STATUS OF THE WIDOW ROCKFISH FISHERY

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ABSTRACT

Cohort and catch-at-age analysis were used to estimate fishing mortality rates and population size for widow rockfish (Sebastes entomelas), using 1980-1987 catch-at-age data. Fishing mortality was moderately higher in 1987 than in 1986, due to an increase in the harvest. Projections of stock biomass for 1988 and 1989 indicated that stock levels should be lower than the estimated levels in 1986 and 1987. The results indicated that the 1980 and 1981 year classes are strong. However the cohort analysis indicated that these year classes are much stronger than all but the 1970 year class, while the catch-at-age analysis indicates the two year classes are close to average values. While results from cohort analysis indicates that the stock is close to 1980 levels, results from catch-at-age analysis indicates that the stock at the beginning of 1988 was 30-35 percent of the 1980 level, and at the beginning of 1989 will be about 30 percent of the 1980 level. Using results from cohort analysis, estimates of MSY ranged from 8,200 to 13,300 mt, with an average of 10,700 mt. The recommended fishing mortality rate for fully recruited fish was 0.30, if M = 0.20 and 0.25, if M = 0.15. At this level of fishing effort, average yield in 1989 and 1990 (an estimate of ABC) would be 17,200 mt. Using results of catch-at-age analysis, estimates of MSY ranged from 5,900 to 11,400 mt, with an average of 8,400 mt. At the recommended fishing mortality rates for fully recruited fish, average yield in 1989 and 1990 would be 7,600 mt. Because of the considerable uncertainty in the status of the stock we recommend that ABC be set at the average estimate of MSY (9,500 mt). The recommended ABC is 21 percent below the 1988 ABC and slightly higher than average landings between 1983 and 1986.

INTRODUCTION

This report represents an update of the widow rockfish (Sebastes entomelas) status report submitted in August 1987 (Hightower and Lenarz 1987). Included is (1) a review of the 1987 report and of recent events in the fishery, (2) estimates of the current status of the stock, (3) and recommendations for harvest in 1989.

SUMMARY OF PREVIOUS ASSESSMENT

The estimate of acceptable biological catch (ABC) for 1988 was 12,100 mt, a decrease of 400 mt from the 1987 ABC. The stock was estimated to above the maximum sustained yield (MSY) level because of the relatively large 1977-1980 year classes. Estimates of total stock biomass projected a decline from 1987 to 1988 and that spawning stock would remain the same or show a slight decline.

RECENT HISTORY OF THE FISHERY

Landings in 1987 were higher than in 1986, due to increased landings in the northern part of the Columbia International North Pacific Fisheries Commission (INPFC) Area (Table 1, Figure 1). An increase in OY to 12,500 mt allowed the increased harvest. The fishery proceeded at a

Table 1. Landings (metric tons) of widow rockfish by area and year from 1979 through 1987.

Year	INPFC Vancouver	N. Columbia	S. Columbia	INPFC Columbia	INPFC Eureka	INPFC Monterey-Con.	Total
1979	329	432	1,894	2,326	2,166	120	4,941
1980	143	9,426	5,781	15,207	4,736	304	20,390
1981	1,991	7,969	12,301	20,270	3,430	2,000	27,691
1982	3,969	4,625	6,929	11,554	3,993	6,997	26,513
1983	1,596	2,490	2,129	4,619	2,442	1,554	10,211
1984	594	2,086	3,747	5,833	2,256	988	9,671
1985	446	2,128	2,993	5,120	2,313	977	8,856
1986	557	3,508	2,662	6,170	1,632	971	9,330
1987	496	6,603	2,689	9,292	1,598	799	12,185
Total	10,121	39,267	41,125	80,391	24,566	14,710	129,788

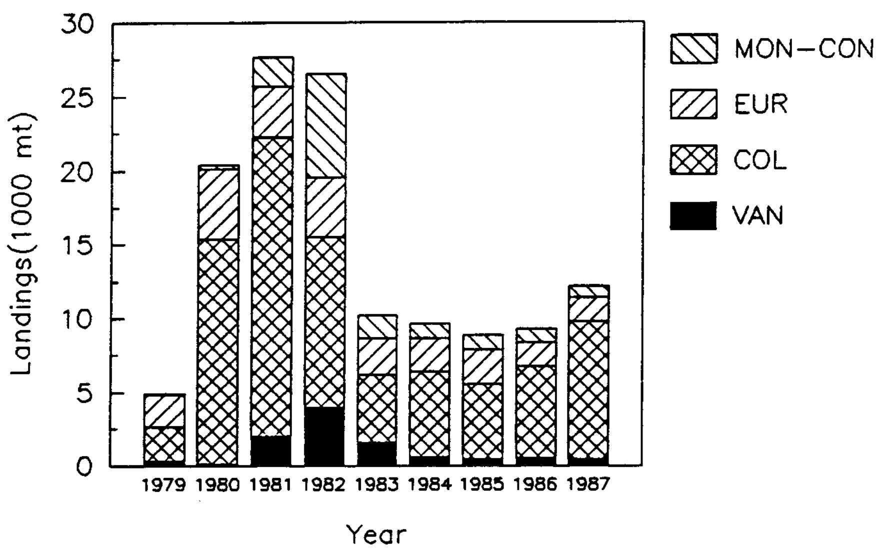


Figure 1. Landings of widow rockfish by INPFC area from 1979-1987.

faster rate in 1987 than in 1986, even though there continued to be good fishing for pink shrimp (Pandalus jordani). There were reports that schooled fish were more available in the Northern Columbia Area than in the past few years. We are not aware of changes in the availability of widow rockfish in other areas.

The 1980 and 1981 year classes dominated the catch numerically in 1987, although as in earlier years, the 1977-1979 year classes were also an important component (Table 2, Figure 2). Also as in earlier years, a large percentage of the 1987 catch (76 percent by number) was comprised of fish less than age 9, the age at 95 percent maturity (Figure 3). As of 1987, peak catches have occurred for all year classes through 1978.

The OY for 1988 was set at 12,100 mt which was the estimate of ABC (Hightower and Lenarz 1987). Vessels have been restricted to 30,000 lb trip limits with no more than one trip per week. Preliminary estimates are that 1988 landings will be about 12,100 mt, and that it will be necessary to place the fishery on more restrictive trip limits in October or November to avoid exceeding OY.

ASSESSMENT METHODOLOGY

The approaches and assumptions used in the 1987 assessment were similar to those used in this assessment. Some changes were made in response to the SSC review of the 1987 assessment and reconsideration of the assumptions (See Appendix I for a review of the 1987 assessment by a member of the SSC.)

Population fecundity is used to estimate spawning potential instead of the biomass of mature fish. The population fecundity of an age group is the portion of mature females times the fecundity times the number of fish. The total population fecundity is the sum of age specific population fecundity over all age groups. We believe that population fecundity is likely to be more closely related to spawning potential of the stock than is biomass of mature fish. Population fecundity gives slightly more weight to older fish than biomass of mature fish. Relationship(s) between age and viability of released larvae are not known. Estimates of age specific average weight, portion of mature females and fecundity are shown in Table 3.

As before, all analyses were done using two levels for the instantaneous rate of natural mortality (M). These assumed rates were based on a catch curve analysis, and were thought to be approximate lower (0.15) and upper (0.20) bounds for M.

Since the 1985 assessment (Lenarz and Hightower, 1985), cohort analysis (Murphy, 1965) has been done by linking adjacent cohorts, under the assumption that F was equal for 9- and 10-year-old fish in a given year. For the 1970 through 1978 cohorts, we used the same starting value used in the 1985, 1986 and 1987 assessments (F_9(1984)). This starting value was originally selected (1985 assessment) by varying F_9(1984) until we produced a decline in average F of about 50 percent from 1982 to 1983.

Table 2. Estimates of the number of widow rockfish landed by year class (millions) from 1980 through 1987.

Year Class	1980	1981	1982	1983	1984	1985	1986	1987	Total
65+	1.856	1.409	2.945	1.357	0.810	0.473	0.493	0.329	9.672
66	0.567	0.579	0.826	0.191	0.116	0.062	0.062	0.046	2.449
67	0.855	0.853	1.093	0.279	0.144	0.073	0.061	0.084	3.442
68	1.675	1.356	1.403	0.365	0.237	0.093	0.090	0.116	5.335
69	2.237	2.194	1.647	0.364	0.338	0.067	0.085	0.107	7.039
70	5.590	5.633	3.849	0.690	0.744	0.400	0.338	0.214	17.458
71	3.580	5.130	1.960	0.391	0.392	0.173	0.084	0.138	11.848
72	0.904	1.483	0.727	0.222	0.102	0.047	0.036	0.044	3.565
73	0.460	0.885	0.933	0.272	0.170	0.037	0.049	0.048	2.854
74	0.454	1.626	1.513	0.322	0.189	0.148	0.166	0.144	4.562
75	0.300	2.219	1.924	0.620	0.471	0.268	0.241	0.211	6.254
76	0.001	0.690	1.512	0.705	0.576	0.292	0.156	0.112	4.044
77	0.000	0.899	2.599	2.484	3.046	1.801	1.267	0.907	13.003
78		0.000	0.510	2.272	3.338	3.786	2.210	1.072	13.118
79			0.015	0.334	0.516	1.402	1.580	2.126	5.973
80				0.015	0.026	0.920	2.610	5.633	9.204
81					0.002	0.053	0.623	3.102	3.780
82						0.001	0.030	0.474	0.505
83							0.000	0.066	0.066
84								0.006	0.006

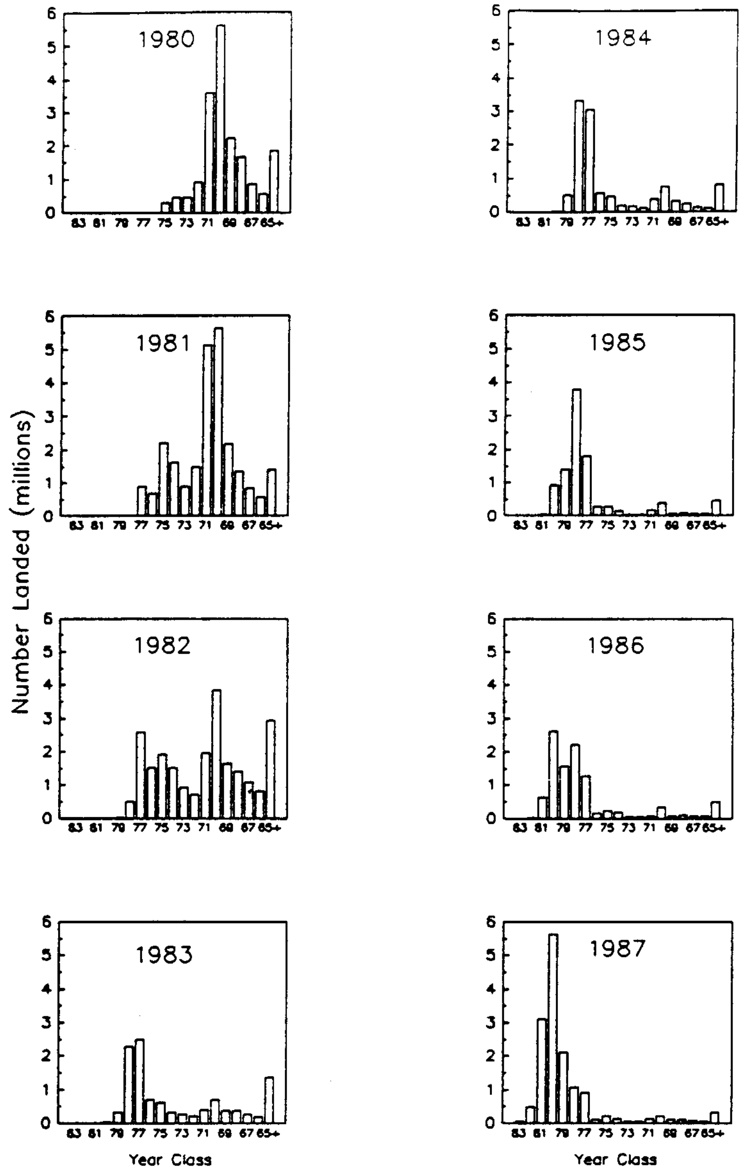


Figure 2. Total numbers of widow rockfish from each cohort in Washington, Oregon, and California landings from 1980-1987.

