SOUTHWEST FISHERIES CENTER

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PROGRESS IN ROCKFISH RECRUITMENT STUDIES

By

Staff of the Tiburon Laboratory

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Progress in Rockfish Recruitment Studies

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Ralph J. Larson, Editor

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INTRODUCTION

Rockfishes of the genus Sebastes are major targets of both commercial and recreational fisheries. Like other marine organisms, their reproductive success can vary strongly from year to year, affecting catches and management strategies. The Tiburon laboratory has been engaged in research designed to measure such variation early in the life cycle of rockfishes, and to determine some of its causes. These objectives have been addressed in four general approaches that focus on different methods and on different ontogenetic stages. The Physiological Ecology group has recently begun to assess the condition and reproduction of adult fish. Their results will, among other things, help to determine how variation in the production of larvae affects variation of recruitment. Two studies address pelagic young of the year--after the larval stage but before settlement to post-pelagic habitats. One study, conducted largely by the Groundfish Analysis group, examines the distribution and abundance of pelagic juveniles using samples from midwater trawls. This project is also analyzing biological features such as age, growth, and diets of pelagic juveniles. Another study, conducted by the Groundfish Communities group, is examining the occurrence of pelagic juveniles in the stomachs of a major coastal predator, the king salmon, in order to evaluate the use of predator stomach contents as an index of year-class strength. Finally, members of the Groundfish Communities group are assessing the abundance and distribution of post-pelagic juveniles in nearshore habitats, using underwater observations.

The overall objectives, general methods, and previous results of the latter three projects have been addressed in previous administrative reports (Lenarz and Moreland 1985, Hobson et al. 1986). This report provides an update of their findings, and introduces work begun recently by the Physiological Ecology group.

GUIDE TO YOUNG-OF-THE-YEAR ROCKFISH

A field guide for the identification of larval and juvenile rockfish has been completed by an outside contractor and is currently under review. The guide describes 72 species from the Northeastern Pacific and North Atlantic Oceans. Meristics, morphometrics, body and fin pigmentation patterns, and body margin characteristics are tabulated. Illustrations of larval and juvenile stages for 56 of the 72 species are included.

PROGRESS IN OFFSHORE MIDWATER TRAWL SURVEYS

The midwater trawl sampling plan was revised in 1986, with a reduction in geographical range and number of stations visited but with provisions for temporally-replicated samples. The revised station plan (Fig. 1) restricted sampling to the area between Tomales Bay in the north and Cypress Point in the south. Stations were visited in three sweeps, spread through the month of June. The Groundfish Communities Investigation team also completed midwater trawls surveys of the Gulf of the Farallones in April and in late May/early June.

Biological information gathered on pelagic juvenile rockfishes in 1986 included the tabulation of length frequencies and the analysis of stomach contents. The development of laboratory and computer techniques for the determination of ages from the daily increments on otoliths were largely completed.

Here we report on progress in (a) the analysis of bathymetric distributions, (b) the preliminary analysis of the spatial and temporal patterns of distribution and abundance, and (c) the preliminary analysis of diets of pelagic young-of-the-year rockfish.

Bathymetric Distributions

Midwater trawls are usually done with 90 m of wire out, aimed at sampling a depth of 30 m (Lenarz and Moreland 1985). At stations with a shallow bottom only 30 m of wire is let out. At some of the deeper stations, trawls with different warps are carried out to analyze the bathymetric distributions of pelagic juveniles. At most of these stations, replicates are made with 90 and 300 m of wire out. From 1984 through 1986, 19 such pairs of tows were carried out, the results of which are shown in Table 1. Several of the species analyzed were slightly more abundant in the shallower tows (*S. paucispinis*, *S. auriculatus*, *S. goodei*, and *S. jordani*). Of these, only *S. paucispinis* and *S. auriculatus* showed differences of any magnitude. None of these differences was statistically significant (Table 1). *S. entomelas*, *S. flavidus*, and, to a much lesser extent, *S. pinniger*, were more abundant in the deeper tows. This difference was significant for *S. entomelas*, and approached significance for *S. flavidus* (Table 1).

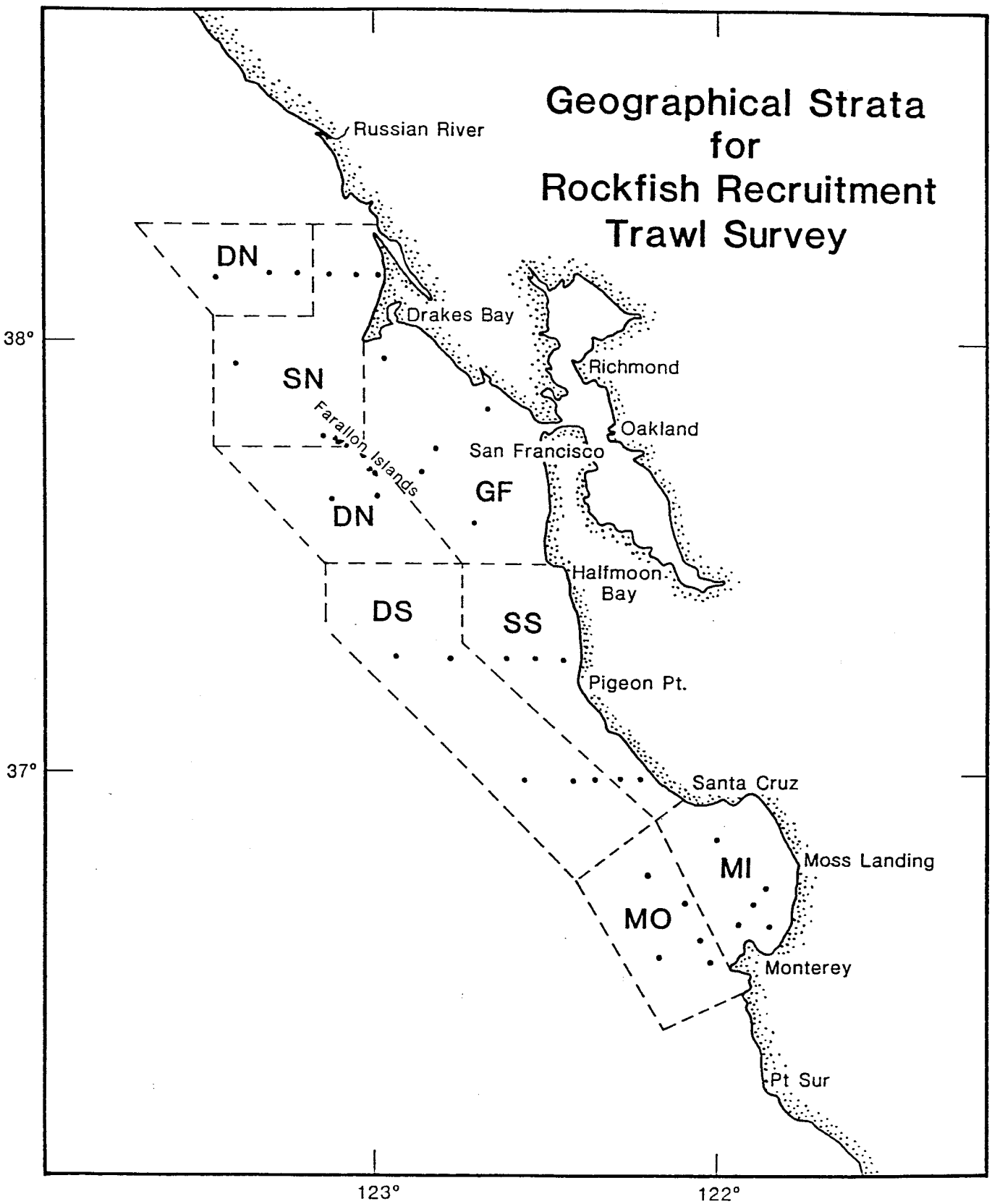


FIGURE 1.--Locations of midwater trawl stations and the geographical groupings used in some analyses. (See Table 3.)

TABLE 1.--Comparison of catch rates for pelagic age-0 rockfishes in replicate midwater tows made with 90 m and 300 m of wire out in 1984, 1985, and 1986. Catches were transformed to ln(x+1). Shown for each species are the overall averages of log-transformed counts at each warp, and statistics for a paired-comparisons t-test of log-transformed catches at the two depths. With the exceptions noted, statistics are based on all pairs of hauls. Elimination of stations at which both hauls yielded no individuals of a species made no difference in significance levels.

