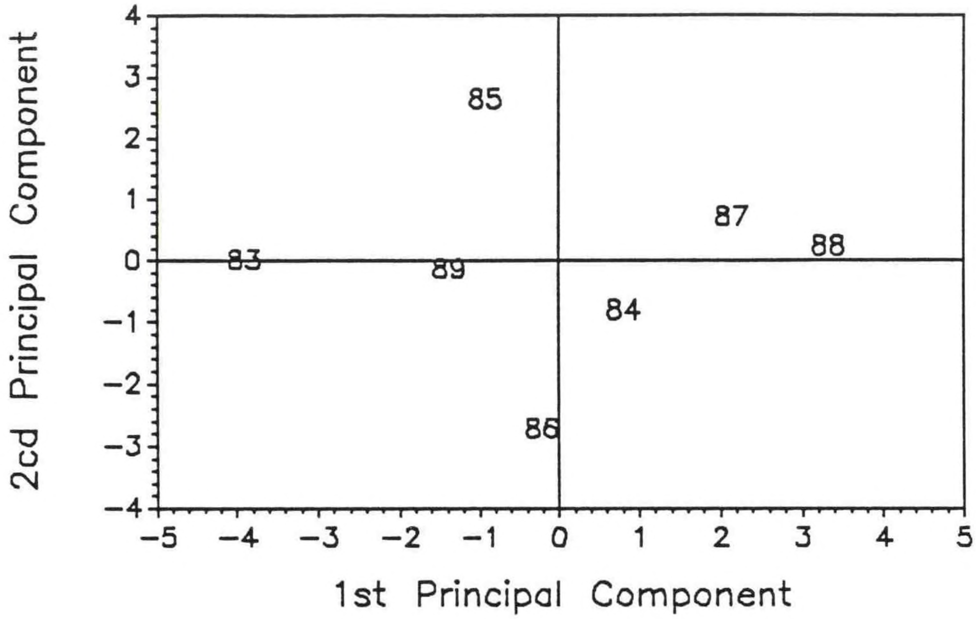


Fig. 4.--Yearly scores of pelagic YOY abundance plotted on the first two principal components.

Still, the years 1985 and 1986 are distinctive in their departure from this generalization (Figs. 3 and 4). In those years the overall pooled abundance of YOY Sebastes spp. was intermediate (note position along the first principal component in Fig. 4). On an individual basis, however, the 10 species tended to do either quite well or quite poorly. Moreover, success seemed to be related to vertical distribution in the water column (see Hobson 1989). For example, in 1985 the deeper dwelling species (S. entomelas, S. flavidus, and S. mystinus) were much more abundant than in 1986 (Table 2). Conversely, species occurring in shallow water (S. auriculatus, S. jordani, and S. paucispinis) were substantially more abundant in 1986 than in the year before. These results show that, to some degree, species-specific factors control the abundance of pelagic YOY rockfishes in our surveys, and that care must be exercised in generalizing particular findings to the genus as a whole. (S. Ralston and J. Bence).

Statistical Power of Predicting Fishery Recruitment

A major long-term goal of the midwater trawl surveys is to estimate the strength of a year-class when it enters the fishery (e.g., age V for widow rockfish [S. entomelas]; Hightower and Lenarz 1989) from abundance at age 0. This requires that a positive relationship between recruitment to the fishery and age-0 abundance be established. Recent work has examined the statistical power needed to establish such a relationship (Bence 1990). This was done for a range of specified assumptions. The first case considered was when expected recruitment to the fishery is directly proportional abundance at age-0. Results showed that high power could be achieved with 10 or more years of data, provided the standard deviation of recruitment to the fishery, given a particular value of the age-0 abundance index, is not too large (on the order of several to 10 times the standard error associated with the index of age-0 abundance). This allows below or above average year classes to be distinguished from average ones with high probability.

The effect of compensatory mortality, during the period from age-0 to recruitment to the fishery, on estimates of statistical power was also considered. In the face of moderate compensation the ability to establish a relationship between recruitment to the fishery and age-0 abundance was not compromised, and there also was moderately high power to detect the existence of compensation. In the face of very strong compensation, the statistical power for detecting a relationship between recruitment to the fishery and age-0 abundance was much lower. In this latter situation a recruitment index is less useful since recruitment is relatively constant.

Although 10 years of data should be adequate, under a range of assumed conditions, for establishing a relationship between recruitment to the fishery and age-0 abundance, we note that there is a substantial time lag between the time the survey estimate of age-0 abundance is made and the time that a reliable independent estimate of recruitment to the fishery becomes available. This time lag can approach 10 years for some species of rockfish. (J. Bence).

<u>Growth of Shortbelly Rockfish in 1989</u>

The growth of larval and pelagic juvenile shortbelly rockfish (*S. jordani*) was studied in detail during the last year. Analyses were carried out through the examination of otolith microstructure. Results showed that growth in the early life history is complex; simple models that assume size increases smoothly with age did not accurately predict growth in YOY of this species.

To back-calculate standard length at age, a segmented (piece-wise) regression model was used to relate somatic and otolith growth dimensions. The four segments of this model coincided with different growth stanzas, which appeared to be separated by transitions corresponding to distinct life history events (e.g., flexion and juvenile transformation). Ultimately, the two-stage Gompertz growth model developed by Zweifel and Lasker (1976) yielded the best fit to back-calculated SL at age data (Fig. 5).

The daily periodicity of the otolith increments was validated from length data that increased progressively when a cohort of fish was sequentially sampled during the May-June cruise. For juveniles

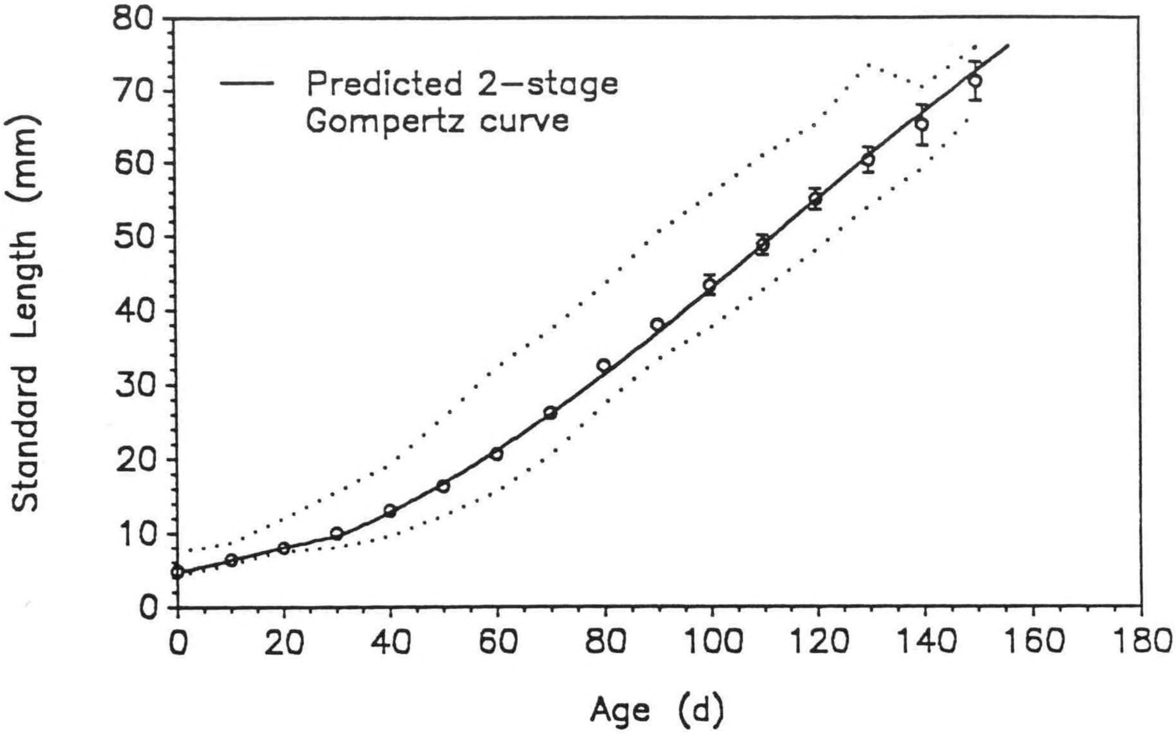


Fig. 5.--Relationship between back-calculated standard length (SL) and age for 1989 shortbelly rockfish (S. jordani) larvae and pelagic YOY. Dotted lines represent the maximum and minimum observed SL at each age; the solid line shows the predicted two-stage Gompertz curve; circles represent average SL at age; bars are confidence intervals.

born prior to Julian day 60 (the primary spawn) the slope of the regression of SL on date of capture was 0.54 mm/Julian day (standard error = 0.016). This compared with a slope of 0.53 mm/increment (standard error = 0.014) for the aged subsample of juveniles taken during the cruise, providing a good correspondence between two independent measures of growth rate and confirming the daily periodicity of increments. (T. Laidig, S. Ralston, and J. Bence).

Moonlight and Catch Rates of Pelagic YOY Rockfishes

The index of pelagic YOY rockfish abundance that is estimated from catches made during our annual research cruises is based upon a mathematical average of the catch taken while trawling. The precision of the trawl survey index is affected by variation in catchability, being fundamentally a catch-per-unit-effort (CPUE) statistic. Since the trawls are conducted at night to reduce net avoidance, moonlight could affect catchability, which in turn could influence the estimate of abundance. As a result a study was undertaken to determine the possible effect of moonlight on catch using data from the 1983-88 period.

Catch rates (represented by Z-scores) were plotted against an index of moonlight intensity. As before, Z-scores were calculated according to:

$$Z = \frac{\log_e[\text{catch}+0.1] - \hat{\mu}}{\sqrt{\hat{\sigma}^2}}$$

where $\hat{\mu}$ and $\hat{\sigma}^2$ are the log mean and variance terms for all catches + 0.1 within the sweep from which a catch was taken, i.e., catches were normalized to their sweeps of origin. An index of moonlight intensity was calculated so that values ranged from 0.00 (new moon) to 1.00 (full moon). Between these extremes the relationship between lunar phase and moonlight intensity was considered linear. In addition, the time of moonrise and moonset was used to determine if a trawl was conducted in the presence of moonlight.

Results showed (Fig. 6) a significant negative effect of moonlight intensity on catches of pelagic YOY rockfishes ($P < 0.05$), however, the coefficient of determination ($r^2 = 0.012$) indicated that the effect was so minor that no corrective action needed to be taken to adjust the data. (D. Woodbury and S. Ralston).