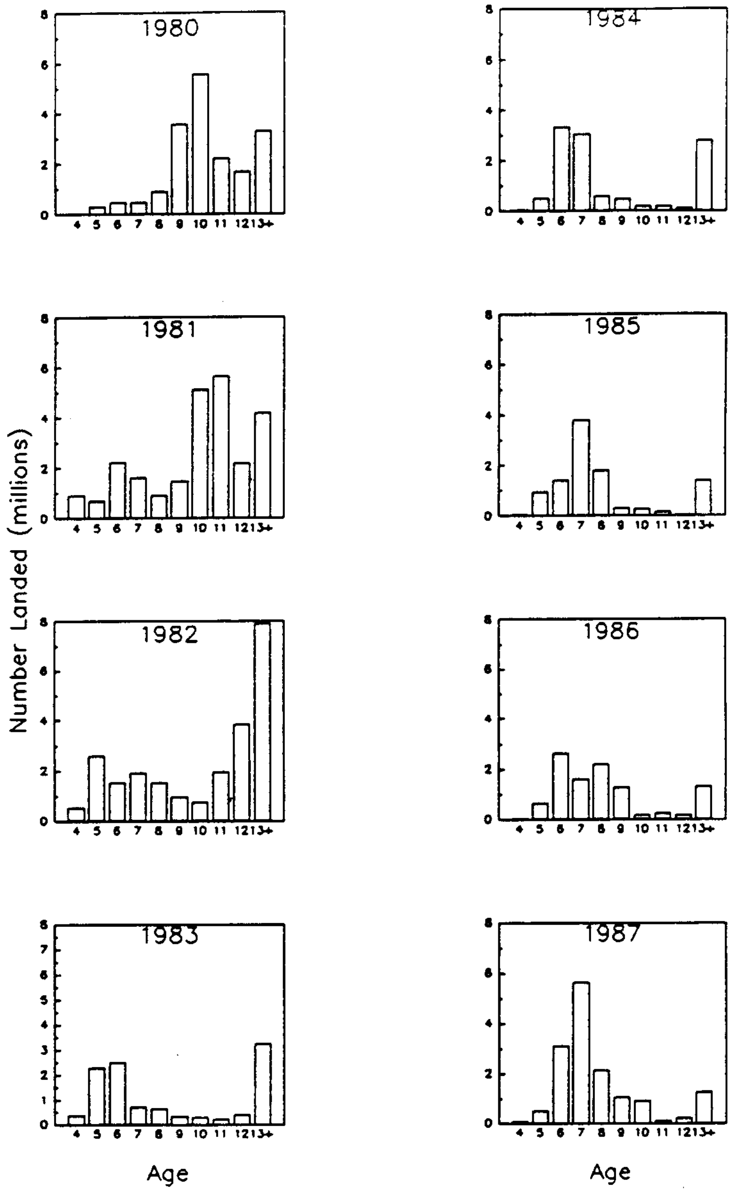


Figure 3. Total numbers of widow rockfish from each age group in Washington, Oregon, and California landings from 1980-1987.

Table 3. Estimates of weight, portion mature and fecundity by age.
Data sources:
Weight at Age: Barss and Wyllie Echeverria (1987) and Lenarz (1987)
Portion Mature at age (Oregon Females): Barss and Wyllie Echeverria (1987)
Fecundity at Age: Boehlert et al (1982)

Age(years)	Weight (kg)	Portion Mature	Fecundity (Million Oocytes)
5	0.5	0.15	0.006
6	0.6	0.17	0.017
7	0.7	0.70	0.114
8	0.9	0.79	0.224
9	1.0	0.95	0.327
10	1.1	0.97	0.392
11	1.2	0.97	0.451
12	1.3	1.00	0.526
13+	1.6	1.00	0.707

Regulations of the fishery should have resulted in significant drops in fishing mortality, and a 50 percent drop seems reasonable because the fishery essentially was closed in September 1983 and there were severe trip limits during the earlier part of the year. When $F_9(1984)$ was set to 0.3 to determine if higher values were reasonable, estimates of F for older fish became too high. Starting F values for cohorts younger than 1978 were obtained by assuming that the ratio of F for ages less than 9 to age 9 was the same in 1987 as in earlier years. For example, the estimate of $F_8(1987)$ was obtained by multiplying $F_9(1987)$ by(Ave. F_8)/(Ave. F_9), where (Ave. F_8) and (Ave.F_9) were averages for years 1980-1986. Starting F values for cohorts older than 1970 were obtained by using the same ratio method, except that estimates of mean F were obtained for the years 1981-1987. As in earlier assessments, the microcomputer program GENCOH was used for the cohort analysis.

Catch-at-age analysis was done using CAGEAN, a microcomputer program developed for use with Pacific halibut (Deriso et al. 1985). The approach differs from cohort analysis in several ways. The most important difference is that fishing mortality is assumed to be separable into a product of an age-specific selectivity coefficient s_a and a full-recruitment fishing mortality rate F(k):

$$F_a(k) = s_a F(k)$$

where $F_a(k)$ is the fishing mortality rate for age-a fish in year k and $s_a = 1$ for at least one age. The separability assumption is important because it reduces the number of unknown fishing mortality parameters from 72 (8 years X 9 ages) to 16 (8 fishing mortality rates plus 8 selectivity estimates (with s_{10} assumed to be 1)). Almost as important is that cohort analysis assumes that catches are known without error while catch-at-age analysis allows errors.

Several studies have noted that catch-at-age data are insufficient to estimate stock abundance, reliably, because estimates of F and N have a large negative correlation (see Deriso et al. 1985). To stabilize parameter estimates, one of two types of auxiliary information can be used: additional information about model parameters or additional assumptions about stock dynamics (Deriso et al. 1985). For our catch-at-age analysis, we used the same assumptions about relative changes in F from year to year that were used to determine appropriate starting F's for cohort analysis. These assumptions were incorporated into the catch-at-age analysis by using average F's from cohort analysis as a relative measure of fishing effort (the annual averages shown in Table 4). In the previous assessment no weight was used to estimate average F. This year we decided that it would appropriate to weight F at age by catch at age in numbers, because the parameters of CAGEAN are estimated by minimizing deviations from observed catch at age. A model parameter (lambda) adjusts the amount of influence given to the "effort" data. If lambda=0, no relationship between F and effort is assumed. If lambda=1000, the relationship between F and effort is essentially exact (Deriso et al. 1985). Results from catch-at-age analyses of Pacific halibut data were similar for lambda values of 0.1 to 1.0 (Deriso et al. 1985), and production runs are done using the value 0.5 (P. R. Neal, unpublished documentation of CAGEAN program). Because we wished to

Table 4. Estimates of F for widow rockfish by age and year obtained by cohort analysis. Annual averages weighted by catch in number.

M = 0.15

Age	1980	1981	1982	1983	1984	1985	1986	1987	Ave.
5	0.030	0.102	0.096	0.082	0.018	0.013	0.012	0.024	0.047
6	0.073	0.297	0.318	0.119	0.159	0.058	0.042	0.073	0.142
7	0.108	0.379	0.428	0.227	0.197	0.257	0.081	0.115	0.224
8	0.201	0.295	0.686	0.224	0.277	0.162	0.222	0.141	0.276
9	0.227	0.551	0.542	0.281	0.250	0.208	0.156	0.151	0.296
10	0.227	0.551	0.542	0.281	0.250	0.208	0.156	0.151	0.296
11	0.217	0.355	0.396	0.296	0.268	0.298	0.277	0.152	0.282
12	0.226	0.323	0.412	0.120	0.203	0.082	0.602	0.393	0.295
13+	0.226	0.323	0.412	0.120	0.203	0.082	0.602	0.393	0.295
Ave	0.214	0.387	0.397	0.138	0.187	0.163	0.188	0.140	

M = 0.20

Age	1980	1981	1982	1983	1984	1985	1986	1987	Ave
5	0.026	0.091	0.088	0.078	0.018	0.014	0.014	0.028	0.045
6	0.066	0.270	0.294	0.113	0.158	0.062	0.048	0.087	0.137
7	0.096	0.350	0.398	0.217	0.198	0.270	0.092	0.140	0.220
8	0.182	0.270	0.643	0.214	0.277	0.172	0.250	0.173	0.273
9	0.206	0.509	0.506	0.269	0.250	0.220	0.176	0.184	0.290
10	0.206	0.509	0.506	0.269	0.250	0.220	0.176	0.184	0.290
11	0.201	0.330	0.371	0.283	0.268	0.316	0.315	0.185	0.284
12	0.226	0.309	0.395	0.117	0.203	0.086	0.708	0.504	0.319
13+	0.226	0.309	0.395	0.117	0.203	0.086	0.708	0.504	0.319
Ave	0.201	0.360	0.376	0.132	0.187	0.172	0.217	0.172	

Table 5. Estimates of F for widow rockfish by age and year, obtained by catch-at-age analysis with lambda = 0.01.

M = 0.15

Age	1980	1981	1982	1983	1984	1985	1986	1987	Ave
5	0.035	0.084	0.112	0.056	0.054	0.043	0.049	0.061	0.062
6	0.108	0.255	0.342	0.171	0.166	0.131	0.149	0.187	0.189
7	0.168	0.395	0.531	0.265	0.258	0.204	0.230	0.291	0.293
8	0.193	0.457	0.613	0.306	0.297	0.236	0.266	0.336	0.338
9	0.196	0.463	0.622	0.311	0.302	0.239	0.270	0.340	0.343
10	0.210	0.496	0.667	0.333	0.323	0.256	0.289	0.365	0.367
11	0.210	0.495	0.666	0.332	0.323	0.256	0.289	0.364	0.367
12	0.174	0.412	0.553	0.276	0.268	0.212	0.240	0.303	0.305
13+	0.055	0.129	0.173	0.086	0.084	0.067	0.075	0.095	0.095

M = 0.20

Age	1980	1981	1982	1983	1984	1985	1986	1987	Ave
5	0.029	0.069	0.091	0.045	0.045	0.037	0.043	0.057	0.052
6	0.090	0.213	0.280	0.139	0.138	0.113	0.133	0.175	0.160
7	0.140	0.332	0.435	0.216	0.214	0.176	0.207	0.271	0.249
8	0.159	0.378	0.496	0.246	0.244	0.200	0.235	0.309	0.283
9	0.157	0.373	0.489	0.243	0.241	0.198	0.232	0.305	0.280
10	0.160	0.381	0.500	0.248	0.246	0.202	0.238	0.312	0.286
11	0.150	0.357	0.469	0.233	0.231	0.190	0.223	0.292	0.268
12	0.118	0.281	0.369	0.183	0.182	0.149	0.175	0.230	0.211
13+	0.052	0.123	0.161	0.080	0.080	0.065	0.077	0.101	0.092

obtain estimates of F that were somewhat independent of the cohort analysis and the estimate of effort is dependent on the cohort analysis, we decided to set lambda at a lower value than in the 1987 assessment. Experimentation with lower values of lambda revealed that results were not very sensitive to reductions in lambda below 0.01, but that there were large changes when lambda is reduced from 0.5 to 0.1 and sometimes when lambda is reduced from 0.1 to 0.01. The results were also consistent with a significant decrease between 1982 and 1983. Fish aged 13 and older were included as a pooled age group.

We used the same age-structured simulation model used in earlier assessments and made the following assumptions regarding recruitment into the fishery:

1) For the average recruitment case, we assumed that the 1983 and subsequent year classes are equal in size to the average of the 1968 to 1982 cohorts.

2) For the survey recruitment case, recruitment for year classes after 1983 were based on a juvenile rockfish survey off the Central California coast. A mid water trawl survey has been conducted during May-June since 1983. Sample design was changed between 1983 and 1986, but it is thought that the changes were not sufficient to obscure major differences in juvenile rockfish abundance. Annual averages were standardized by dividing by the 1983-1987 average. The standardized annual averages were then multiplied by the average recruitment from the cohort and catch-at-age analyses to produce estimates of abundance for the 1983-1987 year classes. This assumes that densities of juvenile rockfish off Central California are proportional to year class strength. Also it is assumed that the 1983-1987 average year class strength is equal to the 1968-1982 average. The 1988 year class was assumed to be equal to the long term average.

3) For the density-dependent case, recruitment was assumed to be determined by a Beverton-Holt relationship. The parameters were obtained by assuming that recruitment would be reduced by 10 percent if spawning stock was reduced to 50 percent of the unfished level ($R_{0.5}/R_{1.0}$=0.90). Spawning stock estimates were obtained from the stock reconstruction analyses.

Number-at-age vectors at the start of 1989 were obtained as follows. The two stock reconstruction techniques provided estimates of the number-at-age vector at the beginning of 1987. Estimates of F-at-age in 1987 were used to project the number of fish ages 6 through 13+ present at the start of 1988. Recruitment in 1988 was obtained using the above assumptions about the strength of the 1983 year class. We then solved iteratively for the fishing mortality rates needed to obtain a 1988 harvest of 12,100 mt, using a selectivity curve obtained from the mean F-at-age vector (cohort analysis) or the least squares fit (catch-at-age analysis). Recruitment in 1989 was obtained using the above assumptions about the strength of the 1984 year class.

We used two approaches to develop harvest recommendations for 1989. The first approach was to maintain F at the level estimated to produce MSY. The second approach was to maintain yield at a constant level.