Species	N[1]	Mean log catch at warp = 90 m	Mean log catch at warp = 300 m	Mean difference	Variance	Significance of paired t-test
S. paucispinis	9	1.953	1.295	0.658	1.412	.1<P<.2
S. auriculatus	9	1.089	0.561	0.526	0.900	.1<P<.2
S. goodei	9	0.706	0.523	0.183	0.707	P>.5
S. pinniger	9	0.589	0.732	-0.144	0.167	P>.2
S. jordani	19	1.764	1.590	0.174	2.193	P>.5
S. entomelas	19	0.335	0.930	-0.596	1.267	P<.05 *
S. flavidus	19	0.259	0.732	-0.472	1.218	.05<P<.1
All species	19	2.127	2.327	-0.200	1.777	P>.5

[1] The first four species were absent to rare in 1985, so no hauls from that year were included in computations.

Additional bathymetrically-stratified hauls in 1987 will help to resolve the distributions of the species. In addition, multivariate analyses (discussed below) may indicate associations between certain rockfishes and other organisms (such as mesopelagic species or organisms known to be epipelagic or neustonic) that will describe more about their pelagic habitats.

The concentration of sampling effort at depths reached with 90 m of wire out may not seriously bias estimates of relative abundance, even for those species showing bathymetric differences in abundance. First, the net is in the water longer for tows with 300 m of wire out, and one might expect to capture a few more fish in these hauls even if the fish were distributed uniformly with depth. Second, differences between stations far overshadowed differences between depths, so if a species is abundant in an area, it is likely to show up abundantly in hauls with 90 m of wire out.

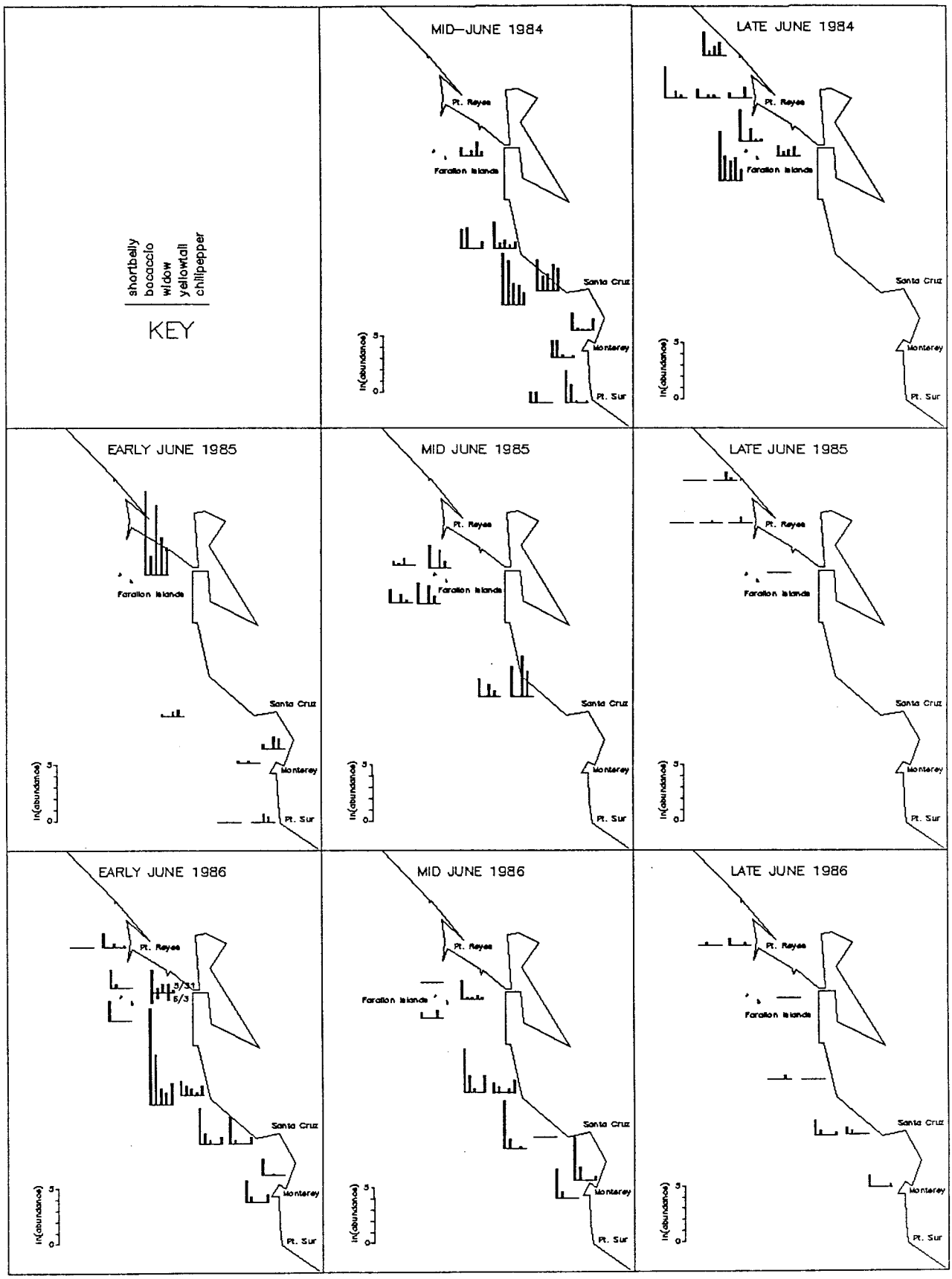
Spatial and Temporal Patterns of Abundance

Data gathered to date, especially from the time-stratified sampling series of 1986, suggest several spatial and temporal patterns of abundance of pelagic young-of-the-year rockfish in our study area. Knowledge of spatiotemporal patterns may facilitate selection of the best indices of year-class strength and set the stage for questions about the processes leading to the patterns. What follows is a preliminary, semiquantitative analysis of spatiotemporal patterns evident in the 1984-1986 midwater trawl surveys.

The following analysis is based on statistics of abundance from small geographical areas (smaller than the strata used in the assessment of year-class strength, which are illustrated in Fig. 1) and restricted periods of time. Usually two to five nearby stations, sampled within a few days of each other, were grouped to form an "area." (The general locations of these areas are indicated in Fig. 2.) Species' counts from hauls in an area were transformed to $\ln(x + 1)$, and the mean of the transformed counts was computed. Samples of areas were divided into those made during early June (late May through about June 10), mid-June (about June 11-June 20), and late June (about June 20-June 30) of each year. For five of the species, bar graphs of the means for areas from each time period were superimposed on maps of the study area, to provide a <u>gestalt</u> impression of spatial and temporal patterns. Further statistics were computed as indices of the consistency with which a species occurred throughout the study area. Calculated for nine species, these statistics included: (a) the number of smaller "areas" (defined above) in which a species occurred, (b) the number of areas in which that species ranked among the top three in abundance, (c) the average "rank," over areas, of that species among the nine under consideration, with a score of 9 given to the most abundant species in an area and a score of 0 to species that were absent, and (d) the mean (over areas) of the $\log_e$-based area means.

Within-year temporal patterns of abundance are best documented for the month of June, when samples were taken over the entire study area, and our best data for June were gathered in 1986, when sampling was stratified temporally. Additional temporal coverage was obtained in 1985 and 1986, when the Groundfish Communities Task sampled the Gulf of the Farallones during the month of April. Temporal patterns within the month of June were similar in 1985 and 1986, but very different in 1984 (Fig. 2). In 1985 and 1986, abundances of all species

FIGURE 2.--Spatial and temporal patterns of abundance of five species of rockfish captured in midwater trawls, 1984-1986. Each bar graph represents the means of ln(x+1)-transformed counts of five species from trawls made at nearby stations. Two to five stations were usually used as a sample, and the position of a bar graph indicates the general location of the stations. Means are presented separately for trawls made in early June (actually from the last few days of May through about June 10th), mid-June (about June 11-20), and late June (June 20-30). Horizontal lines with no bars indicate sample sets in which none of the five species were present. Absence of a bar graph or horizontal line indicates that no trawls were made in an area during that time period. The pair of graphs in the Gulf of the Farallones in early June, 1986, represent separate sets of trawls made several days apart. The species presented, as indicated by the key, are the shortbelly rockfish, *Sebastes jordani*, the bocaccio, *S. paucispinis*, the widow rockfish, *S. entomelas*, the yellowtail rockfish, *S. flavidus*, and the chilipepper, *S. goodei*.


shortbelly
bocaccio
widow
yellowtail
chilipepper
KEY
MID—JUNE 1984
LATE JUNE 1984
EARLY JUNE 1985
MID JUNE 1985
LATE JUNE 1985
EARLY JUNE 1986
MID JUNE 1986
LATE JUNE 1986
Pt. Reyes
Farallon Islands
Santa Cruz
Monterey
Pt. Sur
ln(abundance)
5
0
3/31
6/3

of rockfish were quite low by late June. Differences between early and mid-June samples in 1985 and 1986 were less clear; aside from a few areas of superabundant fish in early June, abundances seemed roughly equivalent. In contrast, rockfish were relatively abundant during both mid- and late June of 1984 (Fig. 2, Table 2). (No samples were taken in early June of 1984.) It would seem, then, that the abundance of pelagic juvenile rockfish often declines toward the end of June, but that the period of peak abundance may change by a week or more from year to year.