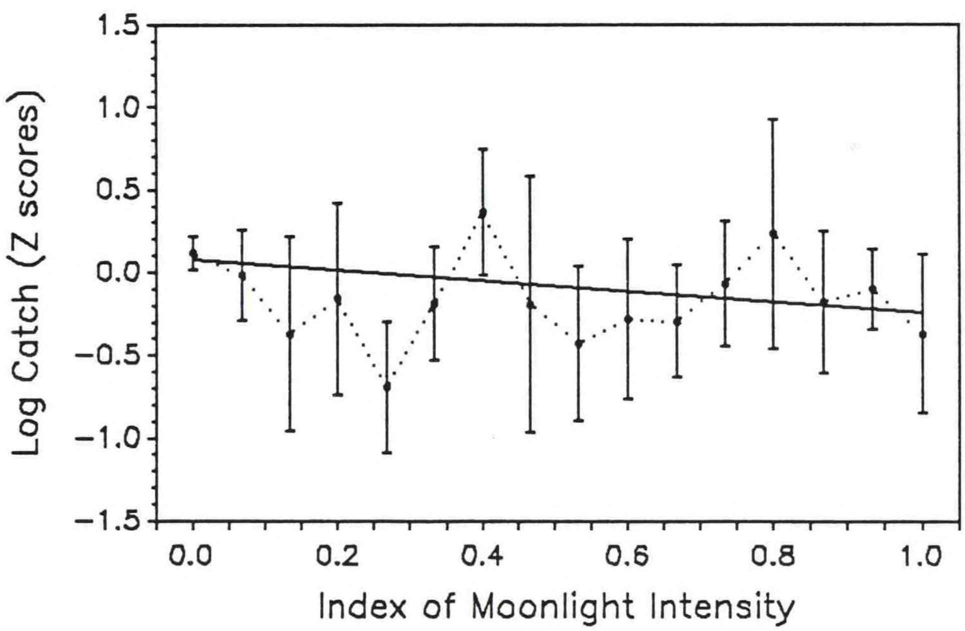


Fig. 6.--The effect of moonlight intensity on the catch rate of pelagic YOY rockfish. Plotted are the means with 95% confidence intervals. The solid line is the fit of a linear regression to the data.

Progress in Trophic Studies of Predators

Estimates of 1989 Year-Class Strength

The average number of juvenile rockfishes in the gut contents of king salmon (*Oncorhynchus tshawytscha*) sampled from the Gulf of the Farallones during 1989 would suggest moderate recruitment (Table 3). However, this value is inflated by exceptionally large numbers observed during three days between May 17-25. Although at other times in 1989 very few juveniles were taken by salmon, more were sampled on those three days than on any other day since this study began in 1983. The stomach contents of salmon sampled on May 17th were particularly exceptional. These contained an average of 17 juvenile *Sebastes* spp. each, and three contained 61, 61, and 64. In fact, the 59 salmon taken on this one day contained over 30% of the pelagic YOY juvenile rockfishes found in the gut contents of the 1,034 salmon sampled during the entire year.

Table 3.--Mean number of pelagic YOY juvenile rockfishes (*Sebastes* spp.) in the stomach contents of king salmon (*Oncorhynchus tshawytscha*) from the Gulf of the Farallones, 1983-1989. (N = number of salmon examined with gut contents)

Year	N	All Species	*S. jordani*	*S. entomelas*
1983	415	0.16	0.00	0.00
1984	503	1.61	0.34	0.02
1985	760	5.72	1.56	0.13
1986	243	0.94	0.18	0.02
1987	416	6.26	5.72	0.30
1988	320	4.51	3.15	0.04
1989	517	3.77	2.80	0.01

Aside from demonstrating the difficulty of using multi-day averages from predator diets to estimate relative abundance in the environment, these findings have important implications in the biology of the salmon and the juvenile rockfishes. Although the evidence generally indicates that the 1989 year-class was relatively weak, it would appear that the juveniles that were present occurred in large, widely spaced aggregations.

A somewhat unusual species composition may have contributed to these results. Although shortbelly rockfish (*Sebastes jordani*) has always been the major species taken, its dominance this year was greater than ever before (86% of all identified juveniles). The second most abundant species (5%) this year was squarespot rockfish (*S. hopkinsi*), which is unusual because this species has been an infrequent component of the diet in other years; blue rockfish (*S. mystinus*) ranked third in abundance (4%). Widow rockfish (*S. entomelas*), usually second in prominence, was represented by fewer individuals this year than during any previous year except 1983 (Table 1). (P. Adams and K. Silberberg).

Identification of Pelagic Juveniles in Predator Diets

It is particularly difficult to identify pelagic YOY juvenile rockfishes to species with samples obtained from predator diets because major distinguishing features, pigment patterns in particular, are lost to digestion. Even meristic characters are sometimes obliterated by digestive action. Because estimates of species composition improve with increased ability to identify the various forms present, much effort has gone into developing methods that improve our ability to identify individuals to species. Techniques involved include histological stains, computerized keys, and interspecific differences in skeletal features.

The identification procedures that have been developed usually involve counts of gill rakers, head spines, and the spines and rays of the various fins. In some cases the cleithrum and the bony elements of the caudal fin are used. First, the specimen is stained with alizarin red S, a bone-specific stain that accentuates fin rays and other bony meristic features, making them easier to count. Identifications using these characters are based on a computerized key. Entries into the key are made for whatever kinds of meristics happen to be available. The result is a list of species, each with the probability of it having the particular combination of features entered. The advantage of this key over traditional keys is that it accepts any combination of meristic characteristics - a particularly important feature when dealing with specimens variably damaged by digestion.

The success of these techniques is evident in that, while only 63% of the specimens taken from salmon stomachs could be identified to species in 1983, the rate has improved to nearly 90% at present. Most of this marked improvement has come with our increased ability to identify species other than the highly distinctive shortbelly rockfish. (P. Adams and K. Silberberg).

STUDIES OF POST-PELAGIC JUVENILES

Progress In Visual Assessments of Post-Pelagic Juveniles in Nearshore Habitats

Estimates of 1989 Year-Class Strength

The number of first-year juvenile rockfishes that settle in northern Californian nearshore habitats continues to vary from year to year. Dominant species this year, as in all previous years of the study, were: the yellowtail rockfish (Sebastes flavidus), the blue rockfish (S. mystinus), and the black rockfish (S. melanops). As before, data were generated from visual counts made underwater using scuba at established sites on the Sonoma and Mendocino coasts.

Results of counts made during the past year (Tables 4 and 5) indicate that the 1989 year-class is relatively weak, particularly that of _S. flavidus_. Although data were collected as weather permitted throughout the season, the tables are limited to numbers of fish present during August and September. Because at least one of the species considered (_S. flavidus_) sometimes continues to recruit through the summer, inter-annual comparisons of year-class strength are best made with numbers present in late summer or early fall (as discussed in previous reports).

Table 4.--Mean number (standard error in parenthesis) of YOY juveniles counted/minute off the Mendocino coast during August and September, 1983-89. (n = number of one-minute counts).

Species	1983 n=36	1984 n=57	1985 n=50	1986 n=103	1987 n=112	1988 n=62	1989 n=181
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)
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)
S. melanops	0.41 (0.14)	0.31 (0.08)	4.34 (1.54)	9.52 (2.08)	7.58 (1.24)	5.94 (1.35)	3.14 (0.59)
Total	0.68 (0.19)	8.38 (2.33)	190.50 (29.82)	23.35 (3.91)	291.67 (33.99)	141.29 (16.88)	10.49 (1.44)

Table 5.--Mean number (standard error in parenthesis) of YOY juveniles counted/minute off the Sonoma coast during August and September, 1984-89. (n = number of one-minute counts).

Species	1984 n=57	1985 n=50	1986 n=103	1987 n=112	1988 n=62	1989 n=186
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)
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)
S. melanops	1.63 (0.52)	4.40 (1.17)	3.00 (1.31)	4.48 (1.70)	6.40 (1.95)	1.66 (0.39)
Total	10.91 (2.12)	257.20 (35.38)	24.97 (5.17)	442.48 (66.72)	221.38 (22.55)	10.39 (1.34)

Juvenile _S. mystinus_ continued to be more numerous off Sonoma than to the north off Mendocino, although differences in the low numbers involved were not significant. However, the faster growth noted in Sonoma recruits during past years was not evident in 1989. As before, _S. mystinus_ recruits were about the same size in both areas during June, shortly after entering the nearshore habitats. However, unlike previous years, when those to the south proceeded to outgrow those to the north, growth this year proceeded at about the same rate in both areas (Student's $t = 1.37$; $df = 61$; $P = 0.18$). Thus, 38 individuals sampled off Sonoma in August were 51-66 mm SL ($\bar{x} = 59$), while 25 sampled off Mendocino during the same month were 48-63 mm SL ($\bar{x} = 57$). Furthermore, growth continued at similar rates on through the fall (Student's $t = 0.81$; $df = 30$; $P = 0.42$), so that 14 individuals sampled off Sonoma in December were 67-78 mm SL ($\bar{x} = 72$), while 18 fish sampled off Mendocino during the same month were 64-78 mm SL ($\bar{x} = 73$).

At least two major pulses of recruitment were evident among the limited number of _S. flavidus_ recruits present. Twelve sampled off Mendocino on 23 August were of two distinct groups: eight were 49-54 mm SL ($\bar{x} = 51.4$) and had birthdates scattered between 13 January and 6 March (based on examination of otoliths), whereas the other four were 35-37 mm SL ($\bar{x} = 35.7$) and had birthdates between 5 April and 7 May. This species has experienced multiple pulses of recruitment at least twice before (in 1986 and in 1987: see reports for those years), but we have no evidence of this in either _S. mystinus_ or _S. melanops_. (E. Hobson, D. Howard, and J. Chess).

Anomalous Oceanographic Features During 1989 May Have Influenced Recruitment

That _S. flavidus_, _S. mystinus_, and _S. melanops_ recruited in relatively low numbers during 1989 may relate to certain anomalous oceanographic features during the preceding winter and spring, as detected by thermographs stationed at permanent sites on the Sonoma and Mendocino coasts. From December-March of most years there is a rise in sea temperatures, with readings of about 13° C during January-February that often are the highest of the year. However, because all three species experience parturition during this period, they may have been adversely affected by the unusual pattern that developed in December 1988. At that time, sea temperatures began to fall rather than to rise and continued at unusually low levels through March, with readings of about 9° C from mid-January to mid-February. These were about 4° C below normal for those months.