RESULTS

The results of cohort and catch-at-analyses differed considerably. Estimates of age-specific F's for 1980-1986 from catch-at-age analysis were similar to the 1987 assessment, except that estimates of F for 13+ fish were lower. Estimates of age-specific F's from the cohort analysis tended to be lower for the 1979-81 year classes than the 1987 assessment. Results of the cohort analysis indicated that F increased for some ages between 1986 and 1987 and decreased for others, Table 4. The weighted average F decreased 26 percent between 1986 and 1987 when M=0.15 and 21% when M=0.20. Interpretation of changes in weighted average F is examined in the discussion section. Results of the catch-at-age analysis indicate that F-at-age increased 26% between 1986 and 1987 when M=0.15 and 21% when M=0.20. Estimates of abundance of recent year classes reflect the differences in F, Table 6 and 7. Catch-at-age analysis estimates of abundance of fish less than 9 years in 1987 are much less than estimates from cohort analysis. The different estimates of young fish are sufficient to cause major differences in estimates of biomass, Table 8. Biomass in 1987 was estimated to be almost as high as 1980 by cohort analysis and only 35-40% of the 1980 biomass by catch-at-age analysis.

Both methods indicate that the 1977-1981 year classes are strong compared to the 1972-1976 year classes, Figure 4. The cohort analysis indicate that the 1980 year class is stronger or almost as strong as the 1970 year class and much stronger than the 1978 year class. The catch-at-age analysis indicates that the 1980 year class is less than half the size of the 1970 year class and about the same size as the 1978 year class. Based on cohort analysis, average recruitment was 29.6 and 34.2 million fish for M = 0.15 and M = 0.20 respectively. Estimates of average recruitment from catch-at-age analysis were 20.8 and 31.1 million fish for M = 0.15 and M = 0.20 respectively.

Estimated selectivity patterns from cohort and catch-at-age analysis were similar for fish ages 5-11 (Figure 5). The pattern derived from catch-at-age analysis indicates sharply lower vulnerability for fish ages 12 and older. A similar result was obtained from cohort analysis in the 1986 assessment, but not the 1987 assessment. The current cohort analysis predicts only slightly reduced vulnerability for older fish, due apparently to the relatively large estimated landings of 11- and 12-year-old fish and 12-year-old fish in 1987 (Table 2). It should be noted that the cohort analysis assumes that F is constant for fish older than

Table 6. Estimates of population size (millions of fish) of widow rockfish by age and year, obtained by cohort analysis.

M = 0.15

Age	1980	1981	1982	1983	1984	1985	1986	1987
5	11.1	7.7	30.6	30.8	31.8	79.5	55.8	21.5
6	6.9	9.3	5.9	23.9	24.4	26.9	67.6	47.4
7	4.8	5.5	5.9	3.7	18.3	17.9	21.9	55.8
8	5.3	3.7	3.3	3.3	2.6	12.9	11.9	17.4
9	18.9	3.7	2.4	1.4	2.3	1.7	9.4	8.2
10	29.5	13.0	1.9	1.2	0.9	1.5	1.2	7.0
11	12.3	20.2	6.4	0.9	0.8	0.6	1.1	0.9
12	8.8	8.5	12.2	3.7	0.6	0.5	0.4	0.7
13+	17.4	16.3	25.1	30.9	16.3	19.0	3.1	4.2

M = 0.20

Age	1980	1981	1982	1983	1984	1985	1986	1987
5	12.9	8.7	34.0	33.2	31.9	75.3	50.8	18.9
6	7.9	10.3	6.5	25.5	25.1	25.6	60.9	41.0
7	5.5	6.0	6.4	4.0	18.7	17.6	19.7	47.5
8	6.0	4.1	3.5	3.5	2.6	12.5	11.0	14.7
9	21.1	4.1	2.6	1.5	2.3	1.6	8.6	7.0
10	33.0	14.1	2.0	1.3	0.9	1.5	1.1	5.9
11	13.5	22.0	6.9	1.0	0.8	0.6	1.0	0.7
12	9.1	9.0	12.9	3.9	0.6	0.5	0.4	0.6
13+	17.8	17.3	26.6	32.4	16.6	18.6	2.8	3.5

Table 7. Estimates of population size (millions of fish) of widow rockfish by age and year, obtained by catch-at-age analysis with lambda = 0.01.

M = 0.15

Age	1980	1981	1982	1983	1984	1985	1986	1987
5	11.4	6.5	23.3	27.9	14.1	28.3	18.3	8.6
6	7.4	9.5	5.2	18.0	22.7	11.5	23.3	15.0
7	4.2	5.7	6.3	3.2	13.0	16.6	8.7	17.3
8	5.0	3.1	3.3	3.2	2.1	8.7	11.6	5.9
9	15.1	3.5	1.7	1.5	2.0	1.3	5.9	7.7
10	28.3	10.7	1.9	0.8	1.0	1.3	0.9	3.9
11	11.9	19.7	5.6	0.8	0.5	0.6	0.9	0.6
12	12.3	8.3	10.3	2.5	0.5	0.3	0.4	0.6
13+	51.4	50.8	43.2	36.4	30.3	24.4	19.8	16.1

M = 0.20

Age	1980	1981	1982	1983	1984	1985	1986	1987
5	14.3	8.2	29.4	35.0	17.3	33.6	21.1	9.5
6	9.0	11.4	6.2	22.0	27.4	13.6	26.5	16.5
7	5.1	6.7	7.5	3.9	15.7	19.5	9.9	19.0
8	6.0	3.6	3.9	4.0	2.5	10.4	13.4	6.6
9	18.7	4.2	2.0	2.0	2.5	1.6	6.9	8.7
10	36.7	13.1	2.4	1.0	1.3	1.6	1.1	4.5
11	16.5	25.6	7.3	1.2	0.7	0.8	1.1	0.7
12	17.7	11.6	14.7	3.8	0.8	0.4	0.5	0.7
13+	55.8	56.2	47.9	41.7	34.0	26.3	20.4	15.9

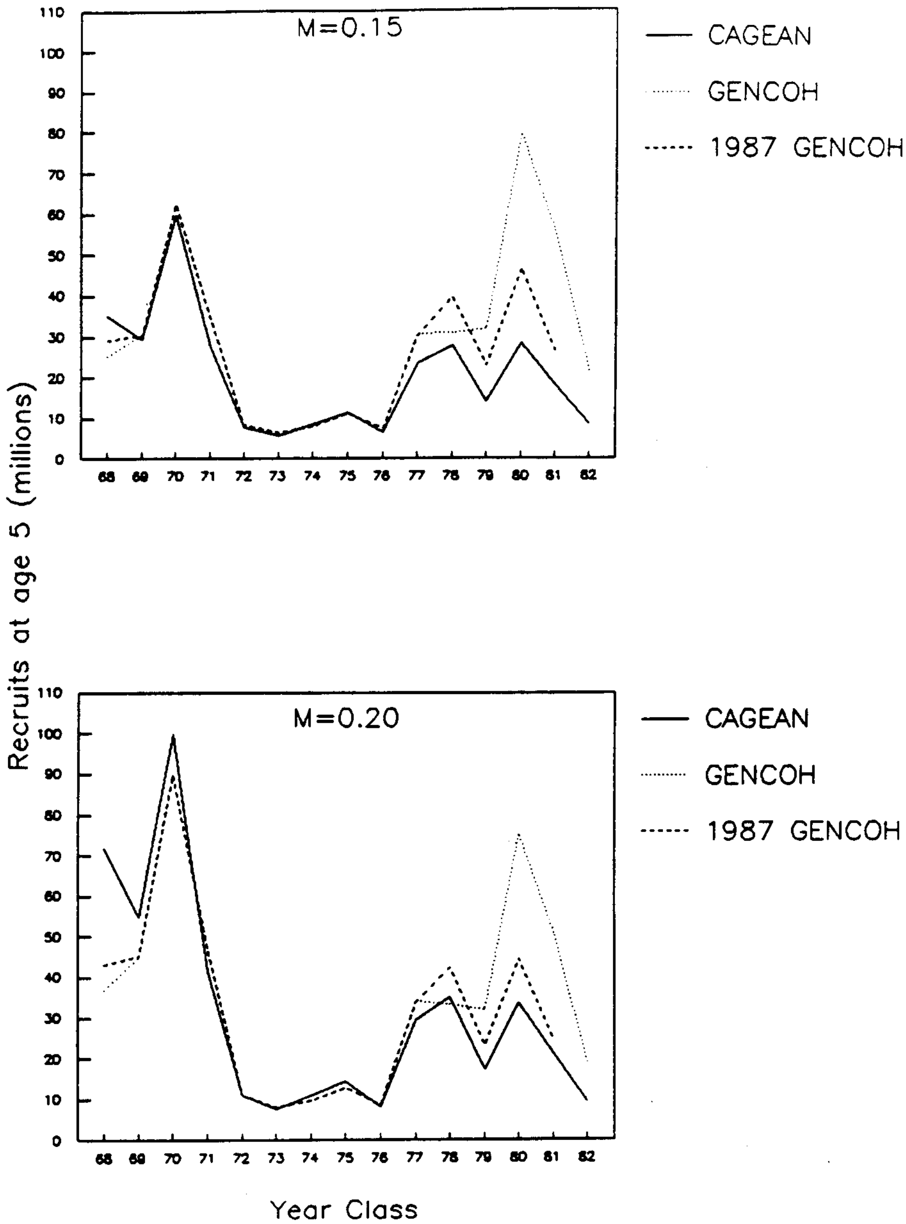


Figure 4. Estimates of widow rockfish recruitment at age 5 obtained from cohort (GENCOH) and catch-at-age analysis (CAGEAN). Estimates from the 1987 assessment (1987 GENCOH) are included for comparison.

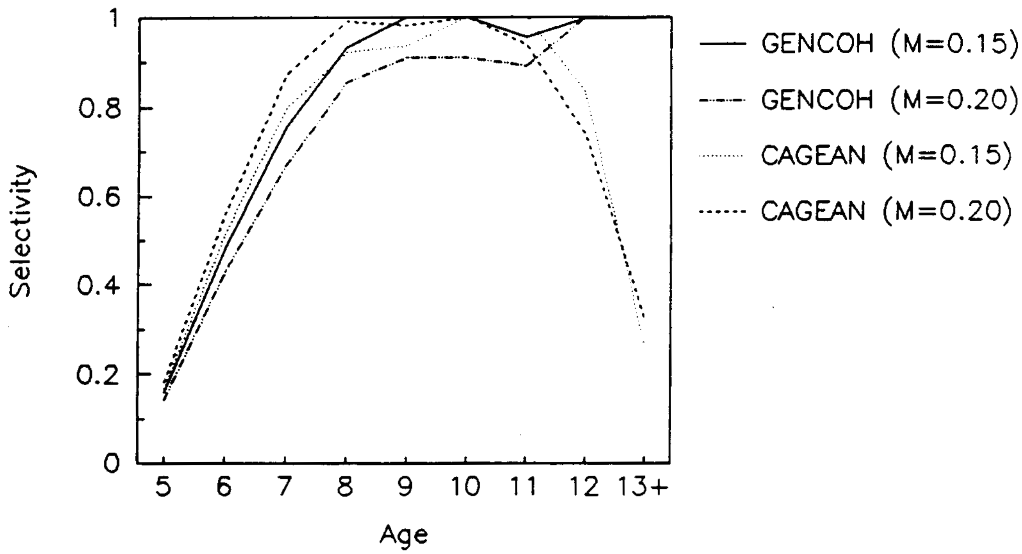


Figure 5. **Estimates of age-specific selectivity for widow rockfish obtained by cohort (GENCOH) and catch-at-age analysis (CAGEAN) at two levels of natural mortality.**

12 years. The 1986 catch of age-12 fish had a particularly great impact on the results because the starting value for the entire analysis is for the same cohort. Because $F_{10}(1984)$ (and therefore $N_{10}(1984)$) is fixed, a large catch from that cohort two years later is attributed to a high rate of fishing mortality. The unusually high $F_{12}(1986)$ and $F_{12}(1987)$ produce a low estimates of $N_{13+}(1986)$ and $N_{13+}(1987)$ because N_{13+} is estimated as C_{13+}/u_{12} under the assumption that the exploitation rate is equal for fish ages 12 and older.

Estimates from catch-at-age analysis were less effected by the 1986 catch of older fish because of the structure imposed by the constant selectivity assumption. In addition in catch-at-age analysis the catch of age 13+ fish must be partially supported by the survivors of exploitation of 12-year-old fish. The disadvantage is that if a change in fishing patterns occurred in 1986 and 1987, it would not be accurately represented by the catch-at-age analysis. The model can be fitted to catch data from two or more periods where selectivity patterns differed. That assumption was not used here, however, because the high catch of older fish in 1986 may be simply a random event or due to sampling error or errors in aging. Either possibility would cause cohort analysis to underestimate the number of age-13+ fish and stock biomass. An additional effect of the high $F_{12}(1986)$ in the cohort analysis is that estimates of $F_{12}(1980)$ are substantially higher than estimates in the 1986 assessment. This change results in a lower estimate of $N_{12}(1980)$, which is used to estimate the size of the 1968 year class (Figure 4).

While estimates of biomass from the cohort analysis indicate little trend, estimates from the catch-at-age analysis indicate that biomass in 1987 is less than 40 percent of 1980 levels, Figure 6. The cohort analysis results indicate that the biomass of fish less than 13 years old increased since 1980. Results from the catch-at-age analysis indicate that biomass of young fish decreased by more than 50 percent.