Samples taken in the Gulf of the Farallones during April of 1985 and 1986 further suggest that there are (a) interspecific differences in the temporal patterns of occurrence of pelagic juveniles, and (b) substantial interannual differences in the temporal occurrence of some species. S. entomelas, S. flavidus, and S. melanops have not appeared in mid-April samples, while other species, such as S. jordani, S. pinniger, S. goodei, S. paucispinis, S. auriculatus, and S. mystinus may be abundant in both April and June. Pelagic juveniles of the latter species thus occur in our study area earlier and/or for a more extended period of time than the former species. S. jordani, S. pinniger, S. goodei, and S. paucispinis seem to remain abundant throughout June, suggesting an extended occurrence as pelagic juveniles in our area. Perhaps not coincidentally, some of these species seem to spawn more than once during a reproductive season (Moser 1967, MacGregor 1970, Wyllie Echeverria in press). S. mystinus declined in abundance in mid- to late June each year (including 1984), suggesting that its April occurrence signifies an early but temporally-restricted spawning season. S. entomelas, S. flavidus, and S. melanops seem to have a relatively later but restricted occurrence as pelagic juveniles in our study area. The temporal occurrence of S. auriculatus is enigmatic. In 1984 it was abundant throughout June, in 1985 it was abundant in April but absent in June, and in 1986 it was absent in April but abundant in June. Its temporal pattern of occurrence was by far the most variable of the species considered. Other species occurring in both months usually showed similar relative changes in abundance from April to June. In any case, temporal shifts in the occurrence of pelagic juveniles may present difficulties in the assessment of year-class strength from midwater trawls, especially for species whose pelagic juveniles are present for an extended period of time. Beginning in 1987, we will sample the entire study area in April as well as in June, enabling us to define more precisely the seasonal occurrence and variability of pelagic juveniles.

The overall abundance of rockfishes in our surveys may vary greatly in space and time within a year, but species composition and relative abundance are usually quite coherent. In both 1985 and 1986, single areas yielded huge catches during one period of sampling (Fig. 2). Catches of all species were high in the Gulf of the Farallones in early June 1985, and in the offshore stations off Pescadero (the upper line of stations between San Francisco and Santa Cruz) in early June 1986. In both cases, catches from these areas dwarfed catches from other areas sampled at the same time and from the same areas sampled later in June. The existence of such spatially-restricted and temporally transient peaks could cause problems in the assessment of year-class strength, since such peaks could be missed in sampling. However, it is encour-

aging to note that the patterns of species composition and relative abundance seen in peak areas also hold for the rest of the study area.

TABLE 2.--Some statistics on the relative and absolute abundance of several species of rockfish from midwater trawls in 1984-1986. Statistics are based on means of ln(x+1)-transformed counts from small areas (the same used in Fig. 2), usually represented by 2-5 stations. For samples of areas from early and mid-June 1985 and 1986, and mid- and late June 1984 (no sampling was conducted in early June 1984, and late June samples in 1985 and 1986 were depauperate), the following were computed for each of nine species: (a) the number of areas in which the species was present; (b) the number of areas in which its mean abundance ranked in the top three species caught, (c) its mean "rank" (over areas) among the nine species, with the top species in an area scoring a rank of 9 and absent species scoring 0; and (d) the mean (over areas) of the $\log_e$-based within-area means.

Species	# Areas present	# Times top 3	Mean rank	Mean catch	# Areas present	# Times top 3	Mean rank	Mean catch
	Mid-June 1984 (N = 7 areas)				Late June 1984 (N = 7 areas)			
S. jordani	9/9	9/9	8.7	2.089	7/7	7/7	8.9	2.031
S. auriculatus	7/9	0/9	3.8	0.516	4/7	1/7	2.9	0.254
S. paucispinis	9/9	5/9	6.4	1.303	3/7	1/7	2.4	0.421
S. pinniger	7/9	5/9	5.0	0.703	5/7	2/7	4.1	0.507
S. goodei	8/9	4/9	5.0	0.669	3/7	0/7	1.6	0.185
S. entomelas	7/9	1/9	4.3	0.568	6/7	4/7	5.8	0.714
S. flavidus	5/9	2/9	3.3	0.643	7/7	6/7	7.1	0.791
S. mystinus	1/9	0/9	0.3	0.035	3/7	2/7	2.4	0.143
S. melanops	1/9	0/9	0.6	0.024	2/7	0/7	0.6	0.072

TABLE 2.--(Continued)

Species	# Areas present	# Times top 3	Mean rank	Mean catch	# Areas present	# Times top 3	Mean rank	Mean catch
	Early June 1985 (N = 6 areas)				Mid-June 1985 (N = 6 areas)			
S. jordani	4/6	3/6	5.0	1.378	6/6	6/6	8.7	1.627
S. auriculatus	0/6	0/6	0.0	0.0	0/6	0/6	0.0	0.0
S. paucispinis	1/6	0/6	0.7	0.278	1/6	1/6	1.2	0.019
S. pinniger	1/6	0/6	0.5	0.183	1/6	0/6	0.8	0.067
S. goodei	1/6	0/6	0.8	0.412	0/6	0/6	0.0	0.0
S. entomelas	5/6	5/6	7.0	1.436	6/6	6/6	8.3	1.557
S. flavidus	4/6	3/6	5.2	0.895	5/6	4/6	5.7	0.733
S. mystinus	5/6	4/6	6.2	0.864	5/6	1/6	5.2	0.620
S. melanops	2/6	0/6	1.2	0.154	0/6	0/6	0.0	0.0
	Early June 1986 (N = 11 areas)				Mid-June 1986 (N = 9 areas)			
S. jordani	10/11	10/11	8.0	2.229	7/9	7/9	6.7	2.005
S. auriculatus	9/11	8/11	6.2	1.183	7/9	7/9	6.2	1.059
S. paucispinis	8/11	4/11	4.2	0.757	5/9	4/9	3.9	0.516
S. pinniger	7/11	5/11	3.8	0.534	5/9	0/9	3.1	0.276
S. goodei	7/11	2/11	3.4	0.454	4/9	1/9	2.7	0.351
S. entomelas	6/11	2/11	3.1	0.322	2/9	0/9	0.9	0.054
S. flavidus	4/11	0/11	1.7	0.254	4/9	2/9	2.8	0.177
S. mystinus	3/11	0/11	1.3	0.104	0/9	0/9	0.0	0.0
S. melanops	3/11	0/11	1.5	0.201	0/9	0/9	0.0	0.0

Nearly all species seem to be abundant in the areas of peak abundance, but the species that are most abundant in these areas are also the most abundant in other areas. For example, S. entomelas and S. flavidus were more abundant compared to the other species in the Gulf of the Farallones in 1985 than in the outer Pescadero stations in 1986, while S. jordani, S. paucispinis, and S. goodei were relatively more abundant at the Pescadero stations in 1986 (Fig. 2). S. entomelas and S. flavidus were also relatively abundant in most of the other areas in 1985 (Fig. 2), consistently ranking high in abundance relative to other species (Table 2). Similarly, S. paucispinis and S. goodei were usually among the more abundant species in all areas during 1986 (Fig. 2, Table 2). S. jordani was abundant in 1985 (as it almost always is), but it too had a consistently higher relative abundance in 1986 than in 1985. Thus the pattern evident in peak areas is carried through in other areas. Conclusions about the relative success of different species in a given year are likely to be robust, since they may not depend strongly on hitting or missing areas of transient peak abundance.