This was also an unusual year in another important respect. During most years, the sudden onset of upwelling that marks the spring transition occurs over just a few days in late March or early April. During 1989, however, the spring transition occurred in mid May--about 6 weeks later than usual. Furthermore, the extended period of strong upwelling that ordinarily follows the spring transition was sharply curtailed this year. If the pattern of onshore-offshore flow characteristic of normal upwelling is important to recruiting juvenile rockfishes, as some believe, the unusual pattern in 1989 may have adversely affected this recruitment. (E. Hobson).

Survival and Mortality Rates

Mortality estimates based on the 1989 year-class were not feasible because sampling during late winter and early spring was prevented by turbulent seas and limited visibility underwater. Nevertheless, we continued to develop estimates of mortality and survival based on data from previous years.

The daily instantaneous natural mortality estimates of juvenile blue rockfish presented in Table 15 of Hobson (1989) are 2.5-8.0 times lower than similar estimates for other species published elsewhere (Table 6). These other estimates, however, involve fishes with widely different life-histories, including anadromous, estuarine, and fresh-water species.

Table 6.--Instantaneous natural mortality estimates for juvenile blue rockfish (*Sebastes mystinus*) compared with similar estimates for juveniles of other species found in the literature.

Species	Instantaneous Natural Mortality (d^{-1})	Reference
Sebastes mystinus	0.0021-0.0085	This study
Alosa sapidissima	0.0192	Crecco *et al*. 1983
Pseudopleuronectes americanus)	0.0121	Pearcy 1962
Clupea harengus	0.0171	Dragesund 1969
Pleuronectes platessa	0.0156	Bannister *et al*. 1974
Micropterus salmoides	0.0294	Timmons *et al*. 1981
Morone saxatilis	0.0151	Dey 1981
Leiostomus xanthurus	0.0419	Currin *et al*. 1984
Micropognias undulatus	0.0230	Currin *et al*. 1984
Engraulis mordax	0.0150	Smith 1985
Oncorhynchus gorbuscha	0.0300	Parker 1968

The exponential natural mortality model assumes a constant mortality rate, but our data show a decrease in population size which exceeds that predicted by the model. This is evident in data from Mendocino (1988-89), which yield a curvilinear plot even following logarithmic transformation (Fig. 7). Rather than indicating a constant mortality rate, the data suggest a higher mortality rate early in the time series. (P. Adams and D. Howard).

COMPARISON OF ANNUAL ESTIMATES OF YEAR-CLASS STRENGTH

Results presented in Tables 2-5 all represent, in one form or another, estimates of year-class strength for specific species of rockfish from 1983-89. These data afford the opportunity to compare and contrast recruitment indices that are based on different sampling methodologies and different life history stages.

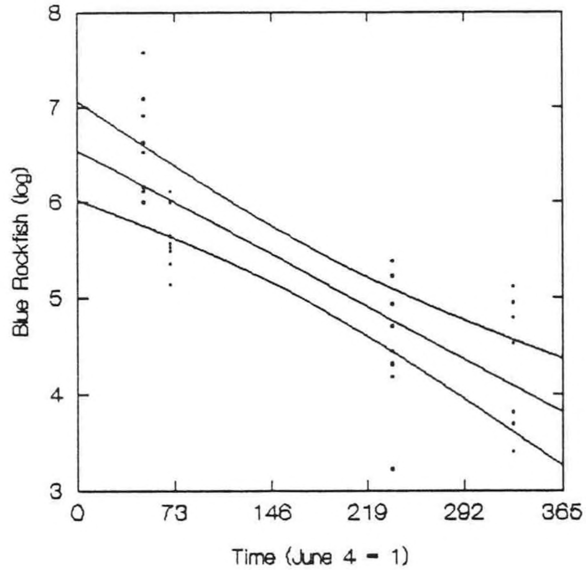


Fig. 7.--Natural mortality estimate for blue rockfish from Whitesboro Cove 1987/88.

Annual abundance estimates of pelagic YOY juvenile rockfish, as measured by midwater trawl catch rates (Table 2) and numbers encountered in the stomach contents of king salmon (Table 3), show a moderate to high degree of positive correlation (Fig. 8). Particularly impressive is the correlation for widow rockfish (S. entomelas). The lower correlation exhibited by shortbelly rockfish (S. jordani) may be due to several factors, including: (1) the midwater trawl survey transits Ascension and Pioneer Canyons, regions of high juvenile and adult shortbelly rockfish abundance, whereas the data on salmon stomach contents is geographically restricted to catches made in the Gulf of the Farallones (Fig. 1), (2) a difference exists in the depth distributions of YOY juvenile widow (deep) and shortbelly (shallow) rockfishes (Hobson 1989), which may relate to the foraging habitat of king salmon, and (3) the numbers of juvenile shortbelly rockfish in the diet of salmon may saturate at very high densities of prey (Type II functional response; Holling 1959). The similarity in results presented for shortbelly rockfish (upper panel) and that of combined Sebastes spp. (lower panel) is due to the strong dominance of shortbelly rockfish in both the midwater trawl catches and in the stomach contents of salmon.

Annual abundance estimates of YOY rockfish, as measured by midwater trawl catch rates of pelagic juveniles (Table 2) and by the numbers of recently settled individuals encountered during underwater SCUBA surveys along the Sonoma coast (Table 5), show good correlation (Fig. 9) for yellowtail rockfish (S. flavidus) and blue rockfish (S. mystinus). Although the time series of data along the Sonoma coast did not begin until 1984, whereas surveys in Mendocino began one year earlier (Table 4), the former site was selected for comparison due to its closer proximity with the midwater trawl surveys (Fig. 1). Results show that both methods are in substantial agreement concerning annual estimates of year-class strength of these two species. (S. Ralston, P. Adams, and E. Hobson).

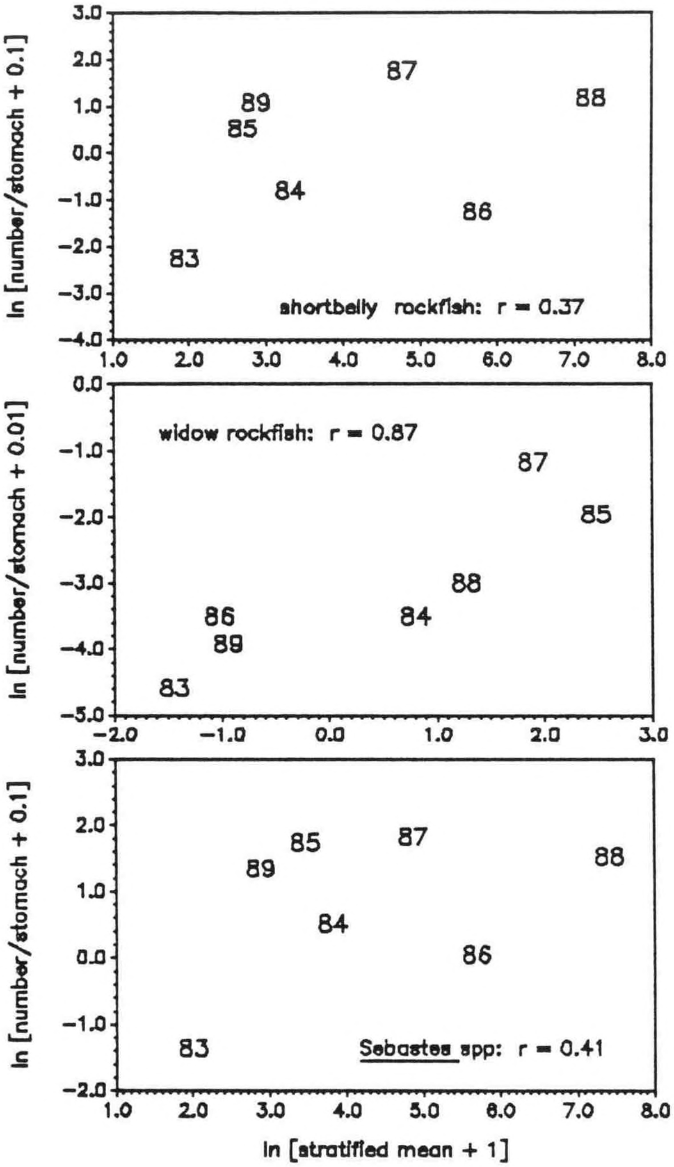


Fig. 8.--Comparison of annual estimates (1983-89) of rockfish year-class strength based upon midwater trawl catch rates (abscissa) and the numbers of pelagic YOY juveniles encountered in the stomach contents of king salmon (ordinate).

STUDIES OF ADULT REPRODUCTION

The Groundfish Physiological Ecology Investigation assesses the condition and reproduction of adult fish. Results will help to determine how variation in reproductive performance affects variation in recruitment. Previous administrative reports have

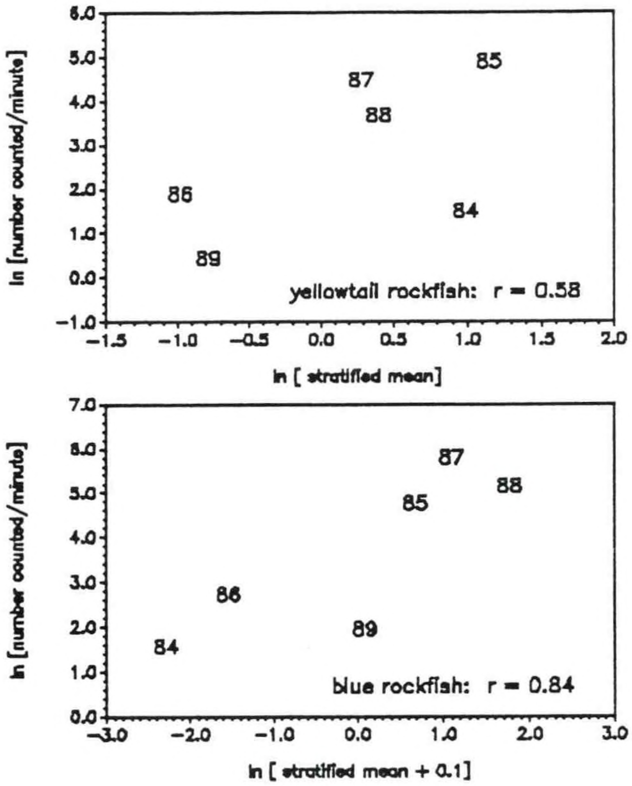


Fig. 9.--Comparison of annual estimates (1984-89) of rockfish year-class strength based upon midwater trawl catch rates (abscissa) and the numbers of recently settled YOY encountered during SCUBA surveys along the Sonoma coast (ordinate).

presented the overall objectives, general methods, and initial findings; this report provides an update of results obtained during the last spawning year (April 1989--March 1990), with additional information on special studies.