Equilibrium yield curves from cohort and catch-at-age analysis were similar to each other and to curves obtained in the 1987 assessment. It appears that when $M = 0.15$ an F of 0.25 for fully recruited fish (age 9) provides about the maximum yield if a stock-recruitment relationship exists and does not extract a large penalty if no relationship exists (Figures 7-8). When $M = 0.20$ the appropriate value of F is 0.30. Assuming that MSY would be obtained at that level of effort, estimates of MSY from cohort analysis results range from 8,200 to 13,300 mt, with an average of 10,700 mt. Biomass at MSY ranges from 54,300 mt to 87,800 mt with an average of 70,500 mt. Using results of catch-at-age analysis, estimates of MSY ranged from 5,900 to 11,400 mt, with an average of 8,400 mt. Biomass at MSY ranged from 45,400 mt to 72,500 mt with an average of 57,900 mt. The average of all estimates of MSY was 9,500 mt. The stock appears to be at or above the MSY level, Table 8.

Equilibrium yield curves provide an indication of the average productivity of a stock; however, they fail to account for the short-term effects of variations in year class strength. We used a constant

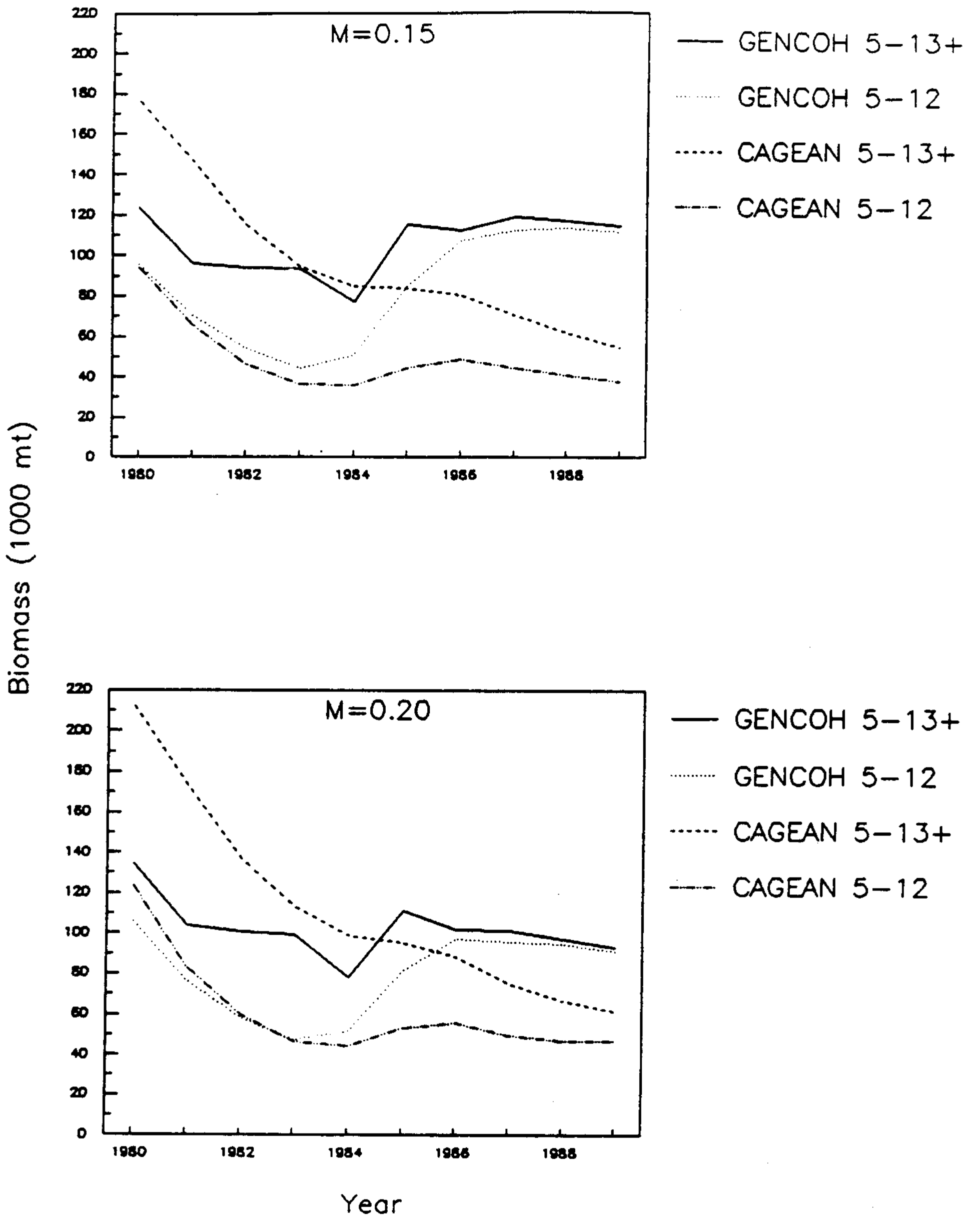


Figure 6. Estimates of widow rockfish biomasss obtained by cohort (GENCOH) and catch-at-age analysis (CAGEAN) at two levels of natural mortality.

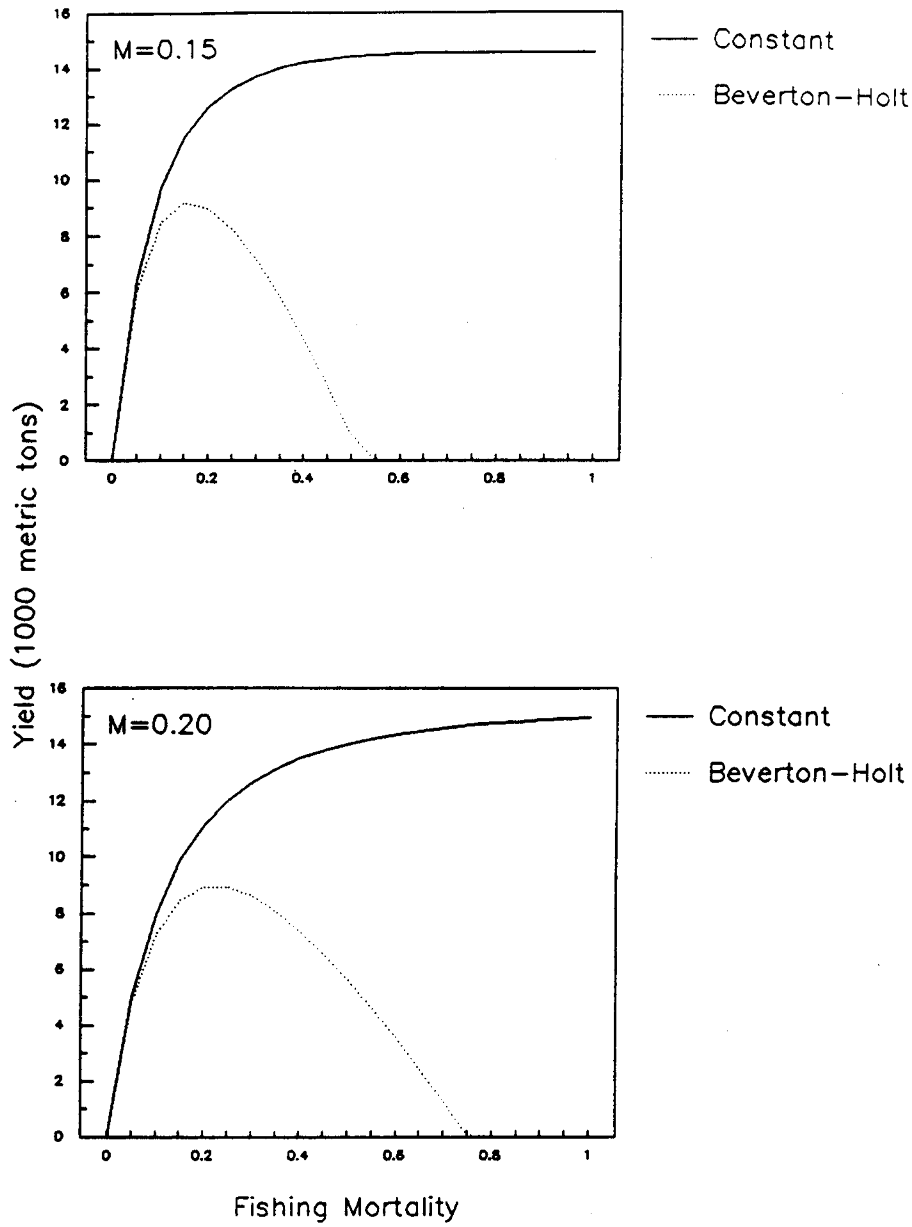


Figure 7. **Estimates of equilibrium yield for widow rockfish based on results from cohort analysis.**

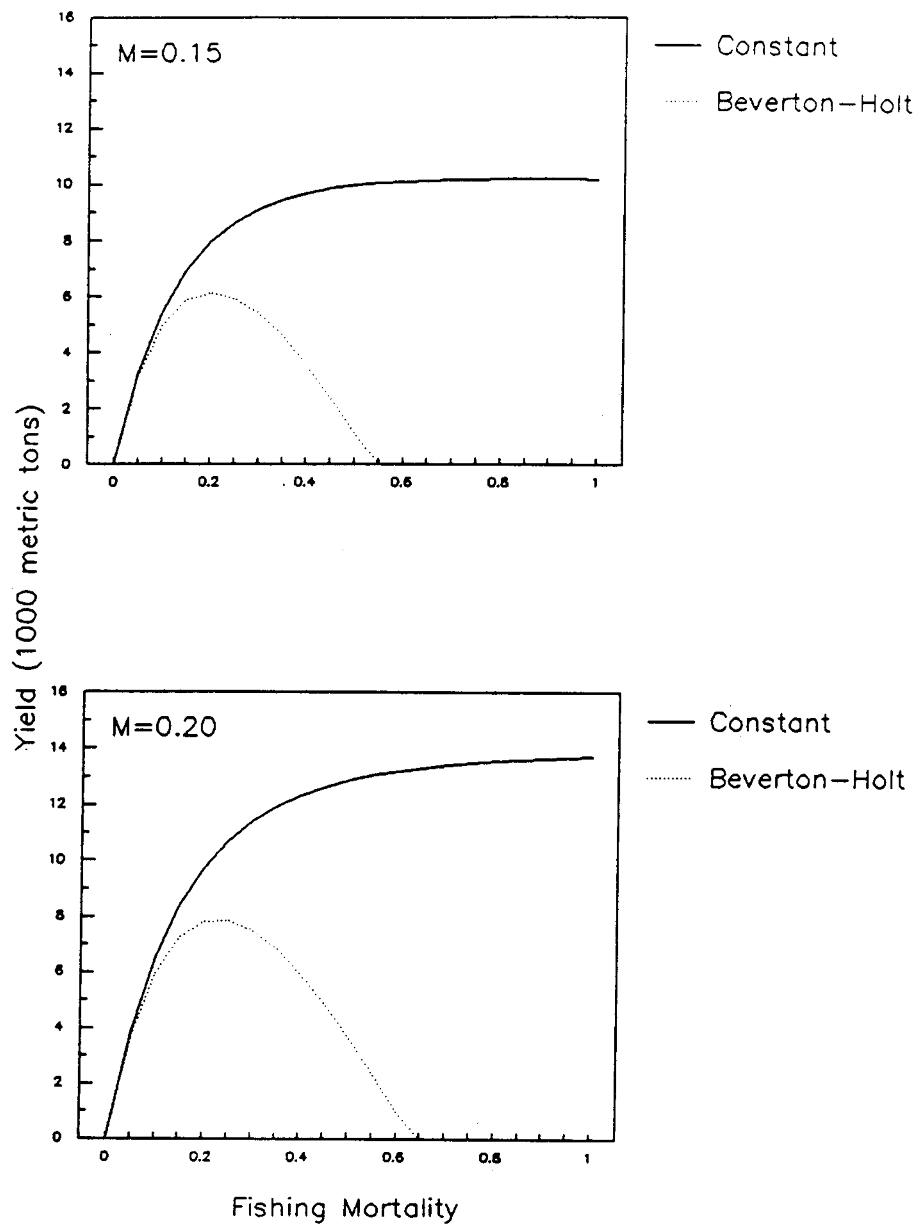


Figure 8. Estimates of equilibrium yield for widow rockfish based on results from catch-at-age analysis.

Table 8. Estimates from cohort (GENCOH) and catch-at-age (CAGEAN) analysis of widow rockfish biomass (older than 4) and population fecundity from 1980 through 1989. Estimates for 1988 and 1989 from the current assessment (88 GENCOH and 88 CAGEAN) are averages for three recruitment cases, using projected number-at-age vectors. Similar bimass projections were made for 1987 and 1988 in the 1987 assessment (87 GENCOH).