Areas of peak abundance are probably associated with oceanographic features that attract or passively aggregate juvenile rockfishes. We are now investigating the oceanographic features associated with such peaks, and the conclusions will help to interpret sampling results and to learn about processes affecting the distribution and abundance of pelagic juveniles.

A possible exception to the geographical coherence of species composition occurred in 1984. While most of the five species illustrated were present in areas north of Santa Cruz, more southerly areas near Monterey Bay and off Pt. Sur yielded mainly S. jordani and S. paucispinis (Fig. 2). Recurring geographical trends in species composition will influence the methods chosen for indexing year-class strength.

Another pattern evident to date is that, as suggested above, some species seem to vary annually in concert. 1985 was apparently a strong year for S. entomelas and S. flavidus, as suggested above, and for S. mystinus as well (Table 2). These species consistently ranked among the most abundant in an area, and had high absolute abundances relative to 1984 and 1986. 1986 was probably a poorer year for these species than 1984, based on absolute and relative abundances (Table 2, Table 3). S. paucispinis, S. goodei, S. pinniger, S. auriculatus, and possibly S. jordani seem to be related as well. The first four species were all rare in June samples of 1985, and abundant in the June samples of 1984 and 1986 (Fig. 2, Table 2, Table 3). By the methods of calculation used in Table 2, S. jordani also seemed to be more abundant in 1984 and 1986 than in 1985. The members of these groups exhibit some independent variation (for example, S. paucispinis seemed to do relatively better than its groupmates in 1984, S. auriculatus did relatively better in 1986, and S. flavidus didn't seem to drop as much in 1986 as S. entomelas), but the covariation among species in a group is evident. The two groups mentioned seem to vary somewhat independently, since both were present in 1984, and both were very weak in 1983 (Table 2, Table 3). The existence of covarying groups of species could, however, prove very useful in both the assessment of year-class strength and in the search for processes affecting year-class strength.

TABLE 3.--Random stratified estimates of the mean and variance of the mean (in parentheses) of juvenile rockfish catches in midwater trawls, 1984-1986. The seven strata indicated in Fig. 1, weighted equally, were used in calculations (except in leg 3 of 1986, when one stratum was not sampled). The number stations sampled gives an idea of sampling intensity, but sample size is 7 for all stratified estimates except leg 3 of 1986. Counts were transformed to ln(x+1).

		Stratified mean catch per net haul				
Year	Stations sampled	Bocaccio	Chili-pepper	Short-belly rockfish	Widow rockfish	Yellow-tail rockfish
1983	21	0.0 (0.0)	0.0 (0.0)	0.209 (0.0602)	0.167 (0.1667)	0.209 (0.8472)
1984	26	0.846 (0.4065)	0.589 (0.2053)	1.879 (1.6754)	0.633 (0.4268)	0.653 (0.3641)
1985	39	0.188 (0.0199	0.450 (0.0977)	1.981 (0.4406)	2.265 (1.1394)	1.079 (0.2324)
1986						
Leg 1	40	0.607 (0.833)	0.381 (0.4145)	1.885 (3.3440)	0.208 (0.3529)	0.188 (0.3083)
Leg 2	32	0.477 (0.3646)	0.252 (0.2650)	1.877 (2.1304)	0.036 (0.0251)	0.198 (0.1376)
Leg 3	30	0.092 (0.0762)	0.077 (0.0747)	0.535 (0.9985)	0.0 (0.0)	0.074 (0.1543)

The results of this preliminary analysis of spatiotemporal patterns underline the need during the near future to continue sampling over a broad scale of time and space. It is possible that future sampling and analysis will indicate ways to reduce sampling effort, but such changes will not be possible without additional data from widespread sampling.

We plan two lines of concentrated analysis of data during the coming year. First, we intend to formalize the analysis of spatio-temporal patterns using multivariate techniques such as cluster analysis of stations and principal components analysis of biological and physical data. The latter will be carried out on at least two levels. The first will be with data on rockfishes alone, to substantiate or not the impression of correlated groups of rockfish species. The second will

include data on other species of fish and invertebrates taken in samples and on physical factors such as temperature and depth. Associations of rockfishes with physical factors and with better-known organisms may suggest features of the pelagic microhabitats of rockfish. The second area of analysis concerns the correlation of oceanographic information with patterns of pelagic rockfish distribution. We intend to employ oceanographic information gathered on board (surface temperatures and salinities and subsurface CTD data) and from other sources (such as satellite sea surface temperature imagery) to characterize sea conditions associated with different features of rockfish distributions. Such an analysis will help to interpret within-year spatiotemporal patterns and interannual differences.

Food Habits of Pelagic Juveniles

As part of the effort to understand the niches of important species of pelagic juvenile rockfish, the diets of pelagic juveniles have been analyzed since 1983. The sampling plan has been to collect five individuals of each species from each station sampled. We have sampled and analyzed 809 stomachs from 10 species for the years 1983 through 1986 (Table 4).

TABLE 4.--Number of stomach samples collected by species and year.

Species	1983	1984	1985	1986
S. entomelas	4	15	75	4
S. flavidus	5	40	30	10
S. bocaccio		50		25
S. goodei		20		5
S. auriculatus		5		68
S. pinniger		25		
S. hopkinsi		15	5	
S. mystinus			25	
S. saxicola		5		

Two principal prey, euphausiids and copepods, dominated the diets of these species during all three years analyzed. The prey identifications were categorized into invertebrate eggs (probably euphausid), larval, small and large juvenile euphausids, juvenile and adult copepods and identifiable Calanus copepods. During 1984 and 1986, five species of rockfish were studied in detail: Sebastes entomelas, S. flavidus, S. goodei, S. jordani and S. paucispinis. Only three species were studied in detail in 1985; S. entomelas, S. flavidus and S. jordani.

Dietary overlap among species pairs for each year was estimated using Schoener's index (the sum of the proportions of each prey type that two species share). In 1984, diet overlap was greater than 48% for all ten species pairs. This is due to the sharing of five major prey types, juvenile and adult copepods, Calanus copepods and larval and juvenile euphausids. Most species pairs had over 60% diet overlap. The most striking difference in this year was with S. paucispinis which ate few juvenile copepods, resulting in the lowest diet overlap with other species. In 1985, three species pairs were compared. High diet overlap occurred due to the common occurrence of copepod juveniles and invertebrate eggs. In 1986, diet overlap for the 10 species pairs ranged from 7% to 85% because of the large diversity of prey types. Percent diet overlap was high for most species in all years regardless of difference in standard lengths.

Fish for stomach analysis were collected throughout the night. Analysis of the mean number of prey items per stomach suggested that most feeding occurred between 2200 hr and 0300 hr, with a peak stomach fullness at a different hour for each of the five major species of rockfish.

The stations sampled are divided into strata based on geographical location and depth (Fig. 1). To determine if a particular stratum provided better food sources the mean prey number per stomach was plotted vs. geographical strata. The 'SS' stations seem to be the best food area for S. entomelas, S. flavidus, and S. jordani. The 'DS' stations were best for S. goodei and the 'MI' stations were the best areas for S. paucispinis.

We will continue to collect and analyze prey items to see if the trends that are beginning to appear are maintained.

PROGRESS IN UNDERWATER NEARSHORE SURVEYS

The numbers of juvenile rockfishes, *Sebastes* spp., that settled in northern California nearshore habitats during 1986, as determined by *in situ* visual counts, continued to demonstrate substantial year to year variation in recruitment (Table 5). Counts of the three target species suggested that 1986 recruitment was moderately successful, with numbers similar in magnitude to those of 1984, but greatly exceeding the exceptionally low numbers of 1983, and falling far short of the exceptionally high numbers of 1985.

TABLE 5.--Mean number (standard error in parentheses) of first-year juveniles counted/min off the Mendocino coast during the same 4-week periods (early August to early September) in 1983-1986.

Species	1983 N = 36	1984 N = 57	1985 N = 50	1986 N = 103
S. flavidus	0.00 (0.00)	6.58 (2.29)	115.60 (21.26)	6.01 (1.50)
S. mystinus	0.27 (0.09)	1.49 (0.30)	70.56 (15.32)	7.83 (1.88)
S. melanops	0.41 (0.14)	0.31 (0.08)	4.34 (1.54)	9.52 (2.08)
Total	0.68 (0.19)	8.38 (2.33)	190.50 (29.82)	23.35 (3.91)

The recruitment success of the black rockfish Sebastes melanops in Mendocino during 1986 deserves special comment. While this species recruited in similar statistically indistinguishable numbers during 1983 through 1985, its numbers were significantly greater in 1986 (Table 6).