As in the past, studies on yellowtail rockfish (Sebastes flavidus) were emphasized. Collection of adults was continued over Cordell Bank off central California (lat. 38.0° N; long. 123.4° W). After the first three years of monthly sampling, a reduced monitoring schedule was instituted in the 1988-89 spawning year (sampling was done for fewer months). Because of unusual oceanographic conditions over the last year, we are again sampling on a monthly basis. In addition, spatial coverage of sampling has been extended to more northern populations off Washington and British Columbia, Canada.

In the beginning of this study the following objectives were outlined (Figure 10a):

> ...To determine the temporal variability (seasonal and interannual) in temperature, upwelling, and other

environmental variables related to variation in the age and condition of adult yellowtail rockfish.

...To determine the effect of inherent population characteristics, such as age distribution, on condition and reproduction in females.

...To determine temporal variability (seasonal and interannual) in adult condition as it relates to reproduction, juvenile abundance, and recruitment.

...To assess spatial (geographic) variability in the condition and reproduction of yellowtail rockfish as it relates to latitudinal variation and to correlate this to variation in juvenile abundance and recruitment in different areas.

The monthly sampling study at Cordell bank, with smaller sampling sizes, is referred to as the synoptic study. The spawning sampling study at several geographic locations and with larger sampling sizes is referred to as the fecundity study. Our sampling period now covers five spawning years (April 1985--March 1990). A spawning year is defined as beginning on April 1 of the first year and ending on March 30 of the following year. The first three years appear to have been fairly similar, with some variation in adults during the first year of the study. The last two years appear to represent both a year of good (1988-89) and poor adult condition (1989-90).

Adult Condition

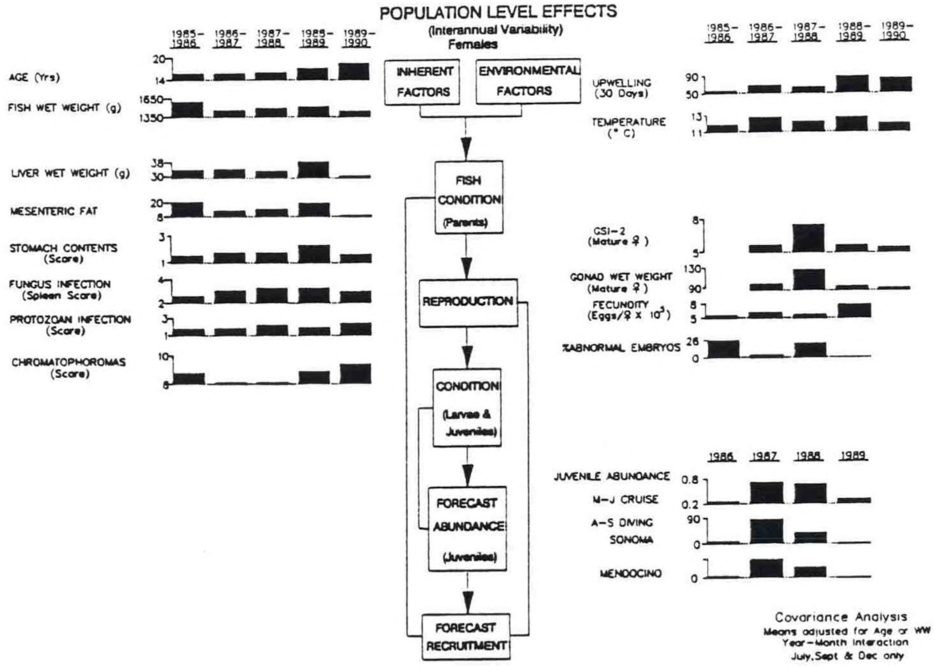
Recruitment success is dependent on several factors, including the age and number of females in the population, the number of larvae released by the female and the mortality of the progeny in the environment. The extent of mortality is, in turn, a function of the extent of predation, the suitability of the environment, and the health, nutritional, and physiological conditions of the larvae at the time of their release.

The nutritional and physiological conditions of adult females determine the quality of oocytes, the success of larval development, and consequently the health of released larvae. The following section provides results of studies that determine the physiological condition of adults.

Wet Weights and Condition Indices

Field-caught rockfish specimens from Cordell Bank were given comprehensive examinations, that included analyses at whole animal, organ, tissue, cellular, and subcellular levels of biological organization. We examined a total of 668 fish (619 adults and 49 subadults). Adults of both sexes ranged in age 6- 45 yr. There were 480 females and 168 males (females were selected in larger

A.



B.

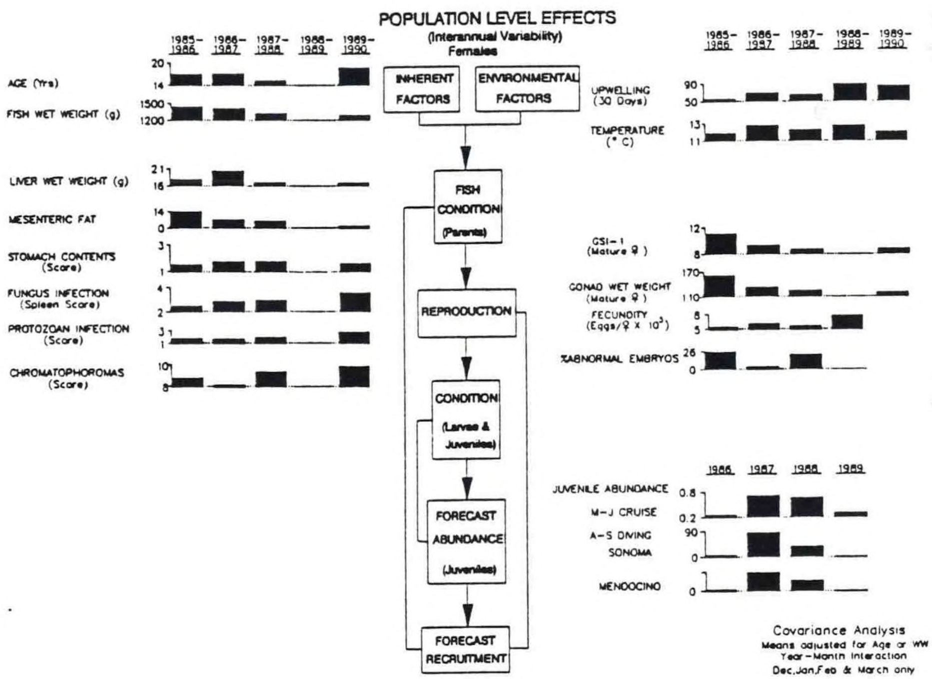


Fig. 10.--Population effects flow chart and analysis of covariance on adjusted means. Means have been adjusted for age or wet weight of fish to facilitate among year comparisons. Juvenile abundances from Groundfish Analysis and Groundfish Communities Investigations. A. (upper panel): Annual variability for 5 years (samples collected in July, September and December only). B. (lower panel): Annual variability for years 1, 2, 3 and 5 (samples collected during spawning season, December, January, February and March only).

numbers for our studies). Results reported in this section are primarily for female adult yellowtail rockfish.

The annual means of variables obtained from recent covariance analyses of data for adult females are shown in Fig. 10(a,b). Means are adjusted for the effect of the total wet weight or age of females, depending on the variable measured. For example, wet weights of organs were adjusted for the effect of total wet weight of the fish, while scores for parasites and diseases were adjusted for the effect of age.

Because sampling in the 1988-89 spawning year was reduced, comparisons are limited through all five years to the months of July, September and December. In addition, comparisons of the years 1985-86, 1986-87, 1987-88 were made with year 1989-90 for the spawning months of December-March. Sample sizes therefore, are reduced accordingly. Previous reports described the importance of seasonal (monthly) variability on nearly every variable measured in adults. Seasonal patterns were also found to vary among the years sampled. This continues to be the case and the month or time sampled is considered carefully in the interpretation of annual variability. In the future, with a return to monthly sampling, a better comparison would be possible.

The data presented in Fig. 10(a) show the means of selected variables for 5 years of sampling. Due to limited sampling in 1988-89, however, the means of condition variables are based only on fish collected in July, September, and December. Means for stomach fullness, upwelling, and temperature are based on all months. Upwelling is the mean index for the 30 d immediately preceding collections; temperature is the mean sea surface temperature at time of collection. Because the timing of reproduction and the dynamics of lipid distribution are so variable from year to year these means should be observed with caution.

Covariance analyses indicate some significant differences in weights ($P < 0.05$). The weight of fish at a given age in 1989-90 was down significantly. The weights of livers and mesenteric fat were significantly higher in 1988-89 fish and were significantly lower in 1989-90 fish. Fungus and protozoan infections were not significantly different among years for the months sampled. However, there were significantly more fish with melanophore hyperplasia during the 1989-90 season. The higher prevalence of melanophore hyperplasia in years 1, 4 and 5 is most likely a result of the greater numbers of old females sampled in those years.

Results presented in Fig. 10(b) show means of selected variables for the first 3 years of sampling contrasted with the last year of sampling. Means of condition variables are based only on fish collected monthly during the spawning season (December-March). Because of limited sampling in 1988-89 it is omitted. Again, covariance analyses indicate some significant differences in weights ($P < 0.05$). The weight of spawning females at a given age in 1989-90 samples was significantly lower. The weights of liver and mesenteric fat of spawning females were also lower in 1989-90 fish. Likewise, fungus and protozoan infections were significantly higher in 1989-90 spawning fish. There were significantly more fish with melanophore hyperplasia in 1989-90, as noted previously. (J. Whipple).

Disease, Parasites, and Chromatophoromas

As fish age, the effects of a higher prevalence of parasites and chromatophoromas become apparent. The diseases and parasites found in yellowtail rockfish adults were described in previous reports. Results indicated that the fungus Ichthyophonus sp. and melanophore hyperplasia (chromatophoromas) may affect growth and condition of yellowtail rockfish from Cordell Bank. Analyses showed that older fish were significantly more parasitized by fungus and had more chromatophoromas than younger fish. There was also a significant relationship between greater fungus infections and melanophore hyperplasia with respect to reduced mesenteric fat and body condition.