Biomass (1000 mt)

Year	M = 0.15			M = 0.20		
	87 GENCOH	88 GENCOH	88 CAGEAN	87 GENCOH	88 GENCOH	88 CAGEAN
1980	129.2	123.2	176.3	141.2	134.4	212.7
1981	96.4	96.0	146.7	104.1	103.8	173.2
1982	93.9	94.1	115.2	100.8	100.9	136.3
1983	97.6	93.4	94.7	103.3	98.9	113.2
1984	76.7	76.8	84.5	77.9	78.0	98.5
1985	98.4	115.1	83.4	95.3	111.0	94.9
1986	80.3	112.0	79.8	73.0	101.6	88.2
1987	80.8	118.5	70.0	72.5	101.2	74.7
1988	74.0	116.7	61.4	65.9	97.3	66.4
1989		114.3	54.0		92.9	61.5

Population Fecundity (billion oocytes)

Year	M = 0.15		M = 0.20	
	GENCOH	CAGEAN	GENCOH	CAGEAN
1980	421.4	660.0	454.8	788.7
1981	330.7	560.5	355.8	657.0
1982	302.7	414.7	321.7	485.0
1983	268.8	297.7	282.8	349.9
1984	165.8	253.8	168.5	290.2
1985	209.8	228.2	204.9	253.0
1986	130.9	209.9	119.3	225.8
1987	203.6	196.2	172.3	205.2
1988	253.6	173.7	201.5	176.4
1989	287.2	143.5	211.5	141.9

effort policy with $F_9 = 0.25$ when $M = 0.15$ and $F_9 = 0.30$ when $M = 0.20$ to forecast yields from 1989 to 1993, starting from the estimated number-at-age vector for 1988 (Table 9). The average yield would be 7,500 to 18,100 mt in 1989 and 7,800 to 16,300 mt in 1990, with an average of 17,200 mt from cohort analysis and 7,600 from catch-at-age analysis. The estimate from cohort analysis is 42% higher than the 1987 ABC and OY, while the estimate from catch-at-age analysis is 38% lower. The cohort analysis predicts a reduction in yield through 1993. The catch-at-age analysis predicts increases in yield through 1993.

Another approach for evaluating the short-term effects of variations in year class strength is to determine the sequence of fishing mortality rates needed to maintain a constant harvest. Using results from the analyses, we determined the levels of fishing mortality needed to produce constant yields of 9,000 to 15,000 mt (Table 10). Under the results of the cohort analysis, yields of 12,000 to 13,000 mt (the average yield under a constant effort policy) could be taken in 1988 and 1989, with slight increases in F after 1989, and F would be about 0.2 which is close to the F that would produce MSY under the density dependent recruitment assumption, Figure 7. Under the catch at age results F would be about 0.5, tend to increase and would eventually reduce equilibrium yields to a small fraction of MSY under the dependent recruitment assumption, Figure 8. If yields are held at the MSY level (9,500 mt), results of the cohort analysis indicated that F would be about 0.15, tend to decrease and be close to the MSY level under the density dependent recruitment assumption. Under the results of catch-at-age analysis F would be about 0.4 and tend to decrease unless the density dependent recruitment assumption is true and $M=0.15$.

DISCUSSION

The conflicting results of cohort and catch-at-age analysis verify that catch-at-age data alone do not provide sufficient data to estimate fishing mortality and population size. This is particularly true for recent year classes. Two constraints were placed on the cohort analysis. Fishing mortality of age 9 and 10 year old fish was assumed to be equal. Results of the catch-at-age analysis indicated that the assumption is reasonable. It was also assumed that fishing mortality dropped substantially between 1982 and 1983, because of regulations implemented in 1983. The choice of $F_9(1984) = 0.25$ was originally made in the 1985 assessment because it resulted in about a 50 percent drop in the sum of F over age from 1982 to 1983. Estimates of F for younger ages in 1982 and 1983 have changed since the 1985 assessment as additional data became available. It now appears that F dropped more than 50 percent between 1982 and 1983; although not for every age group. When $F_9(1984)$ was set to 0.30 unrealistically high values of F were estimated for older aged fish.

Average F for a year may be estimated in a variety of ways. We believe that average F from the cohort analysis should be weighted by catch at age (in numbers) for the purpose of estimating fishing effort for CAGEAN because of the estimation procedure. The weighted average F can change

Table 9. Estimated yield (thousands of metric tons) when F for fully recruited fish is 0.25 for M = 0.15 and 0.30 for M = 0.20 and three assumptions about recruitment.

Cohort Analysis

	Recruitment						
	Average		Survey		Beverton-Holt		Average
Year	M=0.15	M=0.20	M=0.15	M=0.20	M=0.15	M=0.20	
1989	20.7	17.1	18.8	14.9	20.3	16.8	18.1
1990	18.9	15.5	17.0	13.5	18.0	14.9	16.3
1991	17.3	14.6	16.4	13.8	15.8	13.5	15.2
1992	16.3	14.1	16.1	14.2	14.3	12.5	14.6
1993	15.7	13.7	16.7	14.9	13.3	11.8	14.4
Average	17.8	15.0	17.0	14.3	16.3	13.9	15.7

Average for 1988 and 1989 (estimate of ABC): 17.2

Catch-at-Age Analysis

	Recruitment						
	Average		Survey		Beverton-Holt		Average
Year	M=0.15	M=0.20	M=0.15	M=0.20	M=0.15	M=0.20	
1989	6.9	9.5	5.5	7.0	6.7	9.5	7.5
1990	7.1	9.7	5.8	7.7	6.8	9.8	7.8
1991	7.5	10.3	7.1	10.1	7.0	10.5	8.8
1992	7.9	10.8	8.0	11.4	7.2	11.0	9.4
1993	8.1	11.1	8.7	12.3	7.2	11.2	9.8
Average	7.5	10.3	7.0	9.7	7.0	10.4	8.7

Average for 1988 and 1989 (estimate of ABC): 7.6

Table 10. Estimated F for fully recruited fish needed to maintain harvests of 9,000 to 15,000 mt for two values of M and three assumptions about recruitment.

		Cohort Analysis Recruitment						
Target		Average		Survey		Beverton-Holt		
harvest	Year	M=0.15	M=0.20	M=0.15	M=0.20	M=0.15	M=0.20	Average
9,000	1989	0.10	0.15	0.11	0.17	0.10	0.15	0.13
	1990	0.10	0.15	0.11	0.17	0.10	0.15	0.13
	1991	0.10	0.15	0.11	0.16	0.11	0.16	0.13
	1992	0.09	0.14	0.10	0.15	0.11	0.16	0.12
	1993	0.09	0.14	0.09	0.13	0.11	0.16	0.12
10,000	1989	0.11	0.17	0.13	0.19	0.12	0.17	0.15
	1990	0.11	0.17	0.13	0.20	0.12	0.18	0.15
	1991	0.11	0.17	0.12	0.19	0.12	0.18	0.15
	1992	0.11	0.16	0.12	0.17	0.12	0.19	0.15
	1993	0.11	0.16	0.11	0.16	0.13	0.19	0.14
11,000	1989	0.13	0.19	0.14	0.21	0.13	0.19	0.16
	1990	0.12	0.19	0.14	0.22	0.13	0.20	0.17
	1991	0.13	0.19	0.14	0.21	0.14	0.21	0.17
	1992	0.12	0.19	0.13	0.20	0.14	0.21	0.16
	1993	0.12	0.18	0.12	0.18	0.15	0.22	0.16
12,000	1989	0.14	0.20	0.15	0.24	0.14	0.21	0.18
	1990	0.14	0.21	0.16	0.25	0.15	0.22	0.19
	1991	0.14	0.21	0.15	0.24	0.15	0.23	0.19
	1992	0.14	0.21	0.15	0.23	0.16	0.25	0.19
	1993	0.14	0.21	0.14	0.21	0.17	0.26	0.19
13,000	1989	0.15	0.22	0.17	0.26	0.15	0.23	0.20
	1990	0.15	0.23	0.17	0.28	0.16	0.24	0.20
	1991	0.16	0.24	0.17	0.27	0.17	0.26	0.21
	1992	0.16	0.24	0.17	0.26	0.18	0.28	0.22
	1993	0.16	0.25	0.16	0.24	0.19	0.30	0.22
14,000	1989	0.16	0.24	0.18	0.28	0.17	0.25	0.21
	1990	0.17	0.26	0.19	0.31	0.18	0.27	0.23
	1991	0.17	0.27	0.19	0.30	0.19	0.30	0.24
	1992	0.18	0.28	0.19	0.30	0.21	0.32	0.25
	1993	0.18	0.28	0.18	0.28	0.22	0.36	0.25
15,000	1989	0.18	0.26	0.19	0.30	0.18	0.26	0.23
	1990	0.18	0.28	0.21	0.34	0.19	0.29	0.25
	1991	0.19	0.30	0.21	0.34	0.21	0.33	0.26
	1992	0.20	0.31	0.21	0.33	0.23	0.37	0.28
	1993	0.20	0.33	0.20	0.32	0.25	0.42	0.29

Table 10. Continued

Target harvest	Year	Catch-at-Age-Analysis Recruitment: Average M=0.15	Average M=0.20	Survey M=0.15	Survey M=0.20	Beverton-Holt M=0.15	Beverton-Holt M=0.20	Average
9,000	1989	0.34	0.28	0.44	0.40	0.34	0.28	0.35
	1990	0.34	0.27	0.46	0.38	0.36	0.27	0.35
	1991	0.34	0.25	0.38	0.28	0.37	0.25	0.31
	1992	0.33	0.23	0.34	0.24	0.38	0.23	0.29
	1993	0.33	0.22	0.31	0.21	0.39	0.22	0.28
10,000	1989	0.38	0.32	0.49	0.46	0.39	0.32	0.39
	1990	0.40	0.31	0.53	0.44	0.42	0.31	0.40
	1991	0.40	0.29	0.45	0.33	0.45	0.29	0.37
	1992	0.40	0.28	0.42	0.28	0.47	0.27	0.35
	1993	0.41	0.27	0.39	0.25	0.51	0.26	0.35
11,000	1989	0.42	0.35	0.55	0.51	0.43	0.36	0.44
	1990	0.46	0.36	0.62	0.50	0.48	0.35	0.46
	1991	0.48	0.34	0.54	0.38	0.53	0.33	0.43
	1992	0.49	0.33	0.51	0.33	0.59	0.32	0.43
	1993	0.51	0.32	0.49	0.30	0.66	0.31	0.43
12,000	1989	0.47	0.39	0.62	0.57	0.48	0.39	0.49
	1990	0.52	0.40	0.71	0.57	0.56	0.40	0.53
	1991	0.56	0.39	0.63	0.43	0.63	0.39	0.50
	1992	0.61	0.39	0.63	0.39	0.73	0.37	0.52
	1993	0.65	0.38	0.62	0.36	0.87	0.37	0.54
13,000	1989	0.52	0.43	0.69	0.63	0.53	0.43	0.54
	1990	0.59	0.45	0.82	0.65	0.63	0.45	0.60
	1991	0.67	0.45	0.74	0.50	0.76	0.44	0.59
	1992	0.75	0.46	0.77	0.46	0.93	0.44	0.64
	1993	0.85	0.46	0.81	0.43	1.20	0.44	0.70
14,000	1989	0.56	0.47	0.76	0.69	0.58	0.47	0.59
	1990	0.67	0.51	0.94	0.73	0.72	0.50	0.68
	1991	0.79	0.52	0.86	0.57	0.91	0.51	0.69
	1992	0.93	0.54	0.96	0.54	1.19	0.52	0.78
	1993	1.13	0.55	1.07	0.51	1.74	0.54	0.92
15,000	1989	0.61	0.51	0.83	0.76	0.63	0.51	0.64
	1990	0.76	0.56	1.07	0.82	0.82	0.56	0.77
	1991	0.93	0.60	1.01	0.64	1.09	0.58	0.81
	1992	1.18	0.63	1.22	0.64	1.58	0.61	0.98
	1993	1.57	0.67	1.49	0.62	2.78	0.65	1.30

between years even if the F at age vector remains constant. The strong 1977 and 1978 year classes recruited in 1982 and 1983. This tended to reduce the weighted average F in 1982 compared to 1981 and 1983 compared to 1982. Also the relative contribution of older fish decreased in 1983. This also tended to decrease the weighted average F in 1983 compared to 1982. When M = 0.15 if the observed 1982 age composition of the catch had occurred in 1981, the 1981 weighted average F would have been 0.318 instead of 0.387 as observed. If the observed 1983 age composition had occurred in 1982, the 1982 weighted average F would have been 0.346 instead of the observed 0.397.

Another measure of the impact of fishing on the stock is the exploitation rate in terms of biomass. This is calculated by dividing the catch in weight by the biomass. Exploitation rate is also estimated to have decreased by more than 50 percent between 1982 and 1983 by both cohort and catch-at-age analysis, Table 11. The lowest exploitation rate is estimated to have occurred in 1985, which is also the year of lowest catch since 1980 and the earliest date of restriction of the fishery to incidental catches. The cohort analysis indicates that exploitation rate increased to 1983 levels in 1987. The catch-at-age analysis indicates that exploitation rates increased to 1981 levels in 1987.

The number of vessels participating in the fishery for widow rockfish in Oregon (which is the center of the fishery) has doubled since 1982 and 1983 (J. Golden ODFW). However trip regulations are more restrictive. In 1983 there was no trip frequency limit. In 1987, only one trip per week was allowed. The season closed about a month latter in 1987 than in 1983. The number of Californian vessels participating in the fishery appeared to decrease between 1982-1983 and 1987.