TABLE 6.--Contrasts among years in the abundances of Sebastes melanops in timed underwater transects, 1983 to 1985 and 1983 to 1986. Contrasts are based on two analyses of variance (ANOVAs): counts made during the years 1983-85, and counts made during the years 1983-86. Counts were transformed to ln(x+0.001)

1983-1985[1]		1983-1986[2]	
Contrast	F (Probability)	Contrast	F (Probability)
1983-84	0.04 (0.84)	1983-86	12.42 (0.001)
1983-85	0.27 (0.60)	1984-86	15.04 (0.001)
1984-85	0.14 (0.71)	1985-86	10.37 (0.001)

[1]ANOVA for 1983-1985: F=0.14, P=0.83, df=2,140

[2]ANOVA for 1983-1986: F=9.18, P<0.001, df=3,242

The yellowtail rockfish, Sebastes flavidus, recruited over an exceptionally long period in 1986. First-year juveniles of this species first appeared in nearshore habitats during mid-June, and for two weeks arrived steadily but in low numbers. There was a large pulse of arrivals at the end of the month, followed by 6 weeks of continuous low-level recruitment. (New arrivals were readily recognized by their small size (30-35 mm) and lack of pigmentation.) Midway through August there was a second major pulse of arrivals, and thereafter two distinct size-groups were evident. By the time of the fall counts, individuals from the June pulse were 60-70 mm SL (standard length), while those from the August pulse were 40-50 mm SL.

These two pulses of recruitment can be related to the reproductive condition of 10 female S. flavidus collected during the previous March (see the Physiological Ecology section of this report). Of these, the ovaries of four were spent, whereas the ovaries of the other six contained eggs in early stages of development (estimated to be 40-60 days before parturition.) These data suggest that the population from which these specimens were sampled may have produced two distinct batches of larvae, 6-8 weeks apart,

which is consistent with the arrival of two pulses of juveniles in the nearshore habitats.

As was the case in previous years (and noted in last year's report), during 1986 the numbers of juvenile Sebastes spp. generally were higher on the Sonoma coast than along Mendocino (Table 7). However, while juvenile S. melanops were noted to be more abundant than previous years in Mendocino, our data do not show this to be the case in Sonoma.

TABLE 7.--Mean number (standard error in parentheses) of first-year juveniles counted/min during the same period (August) over 3 years off the Sonoma and Mendocino County coasts.

	MENDOCINO			SONOMA		
Species	8/84 N = 57	8/85 N = 50	8/86 N = 103	8/84 N = 37	8/85 N = 84	8/86 N = 60
S. flavidus	6.58 (2.29)	115.60 (21.26)	6.01 (1.50)	4.39 (1.48)	135.17 (26.00)	6.73 (2.29)
S. mystinus	1.49 (0.30)	70.56 (15.32)	7.82 (1.88)	4.89 (1.29)	117.63 (19.50)	15.27 (3.81)
S. melanops	0.31 (0.08)	4.34 (1.54)	9.52 (2.08)	1.63 (0.52)	4.40 (1.17)	3.00 (1.31)
Total	8.38 (2.33)	190.50 (29.76)	23.35 (3.91)	10.91 (2.12)	257.20 (35.38)	24.97 (5.17)

PROGRESS IN MEASURING RECRUITMENT OF JUVENILE ROCKFISH FROM KING SALMON STOMACH CONTENTS

During the years 1983-1986, the Groundfish Communities Investigation conducted trawl studies and took stomach samples from king salmon (Oncorhynchus tshawytscha) in the Gulf of the Farallones as part of a study of predation on juvenile rockfish (Sebastes spp.). Preliminary analysis of data from this study raised the possibility that the stomach contents of predators could be used to estimate year-class strength of juvenile rockfish.

Stomach samples from king salmon were taken from commercial passenger fishing boats. A maximum of 15 stomachs per trip were taken and two to three trips per week were sampled. Previous stomach sampling had shown that king salmon have a seasonal diet cycle, which can be summarized as follows: Early in the season the salmon are inshore, where they feed on anchovies and herring, but in late April they move offshore and feed on juvenile rockfish and euphausiids. In the beginning of July, the salmon return to shore and resume feeding on anchovies. Because predation on juvenile rockfish occurs over a limited period of time, the analysis is limited to stomach contents from May and June. Trawl stations were identified in the Gulf of the Farallones based on traditional fishing areas. These stations were sampled twice during the last week in May and the first week in June. Samples were collected in 10-min trawls using the same gear employed in the midwater trawl survey.

In the Gulf of the Farallones, the relative number of juvenile rockfish in the stomach contents of king salmon matched closely the relative number taken in the trawls. A plot of average number of juvenile rockfish per trawl (on a log scale) versus average number of juvenile rockfish per stomach has a strong positive relationship (Fig. 3) with 1983 and 1985 being extremes and 1984 and 1986 being intermediate. The four years of data represent very different situations. 1983 was the El Niño year and was almost a total failure for juvenile rockfish. 1985 was a year in which recruitment of certain species of rockfish was very successful, and trawls in the Gulf of the Farallones yielded particularly large catches (see sections on midwater trawl surveys and underwater observations). 1984 and 1986 were intermediate years in terms of overall levels of rockfish recruitment, and catches in the Gulf of the Farallones were moderate (see midwater trawl section). Individual plots (Figs. 4 and 5) for the shortbelly rockfish (S. jordani) and for the widow rockfish (S. entomelas) have the same pattern. Thus, it appears that the number of juvenile rockfish in salmon stomachs is a good predictor of the number of juvenile rockfish found in the trawls. At the very least, good, poor, and intermediate levels of recruitment can be distinguished on a local scale.

The level of precision for estimates of the number of juvenile rockfish in salmon stomachs can be improved by increasing the number of salmon stomachs sampled and by increasing the number of juvenile rockfish identified from the fish sampled. The current sampling was designed with the objective of describing salmon feeding behavior. That part of the project is completed, so sampling plans can be changed to optimize the number of juvenile rockfish taken from the stomachs.

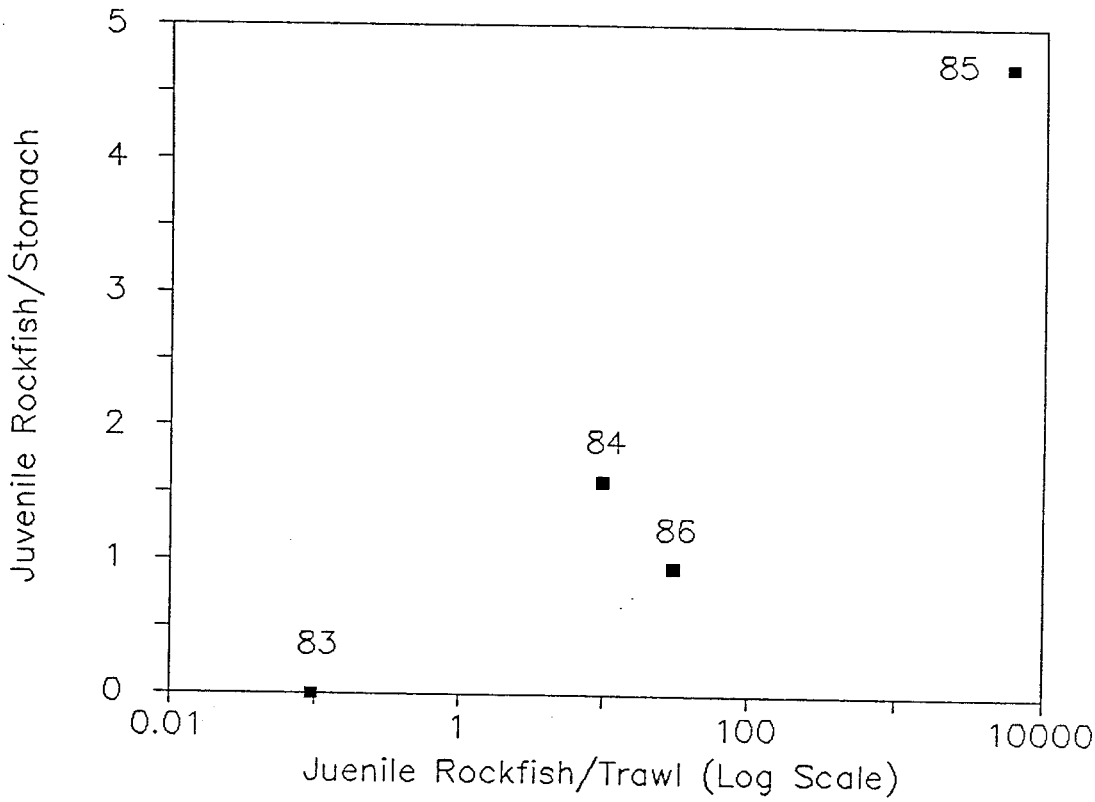


FIGURE 3.--Number of juvenile rockfish taken from the Gulf of the Farallones in midwater trawls vs. number of juvenile rockfish found in salmon stomachs for the years 1983 to 1986.