The prevalence of fungal infections among yellowtail rockfish is 96.3% of the fish sampled from Cordell Bank. Fish further north were found to be infected, but at much lower levels, as reported last year. The effect of fungus on functioning of head kidney, spleen, and liver is being studied in cooperation with the Veterinary Pathology Department at the University of California at Davis (UCD); results will be reported later.

Initial examinations of the pigmented areas on the bodies of yellowtail rockfish were done with Dr. Mark Okihiro of UCD. The pigmented areas have been identified as either chromatophore hyperplasia or neoplasia (chromatophoromas or pigment cell tumors). Types of hyperplastic lesions observed included melanophore (black), xanthophore (yellow), and erythrophore (red or orange). Pigment cell tumors seen were melanophoromas, amelanotic melanophoromas, xanthophoromas, and mixed chromatophoromas. Hyperplastic lesions were sessile while tumors tended to be raised. Melanophore hyperplasia was the most common lesion and was usually found in the head region, over the jaws, and dorsal surface of the fish (areas normally having more chromatophores). Melanophore hyperplasia, which is non-invasive, was thought to be an early preneoplastic stage in the eventual development of pigment cell tumors.

There was a 10% prevalence of melanophore hyperplasia (70 fish of 668 sampled) at Cordell Bank. Melanophoromas were identified in only 10 of 668 fish (1.5% of fish sampled), but it is possible that many fish with invasive malignant tumors have died. We have not observed chromatophore hyperplasia or neoplasia in fish sampled from populations further north. Fish with melanophore hyperplasia appeared to be in poorer condition than unaffected fish. Examination of outliers in box plots indicated that, for most condition variables, fish with melanophore hyperplasia fell in the extreme upper 10% for parasite infections and in the lower 10% for condition variables.

The results provided in Fig. 11 give a visual summary (Chernoff's faces; Chernoff 1973) of the increased intensity of diseases in the last spawning year (1989-90), with greater scores for protozoan infections in the heart (eye vertical), fungus infections in the kidney (nose width) and spleen (brow slant), and greater development of melanophore hyperplasia and tumors (mouth smile). This graphical technique is being explored as a qualitative means of presenting multivariate data. (J. Whipple).

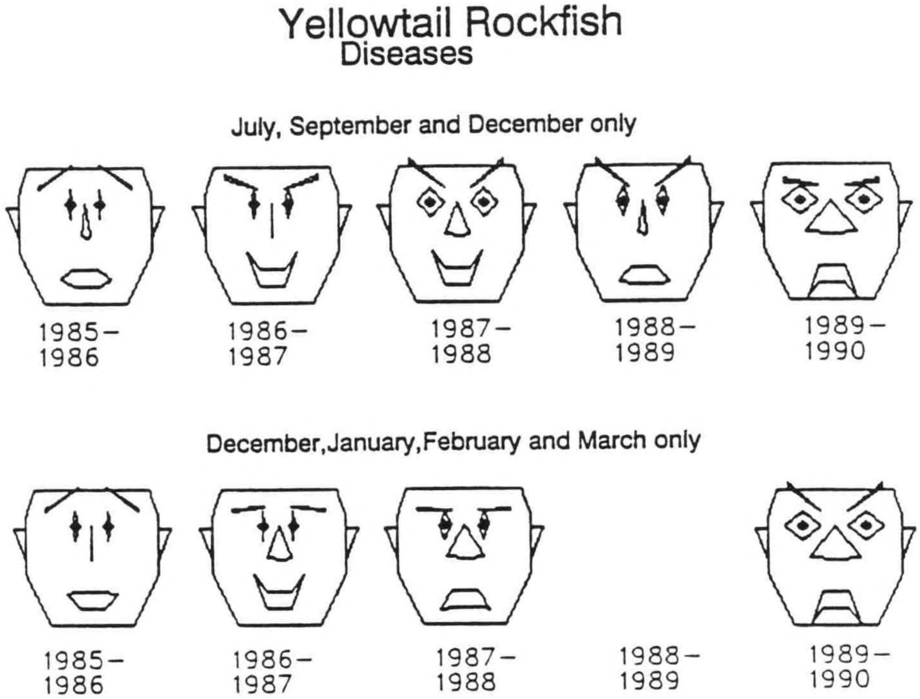


Fig. 11.--Multivariate plot of disease scores for yellowtail rockfish (1985-89). Mean score for protozoan infections in the heart (eye vertical), fungus infections in the kidney (nose width) and spleen (brow slant), and melanophore hyperplasia and tumors (mouth smile).

<u>Age and Senescence</u>

Age is an important factor in determining condition in yellowtail rockfish. Analyses show that several measures of condition vary with age. Many of the older fish were in poorer condition, particularly in the 1989-90 spawning year. In fact, gross observations indicate that reproduction may have been affected. Conclusions cannot be made until histological studies are complete, but it appears that some older females did not mature during the 1989-90 spawning year.

Sample sizes of the oldest fish sampled ($\geq$ 30 yr) are still small (N = 27). Examination of outliers in the total population subsample indicates that most values in the upper and lower 10% of the variant distribution are from older fish. Further examination of means of condition factors shows that fish 30 years or older had lower mean condition indices (KSL, LSI, MFI and GSI) and significantly higher parasite burdens of nematodes, cestodes, and the fungus Ichthyophonus, as well as a higher prevalence of melanophore hyperplasia. Examination of selected serum components also indicates that the oldest fish with melanophore hyperplasia were hypocalcaemic. (J. Whipple).

Nutritional Status of Adult Females

Annual patterns of lipid and protein accumulation, translocation, and depletion, and their relationships to specific developmental events in the annual reproductive cycle of yellowtail rockfish were described in earlier progress reports (Whipple 1988; Hobson 1989). This report will update the evaluation of nutritional dynamics and the annual reproductive cycle and extend interannual comparisons of these variables.

Reproductive success, or the release of the greatest number of healthy, energetically-charged larvae possible, is dependent upon the nutritional condition, or energy status, of adult females. In yellowtail rockfish lipids are the most important energy source. If females do not accumulate sufficient lipids during the time period preceding and concurrent with ovarian development, maximum reproductive success cannot be realized. The consequences of inadequate maternal nutrient concentrations and transfer of lipid and protein components to maturing oocytes may be reduced real fecundity (presumably through follicular oocyte atresia or, at later stages, by embryonic or larval resorption) or the production of larvae with diminished energy stores and/or physiological condition. Such larvae are less prepared to withstand the challenges of the environment.

Annual patterns of lipid and protein accumulation in maternal tissues and their translocation to ovaries during reproductive cycles between April 1985 and February 1990 reveal similarities and differences (Figs. 12-14; Table 7). In general, the temporal patterns relating to ovarian development (e.g., the annual GSI cycle [Fig. 12(a)] are similar for all reproductive cycles. Thus, the liver [Fig. 12(b)] and mesenteric fat depots [Fig. 12(c)] increase in weight due primarily to the accumulation of lipids [Fig. 14(a)] during the summer and fall feeding period and these are depleted during the winter when ovarian growth and development occur.

Serum concentrations of lipids and proteins also show year-to-year similarities. The annual profile of serum vitellogenin (measured by the surrogate calcium, Ca^{++}) [Fig. 13(a)], as well as albumin and total protein, reveal increased transport in the circulatory system coincident with the development of vitellogenic oocytes and later embryonic and larval stages. Serum concentrations of energetic lipids (e.g., triglycerides) and structural

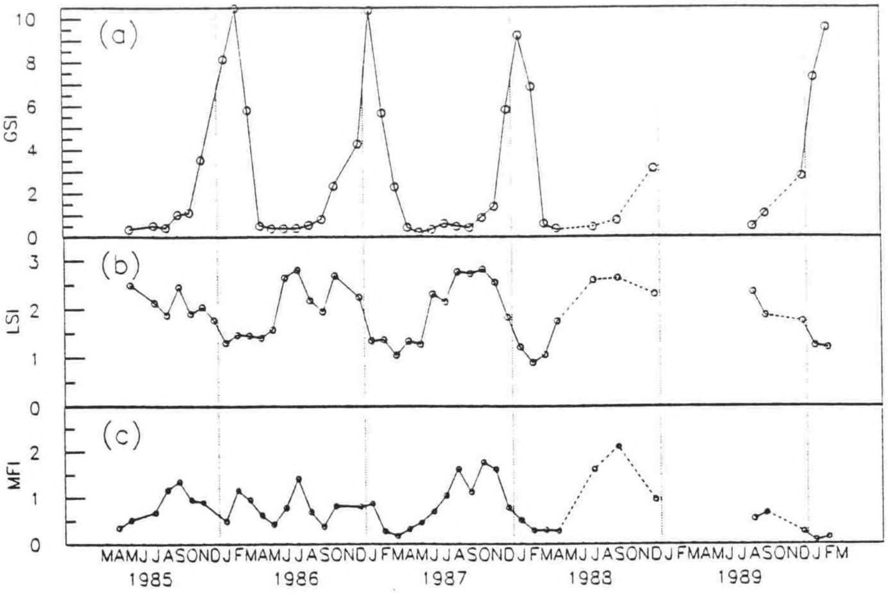


Fig. 12.--Mean monthly values of (a) GSI, (b) LSI, and (c) MFI, mesenteric fat index, for female yellowtail rockfish.

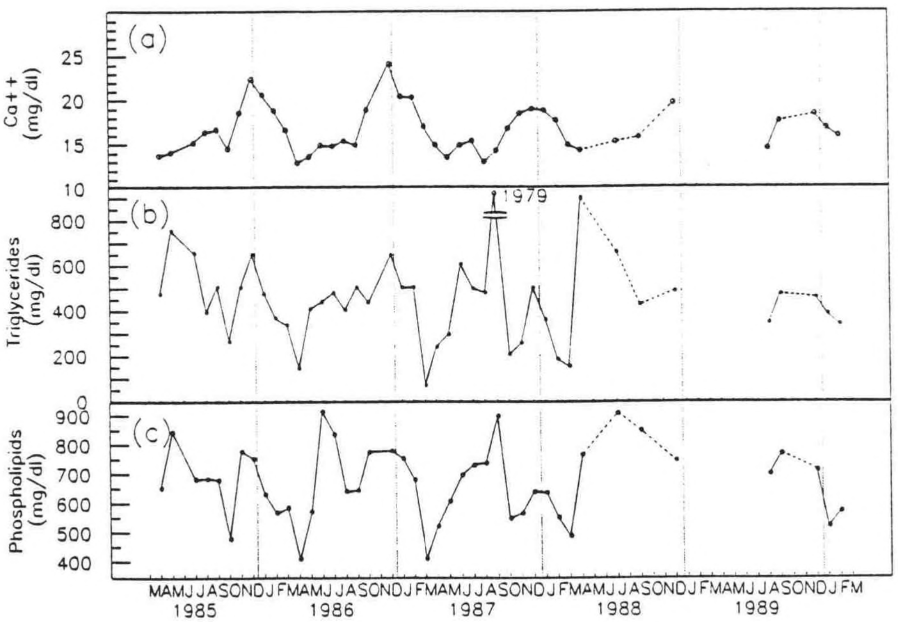


Fig. 13.--Mean monthly values of serum (a) calcium [vitellogenin surrogate], (b) triglycerides, and (c) phospholipids for female yellowtail rockfish.

lipids (cholesterol and phospholipids) also follow predictable patterns. Peak levels occur during feeding periods (summer and fall) and during ovarian development [Fig. 13(b,c)]. As would be expected, lipid and protein concentrations are increased in the ovaries as oocytes progress through successive developmental stages, culminating in fully-developed larvae [Fig. 14(b,c)].