It appears reasonable that fishing intensity in 1987 is as high or higher than 1983. It seems unlikely that it is as high as 1981, because of the regulations and apparent reduced effort in California. However, the increased number of vessels participating in the Oregon fishery could cause 1987 effort to be higher than 1983 effort.

At this time we believe that there is insufficient information to choose between the cohort and catch-at-age results. Since there is a great deal of uncertainty about the strength of recent year classes and these year classes are an important component of the stock, we recommend that ABC be set to the average estimate of MSY, 9,500 mt. The stock would continue to be able to support a 9,500 mt fishery in 1990 without a large increase in fishing mortality.

The strength of the important 1980 year class should be better established with an additional year of data. However, because of the lack of funding some areas were not adequately sampled in 1988. Thus there will be greater than usual uncertainty in the estimates of age composition for the 1988 landings. There is no reason to expect a much better estimate of the apparently strong 1981 year class than we now have for the 1980 year class. Thus unless additional information is

Table 11. Estimated rates of exploitation of widow rockfish age 5 and older in terms of biomass. Projections for 1988 and 1989 are as described in Table 8.

	Cohort Analysis		Catch-at-Age-Analysis		
Year	M = 0.15	M = 0.20	M = 0.15	M = 0.20	Average
1980	0.17	0.15	0.12	0.10	0.14
1981	0.29	0.27	0.19	0.16	0.23
1982	0.28	0.26	0.23	0.19	0.24
1983	0.11	0.10	0.11	0.09	0.10
1984	0.13	0.12	0.11	0.10	0.12
1985	0.08	0.08	0.11	0.09	0.09
1986	0.08	0.09	0.12	0.11	0.10
1987	0.10	0.12	0.17	0.16	0.14
1988	0.10	0.12	0.20	0.18	0.15
1989	0.11	0.13	0.23	0.20	0.17

used for the next analysis, there is likely to be continued uncertainty about the status of the stock.

We have begun exploring one additional source of information. The data indicate that there are fairly consistent differences in age composition among areas. It may be useful to develop an estimation procedure for the selectivity curve of the most recent year of data based on the area composition of the catch. This procedure would estimate changes in selectivity due to changes in the area composition of the catch. For example, catches from the North Columbia Area tend to be dominated by relatively young fish. If the proposed procedure had been applied, starting F's for young fish in 1987 probably would have been higher than those used in the cohort analysis of this report.

An additional source of information is the juvenile rockfish survey off of Central California. If the abundance of juvenile rockfish prove to be related to year class strength, the results of the survey can be used to tune the cohort analysis. The first year class (1983) covered by the survey began recruiting to the fishery as five-year-old fish in 1988. It will take a number of years to verify the utility of the survey results.

LITERATURE CITED

Barss, W.H. and T. Wyllie Echeverria. 1987. Maturity of widow rockfish _Sebastes entomelas_ from the Northeastern Pacific, 1977-82. In Lenarz, W.H. and D.R. Gunderson (eds.), Widow Rockfish, p. 13-18. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 48.

Boehlert, G.W., W.H. Barss, and P.B. Lamberson. 1982. Fecundity of the widow rockfish, _Sebastes entomelas_, off the coast of Oregon. Fish Bull., U.S. 80:881-884.

Deriso, R. B., T. J. Quinn II, and P. R. Neal. 1985. Catch-age analyis with auxiliary information. Can. J. Fish. Aquat. Sci. 42: 815-824.

Hightower, J. E., and W. H. Lenarz. 1987. Status of the widow rockfish fishery. (Document submitted to the Pacific Fisheries Management Council, Portland, Oregon, August, 1987). Southwest Fisheries Center, National Marine Fisheries Service, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

Lenarz, W.H. 1987. Ageing and growth of widow rockfish. In Lenarz, W.H. and D.R. Gunderson (eds.), Widow Rockfish, p. 31-35. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 48.

Lenarz, W.H. and J.E. Hightower. 1985. Status of the widow rockfish fishery. (Document submitted to the Pacific Fisheries Managment Council, Portland, Oregon, October, 1985). Southwest Fisheries Center, National Marine Fisheries Service, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

Murphy, G. 1965. A solution of the catch equation. J. Fish. Res. Bd. Can. 22:191-202.

Whipple, J.A. (ed.). MS. Progress in rockfish recruitment studies. To be published as a Southwest Fisheries Center Administrative Report.

Appendix I. Comments on 1987 stock assessment by a member of the SSC assigned to review the report.

To: GMT/SSC Groundfish Subgroup
From: David Hankin, SSC
Subject: Widow Rockfish stock report
Date: 1 October 1987

At the last SSC meeting I was assigned the responsibility of review for the widow rockfish stock report. Because I will be unable to attend the meeting of 7 October, I'd like to ask that the following comments be considered by the GMT/SSC Subgroup.

At the outset, let me say that I was impressed with the report, especially by the attached tables and figures and with the apparent honesty with which the authors presented sometimes conflicting results. My comments below ought not to be construed as indicating that I think this report is unsound, and should be viewed as constructive or irrelevant criticisms.

1. As Bill Clark pointed out in the previous meeting, both cohort and catch-at-age analyses appear to hinge on choice of F_9(1984) which is based on "forcing" a decline in average F of about 50% from 1982 to 1983, and about 10% from 1983 to 1984. I think the report should include some <u>strong</u> justification for this important assumption, or refer the reader to such in an earlier assessment document (which I don't have since I'm new at this). In addition, the report would have been stronger if there were some comparative results for choices of initial F that did not meet this assumption. I have no feeling for how important this assumption would be on the final stock assessment in the absence of such contrasting results.

2. It seems reasonable to me to "link" adjacent cohorts through an assumption that $F_9=F_{10}$ in a given year.

3. Isn't there any independent evidence (not presented in the report) for possible decline in "selectivity coefficient" or in "catchability" of fish older than age 11? The curves plotted for the two analysis methods (figure 5) are disturbingly different and it seems unlikely to me that one would see such a decline beginning at age 11 <u>if</u> the age of full maturity is age 9. In just two years after all fish are mature, they decide to become less vulnerable and live somewhere else? I'd sure like to see some additional evidence for this possibility.

4. The apparent agreement between cohort and catch-at-age analyses appears to be tied to pt. #1 above. I'm not impressed by the close agreement between the two methods; in fact, I'm disturbed by it! If the analysis methods are substantively different, they should give *different* results.

5. I'd like to see a maturation curve presented in the report. I am very concerned by the observation that 71% of the catch in 1986 was of fish less than age 9, and I didn't like the looks of the age compositon shifts depicted by Figure 3. Unless there is very substantial spawning activity among fish aged 5-7, it looks to me that there may be serious problems with spawning stock (see

pt #7). In the absence of the maturation curve, I couldn't judge.

6. How long do these fish live? I was greatly impressed with the continued "pile-up" of fish older than age 13 (Table 6). This could be added to the report in a single sentence.

7. Table 7 presents estimates of spawning stock from 1980 through 1987 or 1988. For M=0.2 these suggest that spawning stock has decreased to about 28-32% of that in 1980, and for M=0.15 to about 40-45% of spawning stock. Since the stock was not virgin in 1980 (1979 landings were ≈5,000 mt), this means that the real reduction in spawning stock has probably been greater than that indicated by the 1980-87/88 comparisons. In any event, current spawning stock could be as little as perhaps 20-25% of virgin spawning stock and probably no more than 40%. If such a reduced spawning stock were noted for other groundfish stocks, would there be an expression of concern?

8. I know that it's old hat, but I would have liked to have seen a surplus production model used for comparison. Just out of curiosity, I'd like to know what the recommended % of virgin biomass for MSY would be to compare with these other analyses.

9. I agree that some large cohorts (1977-1980) have been moving through the population and should improve numbers of older fully-mature fish in the near future.

10. The relative stability of landings from 1983 through 1986, coupled with the "timely" appearance of several strong year-classes suggests no immediate cause for panic, but I agree with the suggestion that yields in the years beyond 1990 may have to be seriously curtailed when compared to the proposed ABC.

11. If this is any indication of Hightower's work, the GMT will be have a good new leader to replace Bill Lenarz!!

Appendix II. Sensitivity analysis of catch-at-age analysis (CAGEAN)

The difference in results from cohort and catch-at-age analysis illustrates the need for auxiliary information that would stabilize our estimates of current stock size. Because of the nature of the widow rockfish fishery, however, we have few potential sources of auxiliary information. Surveys of adult widow rockfish have not been attempted because of the high cost of sampling a midwater species with a highly contagious distribution. A midwater trawl survey of juvenile rockfish was begun in 1983 so the first surveyed year class will enter the fishery in 1988. If the survey is continued, the information it produces should be helpful in a few years. At present, our only source of auxiliary information is a four-year series of logbook data for the Oregon midwater trawl fleet. (The logbook data were obtained after the original assessment was completed). The strength of the relationship between logbook estimates of catch-per-unit-effort and fishing mortality rates is unknown. For that reason, we did not feel confident in forcing the CAGEAN model to mimic the pattern indicated by the logbook data. Instead, we used CAGEAN to establish the range of solutions consistent with the catch data, then compared the assessment results with the logbook data.

Our objective was to evaluate the sensitivity of the catch-at-age analysis to random sampling errors, as well as to changes in the assumptions used in the analysis. To evaluate the effect of sampling errors, we generated random catch matrices from the observed 1980-1987 catch-at-age matrix by adding a random error to each catch value. Thus, each replicate catch-at-age matrix represented a random perturbation of the observed data. Analyses by Sen (1984) indicated that the coefficient of variation (CV) for the mean number of widow rockfish per 50-pound cluster by sex and age class ranged from 12 to 24 percent in 1981 samples. Sen presented results only for those ages with CVs $\leq$ 25%; less commonly occurring age groups would have higher CVs. More recent unpublished analyses suggest that current CVs are lower than the 1981 estimates Sen obtained. We assumed a CV of 20% for all age groups in order to estimate the probable upper bound for the impact of sampling error on the assessment.

We produced a set of 100 replicate catch-at-age matrices for each of four assumptions about the ages at which selectivity is assumed equal to 1.0: age 10 only (s[10]=1.0), ages 9-10, ages 10-11, and ages 9-11. We also examined a fifth case with s[10]=1.0 but a starting F of 0.30 (instead of 0.25). The starting F is used in a preliminary cohort analysis that generates starting parameter estimates for the least-squares nonlinear fit. The analyses were done using a natural mortality rate (M) of 0.15. We believe that our conclusions from the sensitivity analysis would not change if the higher level of M (0.20) was used.

As in the assessment, we used average 1980-1987 Fs from cohort analysis as the "effort" data required by CAGEAN. We also used the same low weight (lambda=0.01) for the "effort" data, in order to obtain results that were relatively independent of the cohort analysis. The 1984-1987 annual Fs produced by CAGEAN were compared to estimates of total hours trawled, which were generated as follows. Logbook data from Oregon midwater trawl vessels (J. Golden, Oregon Dept. of Fish. and Wildlife, personal communication) provided estimates of 1984-1987 landings and hours trawled that were used to estimate catch per hour trawled (App. Table 1). Total landings for those years were divided by the catch rate estimates to provide an estimate of total effort. The estimate is based on the assumption that Oregon midwater trawl catch rates are representative of the coastwide rates.

Results

Frequency distributions for estimated 1987 biomass (B[87]) were moderately sensitive to changes in the selectivity assumptions (App. Figure 1). We also observed a shift in the distribution when a higher starting F was used for the preliminary cohort analysis. The results did not appear to be less variable when more restrictive assumptions about selectivity were made. From 4-33% of the B[87] estimates were greater than 200,000 mt. In most instances, these estimates were obtained when recruitment increased over time and selectivity was high for the oldest (age-13+) fish. As App. Figure 2 illustrates for the s[10]=1.0 case, the extremely high B[87] estimates obtained for some of the replicates were due to recruitment estimates much higher than we believe possible (e.g., 1985 recruitment estimates of 1-2 billion fish, resulting in B[87] values of 1-5 million mt). When only the replicates with 1985 recruitment $\leq$ 100 million fish are plotted (App. Fig. 3), the results show that most recruitment estimates were less than 40 million fish and most estimates of s[13+] were relatively low (about 0.2-0.3).

Estimates of 1987 fishing mortality rates for age-10 fish (F[87]) varied in an inverse relationship with B[87] (App. Fig. 4). Even if B[87] values > 200,000 mt are excluded, F[87] still varied over a relatively wide range.