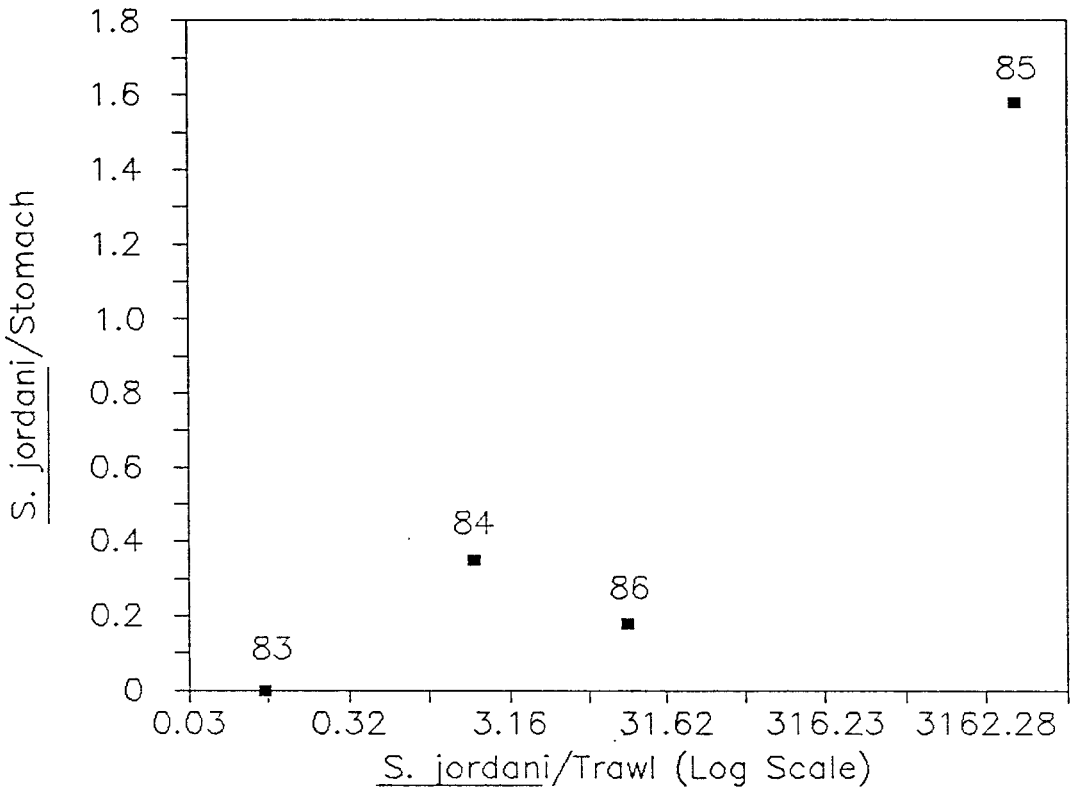


FIGURE 4.--Numbers of S. jordani taken from the Gulf of the Farallones in midwater trawls vs. number of S. jordani found in salmon stomachs for the years 1983 to 1986.

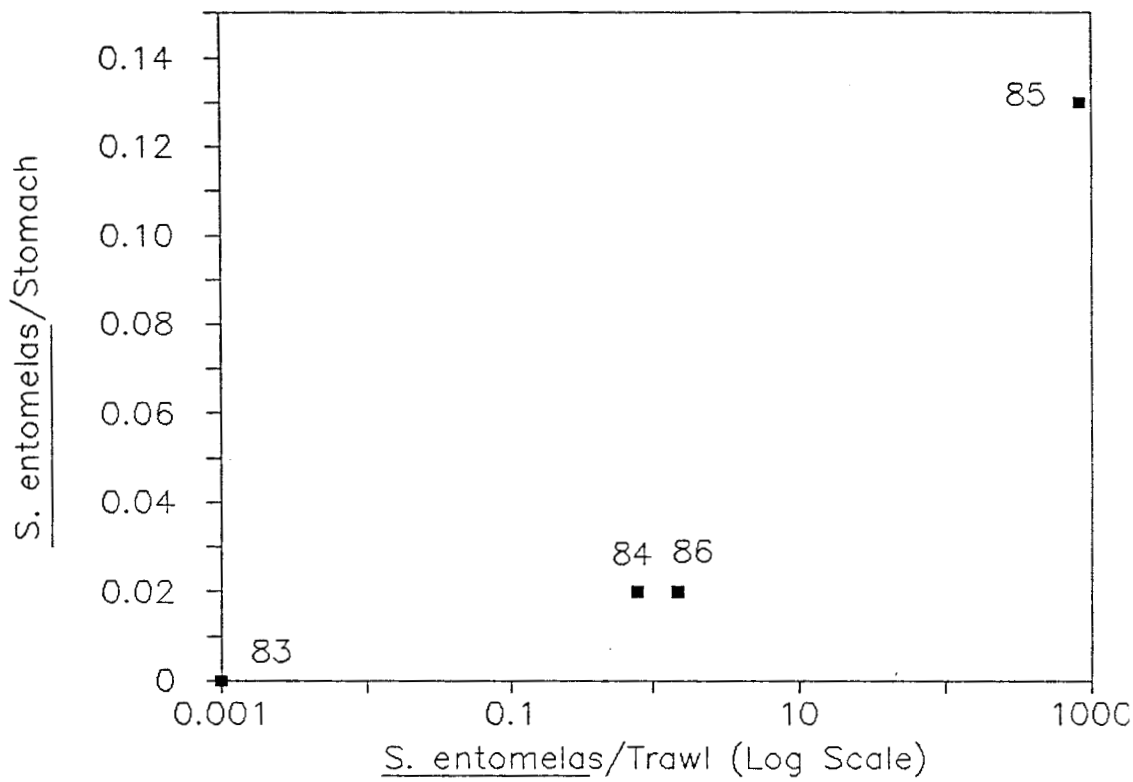


FIGURE 5.--Numbers of S. entomelas taken from the Gulf of the Farallones in midwater trawls vs. number of S. entomelas found in salmon stomachs for the years 1983 to 1986.

Work on a new sampling plans is in progress. The second improvement is to identify more juvenile rockfish that are found in the stomach sampling. Currently we are only able to identify 40-50% of the juvenile rockfish found in the stomachs. Because of digestion, the proportion of these fish identified will never be high, but by focusing on just identifying certain species, improvements of the order of 10 to 20% should be possible. These changes may facilitate the use of salmon stomachs to assess year-class strength in other commercially important species of rockfish (such as bocaccio, S. paucispinis) that are less common in salmon stomachs than S. jordani and S. entomelas.

The major unresolved problem with the use of salmon stomach contents as an index of rockfish year-class strength, however, is the effect of predator behavior on the consumption of rockfish. Changes in the numbers of juvenile rockfish in the stomachs are due both to changes in the abundance of juvenile rockfish and to changes in the predatory behavior of the salmon. Only with a thorough understanding of the predatory behavior of the king salmon can this method provide reliable estimates of juvenile rockfish abundance.

PROGRESS IN PHYSIOLOGICAL ECOLOGY STUDIES

Background and Introduction

In October 1985, the Physiological Ecology Investigation (PEI) staff initiated a task entitled the Physiological Ecology of Pacific Groundfishes. Research, consisting of integrated, multidisciplinary studies, was designed to examine functional relationships between groundfishes and their environments. Studies were directed toward providing relevant information needed to understand the groundfish fisheries and to manage the northern California coastal stocks.

Effective PFMC management of groundfish stocks requires information such as the ability of individuals populations to grow, reproduce, and survive. Both inherent and environmental factors directly affect these processes by influencing fish condition and reproduction (Fig. 6). Understanding the factors which determine fish condition and subsequent reproductive effort and success contributes to our ability to assess the health of the stock and ultimately to forecast recruitment in the population.