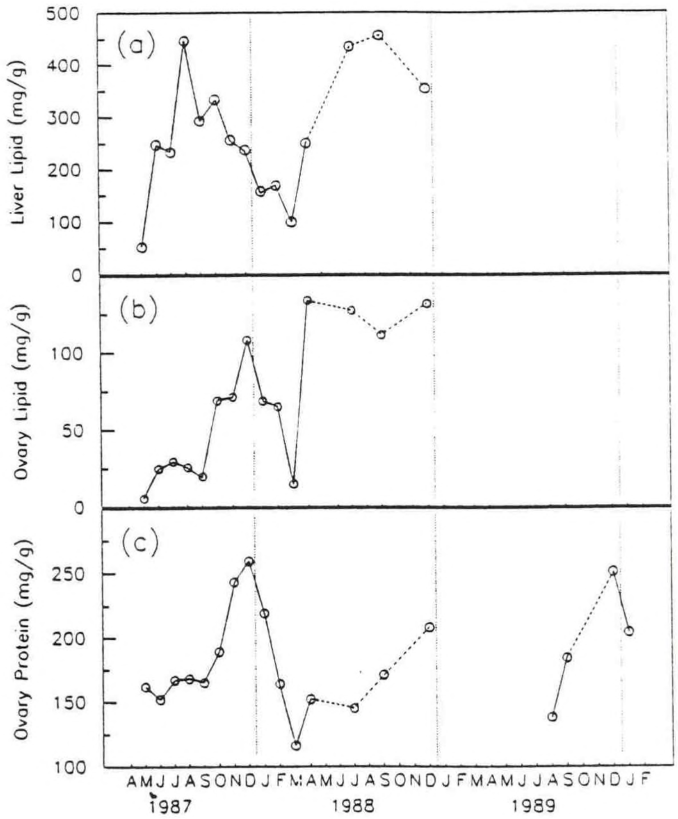


Fig. 14.--Mean monthly values of (a) liver lipid, (b) ovary lipid, and (c) ovary protein for female yellowtail rockfish.

The major differences in nutritional dynamics between reproductive cycles relates to concentrations of nutrient compounds in tissues and serum. Mean values of tissue and serum nutritional variables during the annual intervals of ovarian development are presented in Table 7. Despite limited data for the 1988-89 reproductive cycle and incomplete data for the current year (i.e., 1989-90), the nutritional status of females over the last 5 reproductive cycles can be compared. The data suggest that females in the current reproductive cycle (1989-90) are in the worst nutritional condition observed, whereas yellowtail rockfish were in their best condition during the 1988-89 cycle. As stated in the most recent progress report (Hobson 1989), the reproductive years 1985-86, 1986-87, and 1987-88 were similar from an energetic or nutritional perspective and probably represent the typical nutritional status for this species.

The quantitative relationships between nutritional variables and measures of reproductive success over the last 5 reproductive cycles will be established as soon as the data on reproductive processes (atresia/resorption, fecundity, etc.) are available. (B. MacFarlane).

Table 7.--Mean values of selected nutritional variables from female yellowtail rockfish with ovaries in yolk accumulation or later stages of maturation during annual reproductive cycles. Values represent means ± SE (N in parentheses).

Variable	1985-86	1986-87	19887-88	1988-89	1989-90
LSI	1.55±0.84 (32)	1.92±0.14 (30)	1.48±0.11 (23)	2.41±0.13 (7)	1.32±0.13 (38)
MFI*	0.90±0.09 (32)	0.81±0.14 (29)	0.63±0.09 (23)	0.94±0.15 (7)	0.17±0.04 (38)
Serum Ca^{++} (mg/dl)	19.3±0.7 (31)	21.9±1.0 (29)	18.9±0.6 (23)	19.0±0.7 (7)	17.2±0.4 (34)
Serum Triglyceride (mg/dl)	472±40 (31)	561±41 (29)	393±47 (23)	573±110 (7)	408±31 (34)
Serum Cholesterol (mg/dl)	154±13 (31)	234±10 (29)	171±10 (23)	232±32 (7)	127±10 (34)
Serum Phospholipid (mg/dl)	659±30 (27)	756±26 (30)	617±22 (23)	745±60 (7)	576±27 (38)
Serum Albumin (mg/dl)	1.29±0.06 (31)	1.53±0.06 (29)	1.24±0.04 (23)	1.74±0.05 (7)	1.33±0.06 (34)
Liver Lipid (mg/g)			195±17 (16)	311±24 (7)	
Gonad Lipid (mg/g)			81±7 (16)	134±4 (7)	
Gonad Protein (mg/g)			223±22 (16)	217±8 (7)	225±11 (24)

* Mesenteric Fat Index (MFI) = [mesenteric fat (g)/body fresh weight (g)] X 100

Adult Reproduction

Weight of Gonads and Condition Indices

Data for the first three years of this study (1985-86, 1986-87, and 1987-88) indicate that maturity, gonadal weights, and fecundity were equivalent, although there was an indication of higher GSI, but slightly lower effective reproduction, in year 1. Examination of variable outliers indicates extreme values occurred in the oldest females (> 29 yrs) of the 1985-86 spawning year.

Results presented in Fig. 10(a) show means of selected reproductive variables for 5 years of sampling. However, because of limited sampling in 1988-89, means of condition variables are based only on fish collected in December. Covariance analyses indicate that mean gonadal weight (adjusted for wet weight of the fish) and GSI were significantly higher during the 1987-88 spawning season. Still, this was for December only, and because of the yearly variation in the onset of reproductive maturity and spawning, this comparison is probably not meaningful. Mean fecundities have not been determined yet for the 1989-1990 spawning season, but mean fecundity for the 1988-1989 season appears to be significantly higher in fish collected for the synoptic study (see also fecundity section below).

The data in Fig. 10(b) show the means of selected reproductive variables for the first 3 years of sampling contrasted with the last year of sampling. Means of GSI and gonad wet weight condition variables are based only on fish collected during the spawning season (December-March) with GSI indices greater than 5%. Because of limited sampling in 1988-89, this year is omitted. Results are incomplete, but covariance analyses indicate that GSI and gonad wet weight were not significantly different among years if the timing of reproduction is accounted for. The lowest mean gonad weights (adjusted for wet weight of fish), however, occurred in fish collected in the 1989-90 spawning season. Indications of abnormal reproduction (no development of ovary, some atresia) have been observed from gross examinations. Further analyses of fecundity and histology of the ovaries sampled this spawning season must be finished before conclusions are made. (J. Whipple).

Fecundity

Fecundities of yellowtail rockfish collected from Cordell Bank have been estimated since the 1985-86 reproductive season. The objective of the fecundity study has been to provide some measure of reproductive effort and to determine what inherent and environmental factors influence it. To obtain more accurate estimates of fecundity with age, larger samples were collected and added to those collected for the synoptic study. As previously reported, comparisons of these fecundities for three consecutive years showed no significant differences on the basis of total body wet weight, standard length, and age. Fish presumably compensated among the years for differences in their environments and physiological conditions such that the reproductive effort was consistent. Measurements from specimens collected during 1988-89, however, showed a change in the previous pattern. As presented in Tables 8 and 9 and Fig. 15, fecundity by weight, length, and, especially age, was higher for yellowtail rockfish during last year when compared to the previous three years. Older, larger fish had higher fecundities. The 1988-89 fish examined had a lower mean age, but were of approximately the same size (Table 8). It appears that last year's conditions were favorable for growth and egg production. This was particularly indicated by the higher mesenteric fat stores during 1988-89 compared to previous years. The mean mesenteric fat rank (nonparametric measure; 1-5) from 1985-87 was 2.0 compared to 2.7 found in 1988-89.

Table 8.--Age (yr), total wet body weight (g), standard length (SL [cm]) and fecundity (eggs/female) of yellowtail rockfish from 1985-90 (mean ± standard deviation).

Variable	1985-87	1988-89	1989-90
Age:	16.3 ± 7.4	12.9 ± 7.8	15.2 ± 7.3
Wet Weight:	1432 ± 396	1280 ± 393	1232 ± 356
SL:	37.2 ± 3.8	36.0 ± 3.6	35.9 ± 3.9
Fecundity:	652079 ± 679088	583997 ± 334959	N/A

Table 9.--Linear regressions with correlations (r) of fecundity (F) on total wet body weight (W), standard length (L), and age (T) for yellowtail rockfish from Cordell Bank.