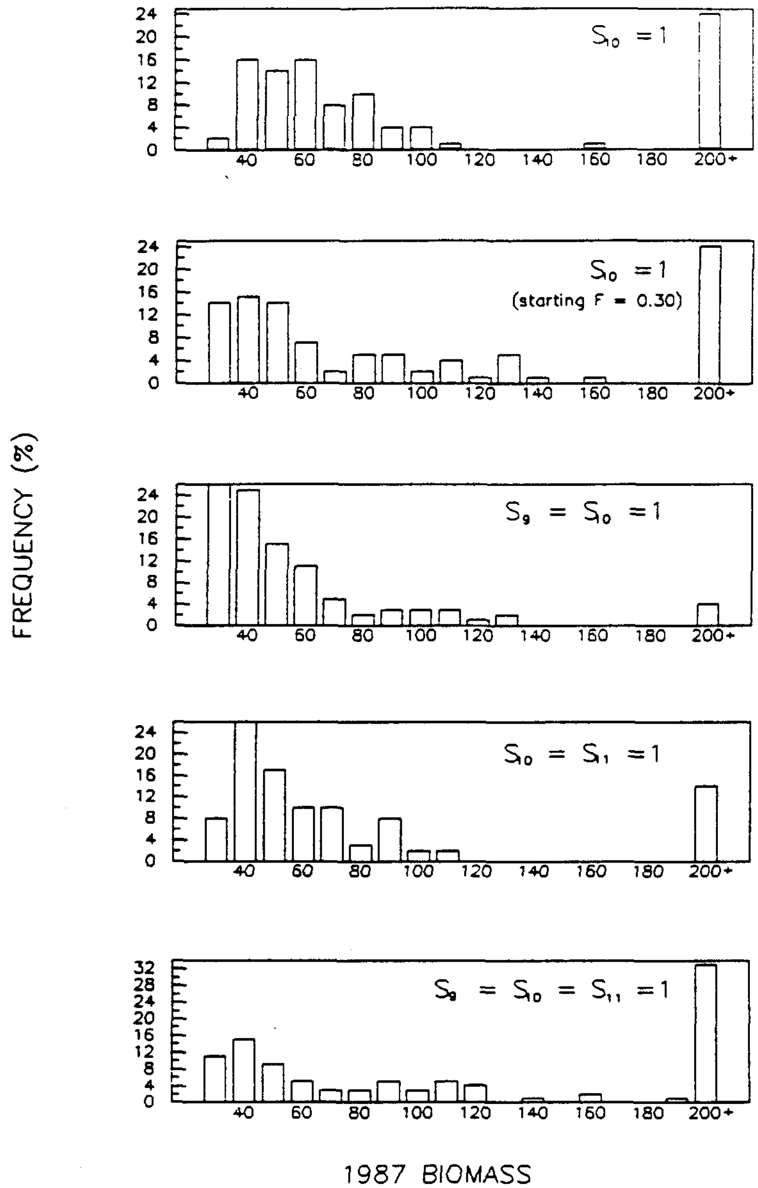
Correlations between 1984-1987 Fs and estimates of total hours trawled ranged from nearly -1 to 1 for the five cases we examined (App. Fig. 5). Large negative correlations were obtained when B[87] was large, because those were the instances where biomass increased from 1980-1987. Increasing biomass and relatively stable catches resulted in decreasing Fs over that interval, the opposite of the trend suggested by the effort data. Large positive correlations were obtained in those replicates where B[87] declined from 1980 to 1987, because the effort data are consistent with a substantial decline in stock size since the fishery began.

We draw several conclusions from these results:

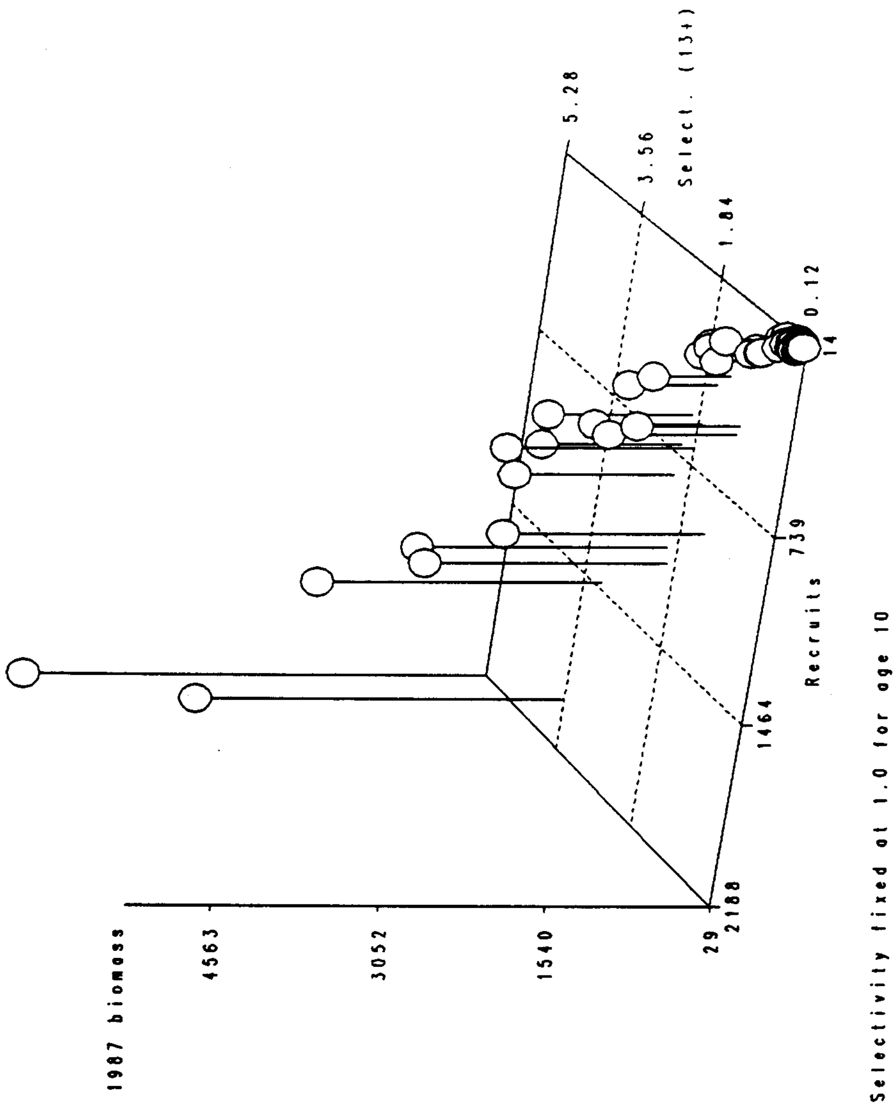
(1) A wide range of solutions is possible, given only an 8-year series of catch data and a low weight (lambda=0.01) applied to the "effort" data (cohort analysis F values) used in CAGEAN. These solutions include instances where stock size is increasing sharply in response to sharply increasing recruitment,

App. Table 1. Hours trawled, landings, and catch per hour trawled for the Oregon midwater trawl fleet from 1984-1987, and estimates of hours trawled coastwide (total coastwide landings divided by Oregon catch/hour trawled).

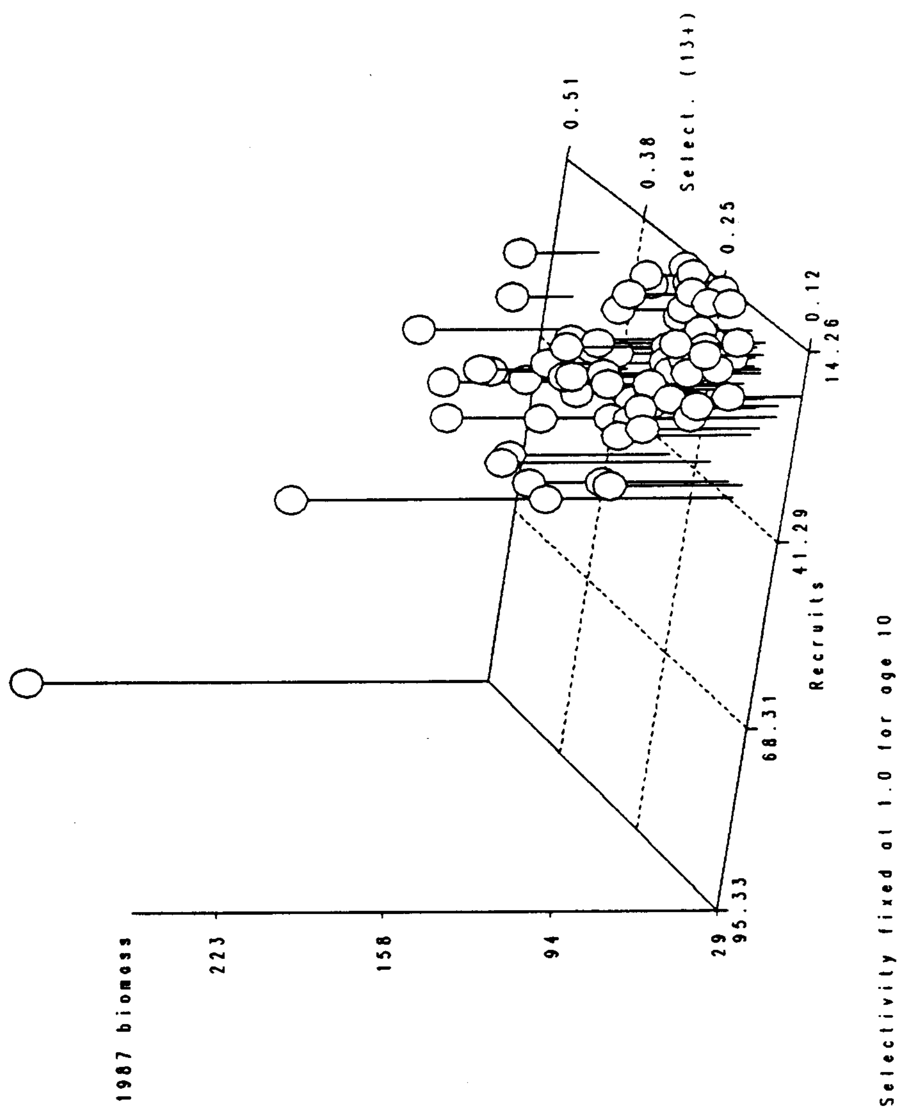
Year	Hours trawled Oregon fleet	Landings Oregon fleet	Catch/hour trawled Oregon fleet	Estimated coastwide hour trawled
1984	1,781	3,925	2.20	4,396
1985	2,227	3,425	1.54	5,751
1986	2,325	3,103	1.33	7,015
1987	3,103	5,102	1.64	7,430



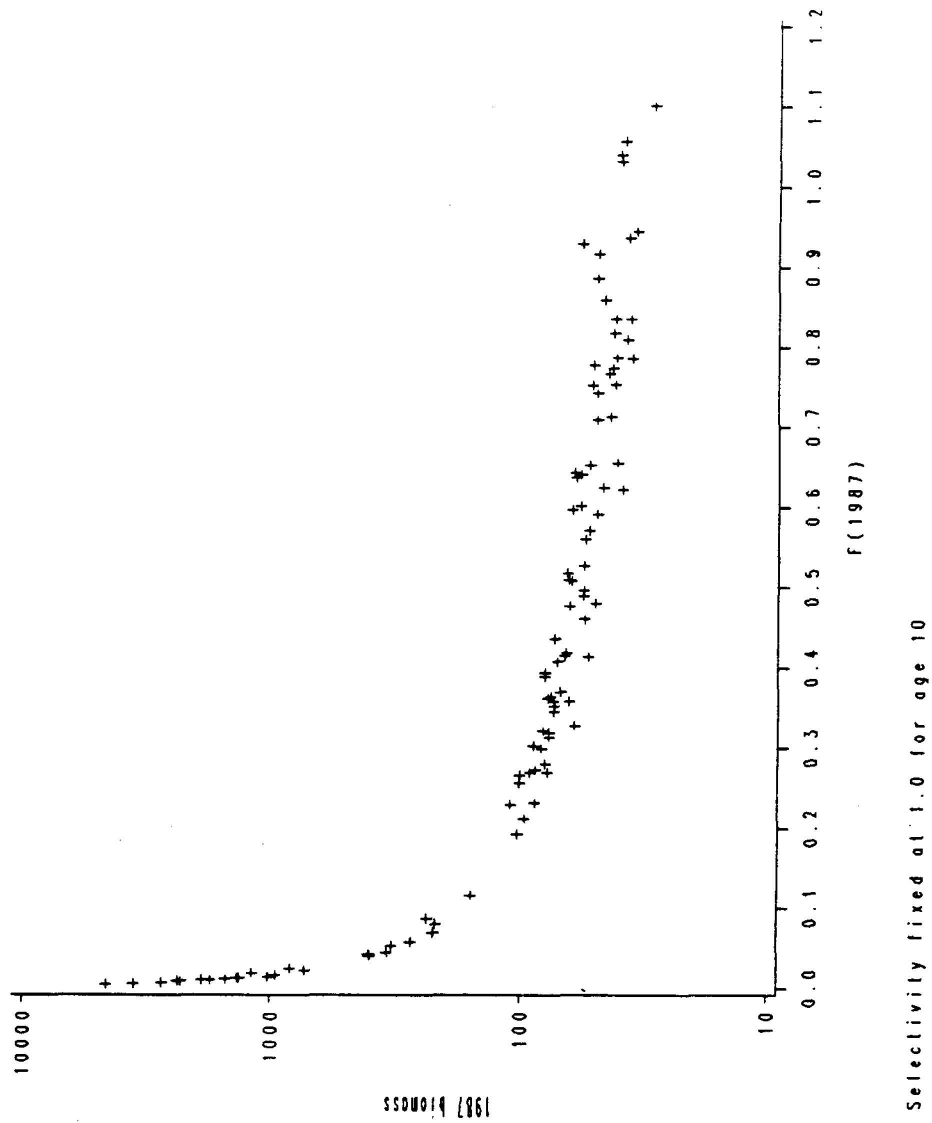
App. Figure 1. **Frequency distributions for estimates of 1987 widow rockfish biomass (ages 5+), based on catch-at-age analysis of 100 randomly generated catch matrices. Four assumptions were examined regarding the ages at which selectivity was assumed equal to 1.0: age 10 only (cases 1-2); ages 9-10; ages 10-11; and ages 9-11. The starting F for the preliminary cohort analysis was 0.25 except in case 2, where 0.30 was used.**