Our studies include monthly field collections and laboratory analyses designed to assess the condition and reproduction of four species of rockfish (yellowtail, S. flavidus; bocaccio, S. paucispinis; widow, S. entomelas; and chilipepper, S. goodei). Fish are collected from Cordell Bank off northern California. Because of its relative commercial importance and suitability for experimentation, initial emphasis was on yellowtail rockfish. Field collections were followed by a series of comprehensive examinations and subsampling, coupled with laboratory experiments conducted at the University of California Bodega Marine Laboratory.

We completed our studies of fish from the 1985-1986 season. We are currently in the middle of studies for the 1986-1987 season. Therefore, the following report represents preliminary results up to the present. Additional data analyses are required to make conclusions for the two years of study.

Health and Condition of Adults

Field-caught rockfish specimens were given a comprehensive examination which included analyses at whole animal, organ, tissue, cellular, and subcellular levels. To date, over 480 fishes from 4 to 45 years old, mostly female yellowtail rockfish, have been examined.

Preliminary results indicate that condition of adults is variable, partly as a result of parasites and diseases. There was a high prevalence of infection by two parasites potentially affecting the condition of yellowtail rockfish. The first parasite is a protozoan occurring in masses on the bulbus arteriosus of the heart, identified as Henneguya sebastoda (Mike Moser, pers. comm.). This parasite occurred in 42% of the yellowtail rockfish sampled. Although occurring in the other species examined, it was most prevalent in yellowtail rockfish.

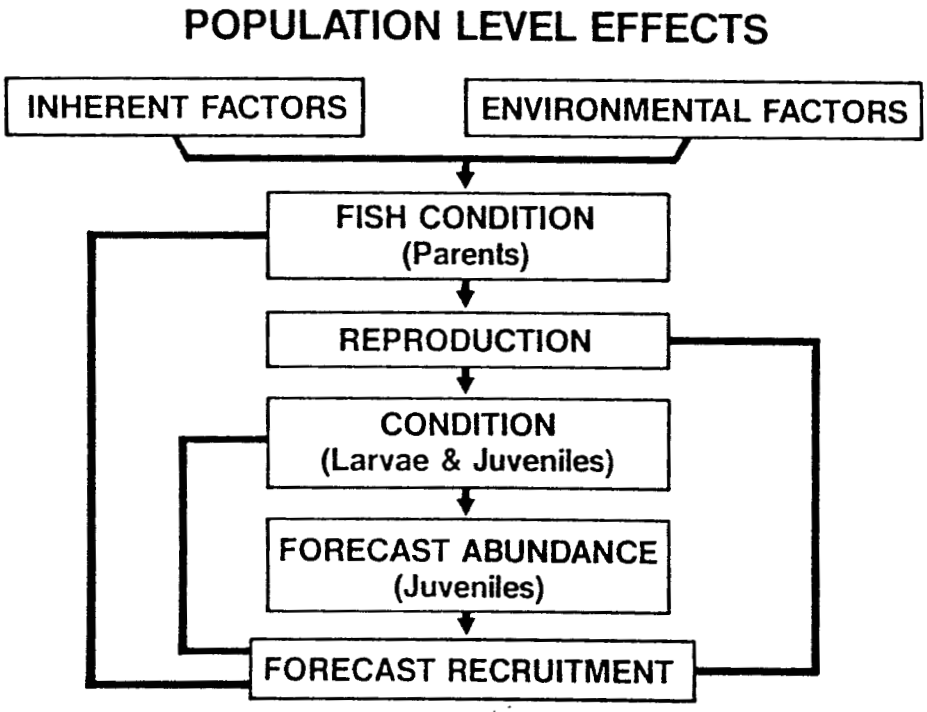


FIGURE 6.--Ways in which information on adult condition and reproduction will be used in the analysis of recruitment in rockfishes.

The second parasite is a fungus occurring as nodules in several organs, particularly in the spleen and head kidneys, occasionally in the heart and liver. This parasite, identified as Ichthyophonus sp. (Ron Hedricks and Mike Moser, pers. comm.) occurs in large numbers in some yellowtail rockfish. It occurred in 94% of the spleens and 90% of the head kidneys of the fish examined. Ichthyophonus occurs in the other species but is not as prevalent.

Rockfish captured at Cordell Bank, particularly yellowtail and bocaccio, have a relatively high occurrence of melanin spots of varying size and extent on the skin. The cells within these melanized areas appear to be tumor cells, and are possibly melanomas or neurofibromas (Ron Hedricks, pers. comm.). The prevalence of these tumors in yellowtail rockfish was 10%.

Preliminary analyses suggest that these parasites and tumors may affect growth and condition of yellowtail rockfish from Cordell Bank off California. Multivariate analyses of data for fish collected in 1985 and 1986 show that older fish were significantly more parasitized and had more melanized tumors. Older fish also had poorer body condition as indicated by derived condition factors and weight of mesenteric fat. Stepwise regression analyses showed a significant relationship of high fungus infections with reduced mesenteric fat and body condition, particularly in older fish. These analyses will be repeated on fish collected during 1986 and 1987. The poorer condition of the older yellowtail rockfish may related to reductions in their fecundity and also affect the reproductive capacity as discussed below.

To compare the health of Cordell Bank yellowtail rockfish with other populations, specimens were collected from a coastwide rockfish survey during July and August 1986. Preliminary examinations indicate that Oregon and Washington yellowtail appeared to be in good condition, with abundant mesenteric fat stores. Yellowtail rockfish collected there were infected with the same protozoan and fungus parasites, but at significantly lower levels, and with many individuals not infected at all. Additionally, yellowtail collected further north did not exhibit melanin skin patches or tumors.

As well as examining condition of the rockfish on the individual, organ, and tissue level, condition was assessed at a functional subcellular level. For example, nutritional bioenergetic studies were conducted to determine the qualitative and quantitative transfer of nutritional resources from maternal stores, such as in the liver, muscle, and mesenteric fat, to developing eggs and larvae. The goal of this research is to establish a model to predict reproductive success based on the ability of fish to provide adequate nutrients to their spawning products. To carry out this research, blood is taken from mature female yellowtail rockfish every month and the serum is analyzed for nutrients, inorganic ions, and compounds indicative of organ function. In addition, liver, muscle, and gonadal tissues are in the process of being assessed for changes in lipid, protein, carbohydrate, water, and ash contents.

Inspection of data generated to date shows that concentrations of serum nutritional and structural compounds are elevated during the winter (November-February), which coincides with the period of rapid egg and larval development. Serum ion concentrations appear relatively stable throughout the year, as might be expected from a stenohaline environment. The greatest variations between monthly means were observed for potassium (approximately threefold) and phosphate (about twofold).

Serum enzyme levels (e.g., LDH, alkaline phosphatase, transaminases) and other indicators of organ function (e.g., blood-urea nitrogen, creatine, bilirubin) have been recorded for each specimen and will be used to determine the effects of organ pathology on reproductive functions and to indicate unhealthy fish so that serum nutrient profiles for normal, healthy fish can be obtained.

Additionally, all data produced from measurements on individual fish will be analyzed to reveal relationships between variables of reproductive importance to define profiles of reproduction and nutrients within the sample population. Variations in reproductive stage and age have been observed within monthly samples; therefore, all data will be grouped and assessed by age and ovarian maturation stage to characterize the age-specific nutritional sequence of egg-to-embryo-to-larval development. After this project, the effects of changes in environmental variables, such as temperature and food availability, on reproductive success will be determined with field measurements and controlled laboratory studies.

Reproduction in Rockfish

A multifaceted research approach was employed to study reproduction in both the field and laboratory. Monthly collections from Cordell Bank provided information on gonadal maturation and fecundity in relation to age, size, life stage, and several condition factors. Ultimately, we hope to relate these factors to environmental conditions. At Bodega Marine Laboratory, experiments were conducted to answer questions about mating, gonadal development, and spawning. Together these studies should provide meaningful information on the ability of rockfish populations to reproduce and the factors influencing their reproduction.