Independent Variable	1985-87	1988-89
Wet Weight:	F = -304878 + 610W (r = 0.92)	F = -496162 + 800W (r = 0.94)
SL:	F = -1659282 + 59744L (r = 0.86)	F = -2543962 + 85484L (r = 0.93)
Age:	F = 50617 + 30635T (r = 0.80)	F = 49981 + 34694T (r = 0.83)

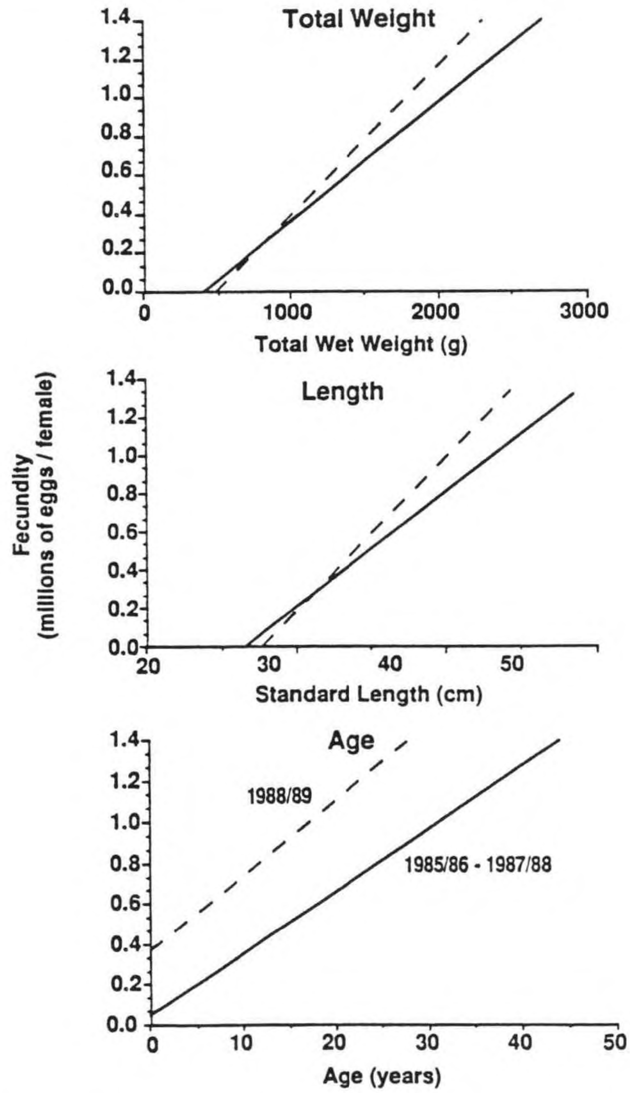


Fig. 15.--Fecundity at total body wet weight, length, and age of yellowtail rockfish from Cordell Bank for the 1985-86 through 1987-88 reproductive seasons (solid line) and the 1988-89 season (dashed line).

If these findings indicate a strong correlation between fat reserves, condition and fecundity, the prospects for the 1989-90 reproductive season are poor. This year's specimens are smaller in length and weight (Table 8) than all previous years despite a similar age distribution, and they have the lowest mesenteric fat reserves measured yet (mean score = 1.6).

During the 1988-89 spawning season, sampling of yellowtail rockfish from coastal areas off Washington state was initiated to allow a comparison of the reproduction of Cordell Bank fish with that of populations located nearer to the center of their distributional range. These studies are continuing this reproductive season (1989-90). A total of 130 females from Washington were examined from last year. Fish were on average much younger than Cordell fish, but they were longer and heavier at age, resulting in higher mean weights and lengths (Tables 10 and 11). Fecundity measurements from these fish are nearly completed. Preliminary analysis shows that fecundity at weight was similar to Cordell fish, while fecundity at length was higher in large fish (> 38 cm) from Washington; fecundity was higher at all ages in Washington yellowtail rockfish (Fig. 16). Much of the higher productivity in Washington fish may be due to their better physiological condition. Mesenteric fat during the egg development and gestation periods was consistently high (index mean = 3.0) and stomach contents indicated abundant prey sources (primarily fish versus euphausiids for Cordell fish).

Table 10.--Descriptive statistics for 127 yellowtail rockfish from central Washington state, collected during 1988-89.

Variable	Mean	Standard Deviation	Range
Wet Weight (g):	1826	458	741-3844
SL (cm):	40.9	3.5	29.5-51.5
Age (yr):	11.1	3.3	5-30
Fecundity (eggs/F):	988009	331834	331837-1972627

Table 11.--Linear regression equations of fecundity (F) on total wet weight (W), standard length (L), and age (T) for yellowtail rockfish from central Washington (1988-89).

Independent Variable	Equation	Correlation Coefficient
Wet Weight (g):	$F = -487852.2 + 744.4783W$	0.80
SL (cm):	$F = -3069805 + 96990.41L$	0.73
Age (yr):	$F = 16261 + 80202.25T$	0.67

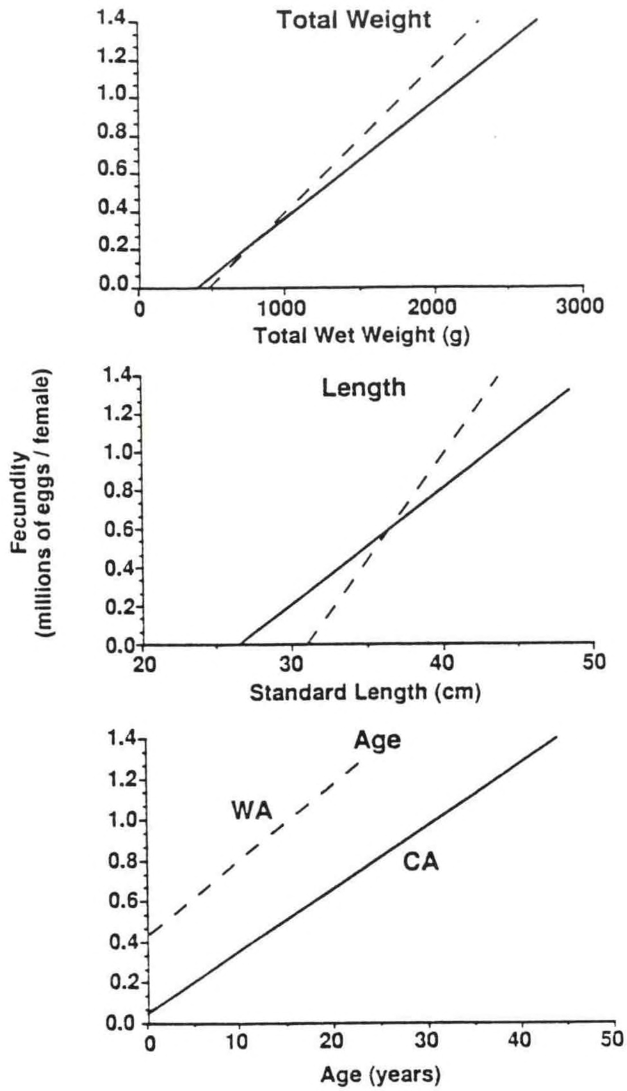


Fig. 16.--Fecundity at total body wet weight, length, and age for yellowtail rockfish from Cordell Bank (solid line) and Westport, Washington (dashed line).

Geographic/population comparisons have also been extended to yellowtail rockfish from Vancouver Island, Canada. Preliminary sampling began in 1988-89 with 45 specimens; 59 fish have been examined to date this year. The Canadian population appears to differ from both the California and Washington populations in that male adults are much older than females, while being similar to the females in weight and length (Table 12). Fecundity data are not yet available for analysis.

Examinations were made of 167 bocaccio (S. paucispinis), 136 widow (S. entomelas), and 37 chilipepper (S. goodei) rockfishes collected from 1986-88. Both bocaccio and chilipepper averaged

9.6 yr of age while widows were older at 12.6 yr. Table 13 presents predictive equations for fecundities of these species. (M. Eldridge and B. Jarvis).

Table 12.--Descriptive statistics of yellowtail rockfish from Vancouver Island collected during the 1988-89 and 1989-90 (partial compilation) reproductive seasons. Values expressed as means ± standard deviations.

Year	Variable	Females	Males
1988-89:	Age (yr):	9.4 ± 2.4	23.4 ± 10.9
	SL (cm):	37.7 ± 4.6	40.3 ± 1.3
	Wet Weight (g):	1464 ± 667	1461 ± 283
1989-90:	Age (yr):	11.1 ± 3.9	18.3 ± 9.1
	SL (cm):	39.9 ± 2.8	39.0 ± 1.9
	Wet Weight (g):	1569 ± 372	1277 ± 406

Table 13.--Linear equations of fecundity (F) on total wet weight (W [g]), standard length (L [cm]), and age (T [yr]) for bocaccio, widow, and chilipepper rockfishes.

Species	Independent Variable	Equation	Correlation Coefficient
Bocaccio	W:	F = -74409.74 + 366.49W	0.90
	L:	F = -2055766 + 58439.11L	0.87
	T:	F = 144068.3 + 84960.52T	0.72
Chilipepper	W:	F = -11188.23 + 171.48W	0.88
	L:	F = -410069.1 + 15820.05L	0.85
	T:	F = 80546.65 + 12835.1T	0.81
Widow	W:	F = -253067.9 + 610.4517W	0.70
	L:	F = -2222529 + 74762.53L	0.76
	T:	F = 240801.1 + 39414.94T	0.65

Calorimetry; Energy Content of Eggs

While fecundity studies provide quantitative measures of reproductive effort, calorimetric determinations provide a qualitative measure of reproduction. Preliminary analyses were completed on egg samples from 27 yellowtail rockfish spanning the last three years. Twelve specimens were from fertilized eggs and 15 were unfertilized.

A comparison of fertilized and unfertilized eggs showed that fertilized eggs contained less calories than unfertilized eggs (6,220 vs. 6,512 cal/g-ash free dry weight, respectively; Student's t, $P < 0.05$). This could be due to early consumption of nutritional energy by embryos.

There may be differences among years in the fertilized samples (1985-86 = 6,248, 1986-87 = 6,463, and 1987-88 = 6,063 cal/g-ash free dry weight). Particular attention will be given to the 1989-90 season because of the preliminary observation of poor condition and low fat reserves in adults.

There were seasonal differences in unfertilized eggs within the same year. Eggs collected early in the egg developmental stage, when yolk is being accumulated in the egg, contained fewer calories (6,225 cal/g-ash free dry weight) than those collected from December through February (6,701, 6,706, 6,706 cal/g-ash free dry weight, respectively; Student's t, $P < 0.05$). It appears that the maximum endogenous energy is accumulated by December, approximately 1-2 months before fertilization and incubation. Age and size variables do not appear to be related to the caloric density of eggs. (M. Eldridge).

Histological Assessment of Reproductive Development

Three consecutive reproductive cycles (1985-86, 1986-87, and 1987-88), analyzed from a histological perspective on ovarian maturation, have revealed seasonal trends and annual variations at various levels of organization. The sequential events of oocyte development, ova maturation, and embryonic development have been described, and a classification scheme for these events has been documented. While variations among individuals exist, oocyte distributions and ovarian maturation data allow a temporal assessment of the population's reproductive status.

A comparison of oocyte to larval development on a temporal scale between the three reproductive years is shown in Table 14. Of particular interest is the variation in the length of time needed for total yolk accumulation and the uniformity in parturition times. While yolk accumulation in the 1985-86 reproductive season was observed to occur for an additional two months, in comparison to subsequent seasons, embryonic gestation and parturition times remained fairly consistent for the three years. It would appear that the accumulation of yolk in oocytes is an event influenced, to some degree, by external factors such as environmental conditions, food availability, and the capacity to transfer vitellogenin and other lipids to the ovaries from maternal sources. Mean serum concentrations of vitellogenin (using Ca^{++} as a surrogate) were lower during the yolk accumulation stages of ovarian development in females collected in 1985-1986 compared to those collected in 1986-1987. This suggests a longer period of time was necessary to sequester yolk in oocytes during the 1985-1986 spawning season. Hormonal modulation then regulates subsequent maturation, including ovulation of mature ova for fertilization. However, this only partially explains synchronous parturition times at the population level. While embryonic gestation takes roughly 30-40 d to complete within an individual, the yellowtail rockfish population displays a prolonged reproductive season. Data analyses for these three reproductive seasons indicate that age and size influence parturition dates. At any point in time during the annual maturation season, older fish tend to display oocytes and embryos in more advanced stages of development than younger females. This situation produces, in addition to a prolonged season, two distinct but overlapping batches of larvae.

Table 14.--Temporal patterns of ovarian maturation in yellowtail rockfish collections during the 1985-86, 1986-87, and 1987-88 reproductive cycles. Data represent monthly samples and not individual specimens.

	Year		
Event	1985-86	1986-87	1987-88
Yolk Accumulation:			
Initiation	July	August	July
Termination	March	February	January
Duration (months)	9	7	7
Embryo/larvae:			
Initiation	January	January	January
Termination	March	February	March
Duration (months)	3	2	3
Parturition:			
Initiation	January	February	February
Termination	March	April	April
Duration (months)	3	3	3

Because atresia (corpora atretica) can potentially influence reproductive success, the occurrence of atretic or resorbing oocytes is currently under study. The majority of resorbing oocytes observed to date are in yolked accumulation stages of development. Since atresia is a typical occurrence, the baseline or 'normal' extent of follicular (oocyte) atresia in yellowtail rockfish needs to be determined. The number of oocytes capable of maturing in a single season may be limited by the available vitellogenin transferred by the maternal system. Oocytes that sequester insufficient amounts of vitellogenin are then eliminated by the resorption process. While a high incidence of resorption in individual yellowtail rockfish females has been observed, the impact at the population level seems insignificant, due to what have been consistent fecundity estimates over three reproductive cycles. Additional factors that may influence the incidence or severity of atresia include environmental conditions and limited nutritional resources. A cursory view of oocyte samples from the 1988-89 and 1989-90 reproductive seasons appears to indicate variations from the three previous years. A higher incidence of atresia is noted in both years, in addition to a wider range of developmental stages of oocytes within monthly samples. (M. Bowers).

Relationship of Adult Condition and Reproduction to Temporal Environmental Variability (Factor Analysis)

Initial descriptive statistics and factor analysis of selected data were done for all fish to determine the distributions and interrelationships of variables. Several reproductive variables measured for this spawning year (1989-90) have not been analyzed (e.g., fecundity, atresia, and calorimetry). Reproductive effort during this spawning year still needs to be assessed prior to final analyses.

Factor analysis was performed with the variables measured through the 1989-1990 season. Analyses were first done with all 668 adult males and females to determine possible sexual differences, as well as relationships of condition variables to age, upwelling, temperature, and feeding. In brief, the major findings from this preliminary analysis show that approximately 72% of the variability in the data was accounted for by 7 factors. The major factors controlling the variability in adult condition and reproduction were determined to be age, year, season (upwelling and temperature) and sex, in respective order of contribution to the variance. Sexes were not found to differ, except in degree of sexual development. As expected, gonads were larger and GSI was greater in females.

A higher prevalence of diseases occurred in older individuals. During the upwelling season, LSI was higher and GSI was lower, as expected. During the winter downwelling period, the reverse was true. Mesenteric fat varied annually, being very low in the last spawning year relative to earlier years. Disease prevalence and severity was greater in the last spawning year. More feeding occurred (based upon analysis of stomach contents) at lower temperatures (upwelling periods) following the winter spawning period. Less feeding occurred in the last spawning year (1989-90), particularly during winter months.

Additional studies have been initiated to examine the type and quantity of food in the stomachs of yellowtail rockfish. Body condition, as exemplified by liver and mesenteric fat weights, may relate to feeding success during different seasons and in different years. Mean scores for stomach contents indicated that in 1988-89 adult females fed more, while in 1989-1990, stomachs were less often full. (J. Whipple).

Juvenile Condition

This section introduces the initiation of a new project that will evaluate the physiological and nutritional conditions of YOY juvenile yellowtail rockfish. During 1989 a project was started to assess the health, or nutritional and physiological conditions of juvenile yellowtail rockfish from Cordell Bank and surrounding areas. Collections will be repeated yearly during the May-June rockfish recruitment assessment cruise and along the Sonoma and Mendocino coasts in association with the Groundfish Communities Investigation sampling program.

The objectives of this project are: (1) to determine how well the current year class is growing and functioning in the environment and to estimate its survivability, and (2) to determine if there is a relationship between the health of the juveniles and the reproductive, nutritional, and physiological conditions of the maternal stock. Clearly, the health of juvenile yellowtail rockfish, free in the environment for several months following parturition, is related to environmental factors, as well as to maternal contributions. By analyzing environmental data (e.g., temperature, upwelling, chlorophyll, etc.) obtained during the intervening period from parturition to juvenile collection, and, using the rate of improvement in the energy status of adult rockfish as an index of environmental conditions (particularly food availability since juveniles and adults utilize euphausiids in varying life stages) during the same time period, it may be possible to estimate the contribution of environmental factors to juvenile health. The evaluation of juveniles will include measurements of:

(1) Morphometrics: length-weight relationship
(2) Lipids: total lipids, energetic to structural lipid ratios, mesenteric fat content. These will provide an indication of energy status.
(3) Nucleic acids and total protein: DNA concentration, RNA concentration, RNA/DNA, protein concentration. Provides a measure of protein synthesis and growth potential.
(4) Calorimetry: total energy content. Evaluation of total energy incorporated into the juvenile, including that metabolically useful and that in the form of structural material.
(5) Abnormalities, parasites, and histology: to determine incidence and potential causes of reduced health, if evident
(6) Age: otolith aging will be used to normalize other data and to permit comparisons between different age groups

The data produced to date from the juvenile assessment of the 1989 year class is presented in Table 15; remaining analyses are in progress. In their present form, the data are useful for spatial and temporal comparisons. Greater information and understanding will be gained as more year-classes are evaluated and by controlled laboratory experiments to calibrate the values of the variables to suboptimal and optimal environmental conditions (e.g., the quantity and quality of prey, temperature, etc.). (B. MacFarlane and E. Norton).

Table 15.--Data for the 1989 year-class of juvenile yellowtail rockfish (N in parentheses).

Variable	Cordell	Sonoma	Mendocino	Other[1]
Wet weight (g)	1.05±0.34(25)	1.60±0.36(7)	1.97±0.50(5)	1.05±0.27(23)
Length (mm)	38.9±4.9(26)	45.4±3.8(7)	48.0±4.5(5)	39.1±3.3(23)
Age (d)	94.0±10.3(26)	131.3±9.8(7)	139.2±22.8(5)	94.5±8.1(22)
RNA (mg/g)	2.47±0.71(5)	2.01±0.32(7)	1.21±0.17(4)	2.71±0.50(16)
DNA (mg/g)	0.233±0.080(5)	0.088±0.028(7)	0.178±0.031(4)	0.262±0.031(16)
RNA/DNA	10.9±2.3(5)	25.6±11.4(7)	7.0±1.8(4)	10.5±1.6(16)
CAL (Cal/g,afdw[2])	5398±159(7)			5292±178(4)
Water Content (mg/g)	800.3±22.0(7)			776.6±0.2(2)
Settling Age (d)		118.0±12.2(4)	126.0±5.9(4)	

1 locations from Monterey Bay to Point Reyes
2 ash free dry weight

Summary of Adult Studies

In summary, the most important factors affecting reproductive success and production of the year-class are (1) the age distribution of spawning fish, (2) the environmental conditions affecting condition of females prior to and during spawning, and (3) the environmental conditions during larval and juvenile development. All three conditions must be optimal to produce the largest year-classes and, conversely, all must be suboptimal when year-classes are smallest. It should be noted, however, that a poor year-class can result from not meeting any one of the three conditions.

Presumably, a good year-class occurs when large old fish occur in the spawning population, feeding conditions are good for the adults during the late spring and summer prior to egg maturation, and feeding conditions are good for larvae and juveniles in early spring and summer and adverse transport does not occur. These environmental conditions are met when the beginning of upwelling is coincident with the end of the spawning period (the end of March in yellowtail rockfish) and the beginning of the planktonic larval stage.

A delay in the onset of upwelling, fewer upwelling days, and less intense or shortened periods of upwelling may result in a poor year class, both by reducing conditions for the spawning population and by providing inadequate food for larval and juvenile survival. Symptoms of poor feeding in adults are empty stomachs, low fat reserves and higher disease levels. The amount of lipids and body fat are probably related to euphausiid abundance. Consequently, we will investigate various simple means of obtaining relative estimates of euphausiid abundance in the Cordell Banks area during the next year.

Our initial work has shown that the condition of females in the first year was somewhat different from females in the latter two years, primarily due to their being older, but that for the first three years of this study (1985-86, 1986-87, 1987-88) fish were relatively similar and exemplified average conditions for yellowtail rockfish. These results are reflected in the juvenile abundance estimates shown in Figs. 10(a,b). In the first year, temperatures were lower and we can speculate that the pattern of a greater mean age of fish in the first year may have been due to a southward migration of larger older fish from the center of the population during the 1985-86 period.

During the 1988-1989 spawning year, the condition of adult females was very good for most criteria measured. However, some reproductive measures are not yet summarized and results are incomplete. Even though environmental conditions were very good for the adults in that year, with good upwelling and feeding conditions in the spring and summer of 1988 prior to spawning, upwelling was delayed for a considerable time in the spring of 1989. It is probable that feeding conditions for the larvae and juveniles in that year were poor, as reflected in the juvenile abundance estimates for that year [Fig. 10(a,b)].

During the 1989-90 spawning year, adult yellowtail rockfish exhibited the poorest condition observed thus far. Environmental conditions were anomalous during the latter part of this year (e.g., the higher temperatures observed near Cordell Bank and other areas offshore). Upwelling indices and temperature profiles are not available yet for the last part of this spawning year, but should provide more information for interpretation of our results. The poor condition of adult yellowtail rockfish indicates that the 1990 year-class will be poor, particularly if feeding conditions for larvae and juveniles are suboptimal this year.

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