Field-based fecundity studies began during the 1985-1986 reproductive season. Special methods were developed to provide accurate fecundity measurements and to determine the viability of eggs, embryos, and larvae. To date, 184 rockfishes of the four target species have been examined. Preliminary results are limited to the yellowtail rockfish. Fertilized eggs did not appear until January. The population appears to have a protracted spawning season since ovaries were found from mid-vitellogenic to spent maturation stage from January to May. In our first year of collections (1985-1986) and with a small sample size, 20% of the fertilized eggs were found to be abnormal. As of January in the 1986-1987 season, 26% of embryos and larvae appear abnormally developed. Possible causes of the abnormalities and the relationship to condition of the female remain to be determined from multivariate

analyses and experiments under way.

Data combined for both spawning seasons (n = 87 females) showed that fecundity ranged from 89,486 to 1,199,405 eggs per female, in fish aged 6 to 48 years, 285-440 mm standard length, and 653-2,388 gm total wet weight. As expected, fecundity is related to age-size of fish, as follows.

Linear	Curvilinear
$Y = 272066.71 + 18870.76\ X_1 \quad (r^2 = .46)$	
	$Y = 673992.22 + 464661.06 \ln X_1 \quad (r^2 = .66)$
$Y = 1444114.50 + 54195.16\ X_2 \quad (r^2 = .62)$	
$Y = -276366.28 + 591.16\ X_3 \quad (r^2 = .76)$	

Where Y = fecundity in total eggs, embryos, or larvae,

X_1 = estimated age in years,

X_2 = standard length in cm, and

X_3 = total wet weight in g.

Linear regression equations are shown for purposes of comparison; however, plots indicated a curvilinear relationship of fecundity with age, standard length, and wet weight. The relationship of fecundity to age showed that the variability in fecundity was significantly greater with age, and that some older females had lower-than-expected fecundities. Table 8 summarizes mean age-specific fecundity for yellowtail (two spawning seasons).

We are presently in the second season of reproductive studies with adult yellowtail rockfish at the Bodega Marine Laboratory. Several experiments are in progress to determine (1) if gonadal development proceeds in the absence of copulation and insemination, (2) to define the process of gonadal maturation, (3) to assess the viability of eggs, embryos, and larvae, and (4) to determine the extent of resorption of eggs in inseminated females. Although studies are still in progress, several significant results have been obtained. Of 34 mature females brought into the laboratory, only seven developed to parturition. The remaining females resorbed their eggs which were at mid- to late vitellogenesis at the time of capture. This demonstrates the adaptive

TABLE 8.--Age-specific mean fecundity in yellowtail rockfish (Sebastes flavidus) collected during the 1985-1986 and 1986-1987 spawning seasons, Cordell Bank off northern California.

Age (yrs)	n 1	Mean number of eggs/female	Standard deviation
6	3	101,523	18,392
7	1	186,369	---
8	3	253,380	102,761
9	5	313,496	96,918
10	3	398,849	31,344
11	6	392,094	55,434
12	5	602,637	148,591
13	2	585,739	72,110
14	2	431,151	51,345
15	1	343,429	---
16	10	625,647	92,921
17	6	637,776	56,165
18	5	796,168	72,625
19	4	685,070	126,869
20	3	875,998	290,624
21	5	705,052	147,444
22	2	745,441	169,072
23	1	1,036,680	---
24	5	747,734	99,978
25	2	808,703	193,325
26	3	824,597	303,513
27	2	788,482	133,165
28	1	1,071,290	---
29	2	902,729	91,739
30	0		
31	1	1,196,930	---
32	0		
33	0		
34	0		
35	0		
36	1	873,803	---
37-47	0		
48	1	631,976	---

plasticity of the yellowtail rockfish. Larvae delivered in the laboratory varied in viability, with some suffering mortality immediately after birth.

To provide fundamental information on the process of oocyte development and the environmental and physiological factors influencing it, a complete seasonal reproductive cycle of yellowtail rockfish was determined from histological preparations of ovaries. Seven oocyte maturation stages based on cell diameters and nuclear and cytoplasmic changes were observed. Following fertilization, 33 embryonic/larval stages were identified. Early vitellogenesis was found to peak in August and yolk accumulation proceeded for about six months while gestation lasted 30-35 days. The parturition period extended from January to May, indicating a protracted reproductive season.

An interesting phenomenon was observed in the March 1986 field collections, where four ovaries examined histologically were spent while six were in varying stages of oocyte and embryological development. If we project the times for maturation and parturition of these ovarian conditions, we can account for the two pulses of larvae seen in nearshore habitat observations by members of the Groundfish Community Task.

Summary

The data collected from the two spawning seasons (1985-1986; 1986-1987) will provide a good basis for comparisons with succeeding seasons. The influence of environmental and inherent factors (e.g., age) on the adult condition and reproductive efficiency of rockfish can be determined by examining variability within sample month, seasonally, and annually. Determining these relationships should enable us to establish the contribution of variation in the production of larvae to variation in year-class strength (Fig. 6), as well as to provide basic biological information critical to population assessment.

Only two years have passed in this study, and the degree of annual variability in yellowtail rockfish is still uncertain. We have found that there is considerable variability within sampling month and seasonal variability in condition and reproduction. It would appear that older fish are in poorer condition, that condition varies with month, and that approximately 30-40% of this variability relates to environmental variables such as parasites and temperature. There also appears to be variability in fecundity and viability of progeny, particularly in older fish, although abnormalties in progeny were seen at all ages of adults. Finally, some of this variability in reproduction was seen to be reflected in nearshore observations of larvae from that spawning season. Knowing these relationships may help us to predict juvenile survival and forecast recruitment in the future.

DISCUSSION

For those species of rockfish whose abundances are well-monitored by two or more methods, estimates of abundance from underwater observations, midwater trawls, and salmon stomach contents suggest similar annual changes in recruitment. The abundance of juvenile rockfish in the stomachs of king salmon is well-correlated with catches of juvenile rockfish in midwater trawls made in the same general area that the salmon were caught. Despite the distance between study areas, underwater observations and midwater trawls both showed low levels of recruitment in 1983, and high levels of recruitment in 1985 for yellowtail rockfish and blue rockfish, two species sampled in common. The relatively high abundance of black rockfish in underwater observations made in 1986 was slightly reflected in midwater trawls (cf. Tables 2 and 5). Some differences in the results of the two methods were also evident. Underwater observations showed the yellowtail rockfish to be about equally abundant off the Sonoma and Mendocino coasts in 1984 and 1986, and virtually absent in 1983, while midwater trawls off the Monterey, San Mateo, and Marin coasts yielded equivalent, low abundances of yellowtail rockfish in 1983 and 1986, and moderate abundances only in 1984.

Spatial and temporal variation in the abundance of juveniles, both onshore and offshore, present some difficulties in the interpretation of data. The two methods that sample pelagic juveniles, midwater trawls and salmon stomach contents, are the most prone to the effects of spatial and temporal patchiness, since they sample a transitory phase whose local abundance may be influenced by factors affecting the timing of their occurrence and the presence of localized aggregations. The results of these methods seem to be well-correlated on a local scale. Some changes in methods, an increased understanding of the predatory behavior of king salmon, and more widespread sampling may further increase the utility of stomach-contents sampling as an inexpensive method of estimating the relative abundance of some juvenile rockfishes in their pelagic phase. Interpretation of the results of midwater trawl surveys, against which stomach samples are likely to be compared, will be aided by continued sampling on a broad spatial and temporal scale. Underwater observations are less prone to problems of spatial and temporal patchiness, since they measure abundance at a less transitory life stage. For those species that settle in the nearshore zone, underwater observations provide a direct measure of successful recruitment to a new habitat. Potentially conducted in a number of areas along the coast, underwater observations can provide direct measures of recruitment strength and points of comparison for the surveys of pelagic juveniles.

We are intrigued by the possibility that recruitment of different species of rockfish may vary in concert. Data from midwater trawls suggest that *S. entomelas*, *S. flavidus*, and *S. mystinus* vary together, as do *S. paucispinis*, *S. pinniger*, *S. goodei*, and possibly *S. jordani*. If true, this phenomenon raises the possibility that recruitment of several species could be assessed on the basis of estimates of a few species. Potentially common features among correlated species, such as geographical range, timing and frequency of spawning, and pelagic microhabitats utilized, may help to simplify hypotheses concerning the

factors affecting year-class strength.

The contribution of variation in reproductive output to variation in year-class strength remains to be seen, as a time series of data on reproduction and recruitment is developed. We already have some evidence linking reproduction and recruitment, however. The possibly bimodal pulse of egg production in S. flavidus in 1986 corresponded with a bimodal appearance in nearshore habitats.

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