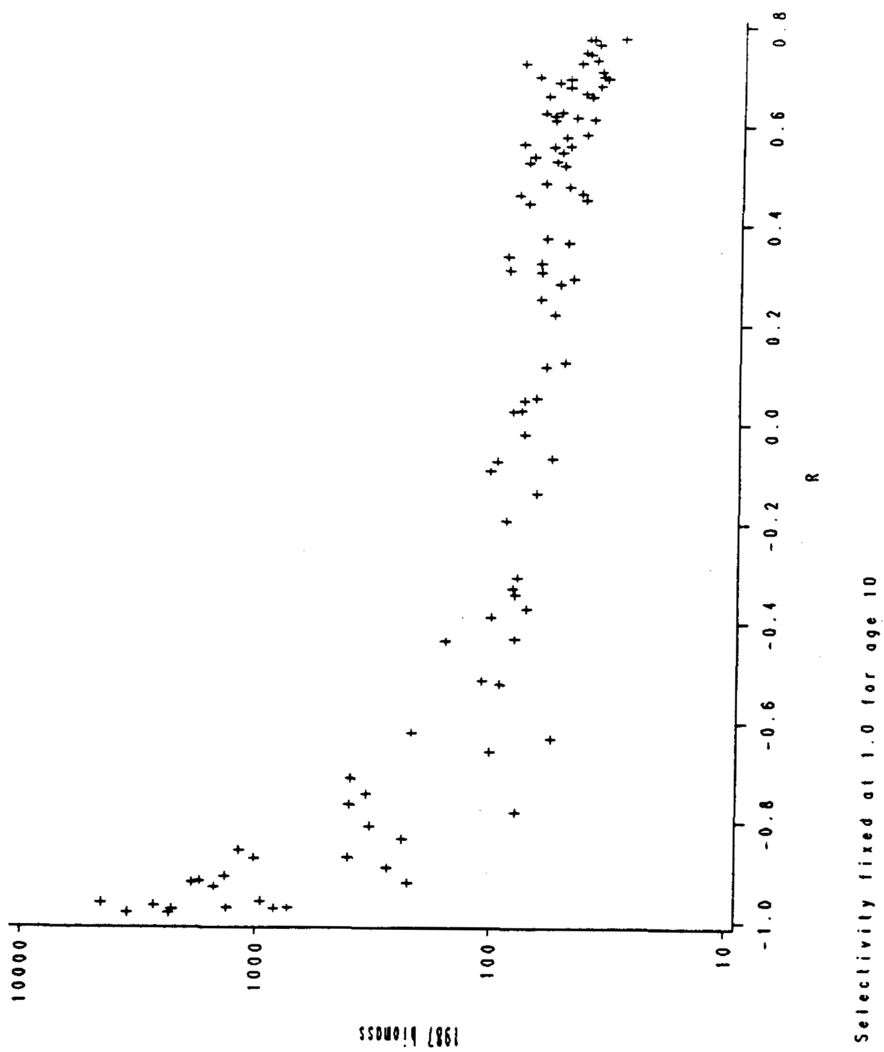
App. Figure 2. One-hundred replicate estimates of 1987 widow rockfish biomass versus number of 1985 age-5 recruits and relative selectivity at ages 13+, for the case where selectivity at age 10 is assumed to be 1.0.



App. Figure 3. Estimates of 1987 widow rockfish biomass versus number of 1985 age-5 recruits and relative selectivity at ages 13+, for the case where selectivity at age 10 is assumed to be 1.0. Only those replicates where recruitment was $\leq$ 100 million fish were plotted.



App. Figure 4. One-hundred replicate estimates of 1987 widow rockfish biomass versus the 1987 fishing mortality rate for age-10 fish, for the case where selectivity at age 10 is assumed to be 1.0. The relationship was similar for the other selectivity assumptions.



App. Figure 5. One-hundred replicate estimates of 1987 widow rockfish biomass versus the correlation between hours trawled (based on Oregon logbook data) and 1984-1987 fishing mortality rates for age-10 fish, for the case where selectivity at age 10 is assumed to be 1.0. The relationship was similar for the other selectivity assumptions.

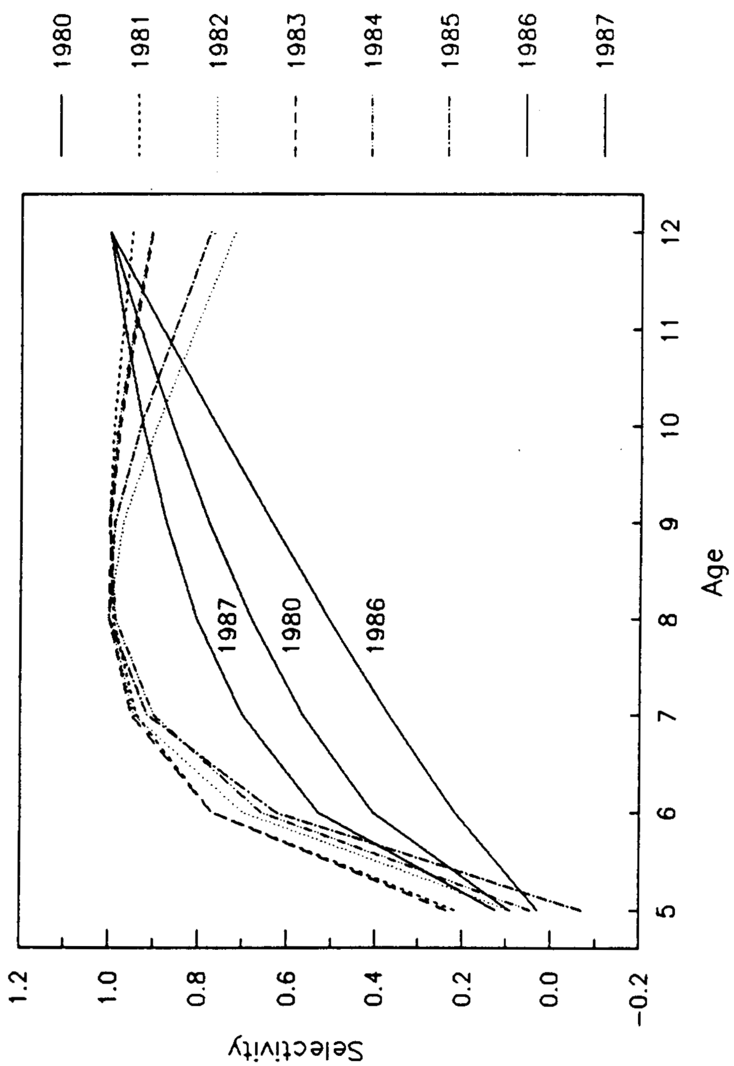
as well as a large number of cases indicating a relatively low current stock size. A more restricted set of solutions could be obtained by increasing lambda; however, forcing the least-squares model to reproduce the cohort analysis results will not provide much additional understanding. We prefer instead to use CAGEAN as a relatively independent estimate of current stock size.

(2) If we assume that stock size has declined since the fishery began in 1980 (ruling out the cases where B[87] $\geq$ 200,000 mt), then most of the replicate analyses indicate that B[87] is between 25,000 and 75,000 mt.

(3) If we assume that the correlation between 1984-1987 F and hours trawled should be greater than zero, then results from all five cases indicate that B[87] is probably less than 70,000 mt. The assumption that F and hours trawled are highly correlated may be inappropriate, given that our measure of effort excludes search time, changes in the level of experience for fishermen, and changes in gear technology. Catch-per-unit-effort for a schooling fish such as widow rockfish may not decline in proportion to the decline in stock size. For example, if school size is maintained but the number of schools declines, catch per tow could remain constant although increased search time would be required to locate schools.

Overall, we believe that results from the least-squares analysis support the conclusion that stock size has been reduced substantially since 1980. The results from cohort analysis, which suggest that B[87] is over 100,000 mt, are highly dependent on estimates of the size of the 1980 and 1981 year classes. Those estimates are unreliable because those year classes have been in the fishery for only 1-2 years and because those estimates are sensitive to changes in selectivity. Improved estimates will be possible after those year classes have been exploited for several years.

In addition, work is underway (R. Methot, Northwest and Alaska Fisheries Center) to develop an assessment model incorporating less restrictive assumptions about selectivity than CAGEAN. Results from cohort analysis indicate that the selectivity pattern for widow rockfish varied over time, perhaps due to changes in the spatial distribution of the fishery. We described the annual patterns by fitting three-parameter curves to the annual selectivity estimates from cohort analysis (App. Fig. 6). One of the assumptions required for CAGEAN is that the selectivity pattern does not change substantially over time. We do not know the impact of the changes depicted in App. Fig. 6. Residuals from catch-at-age analysis (using the



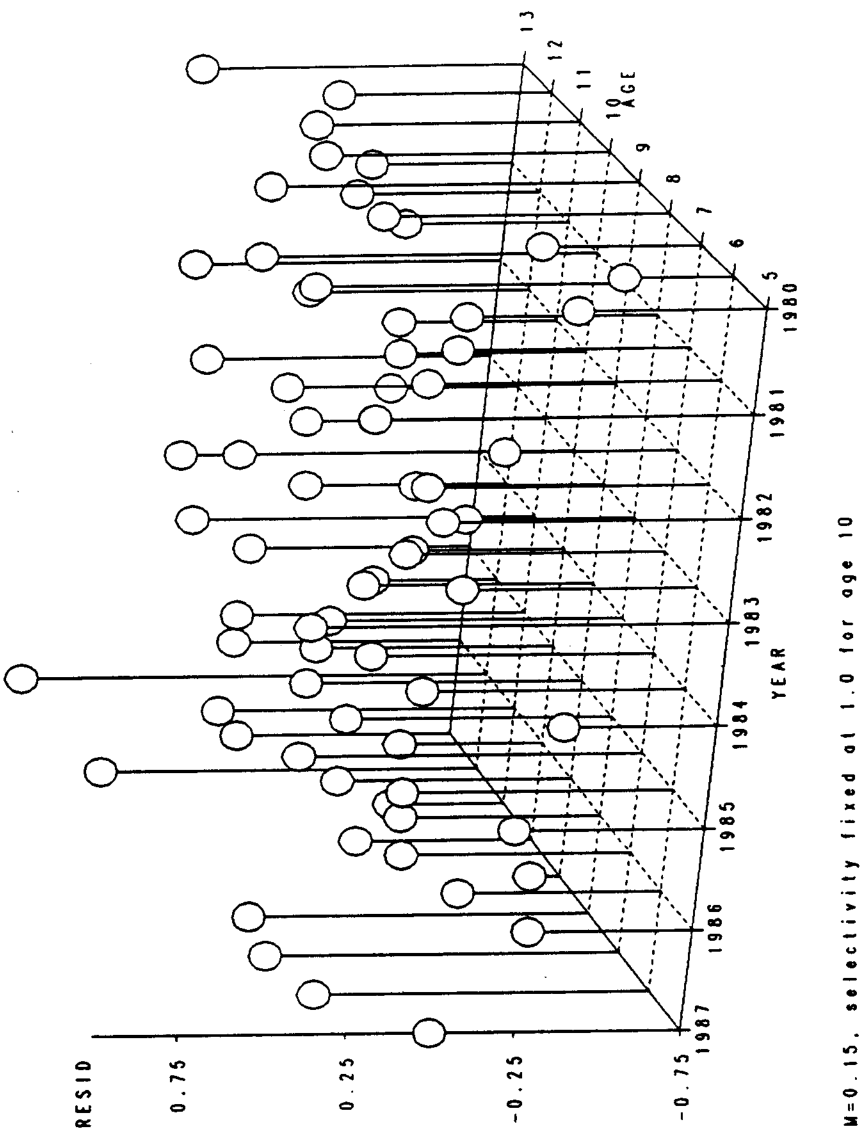
App. Figure 6. **Predicted selectivity patterns for each year, obtained by fitting a three-parameter curve to the annual selectivity estimates from cohort analysis.**

actual 1980-1987 catch data) do not show obvious trends (App. Fig. 7-8, App. Tables 2-3), although the 1987 catches from the 1980 and 1981 year classes are underrepresented by the model. It is possible to use CAGEAN to fit selectivity patterns separately for two or more time periods; however, we are reluctant to subdivide the already short data series.

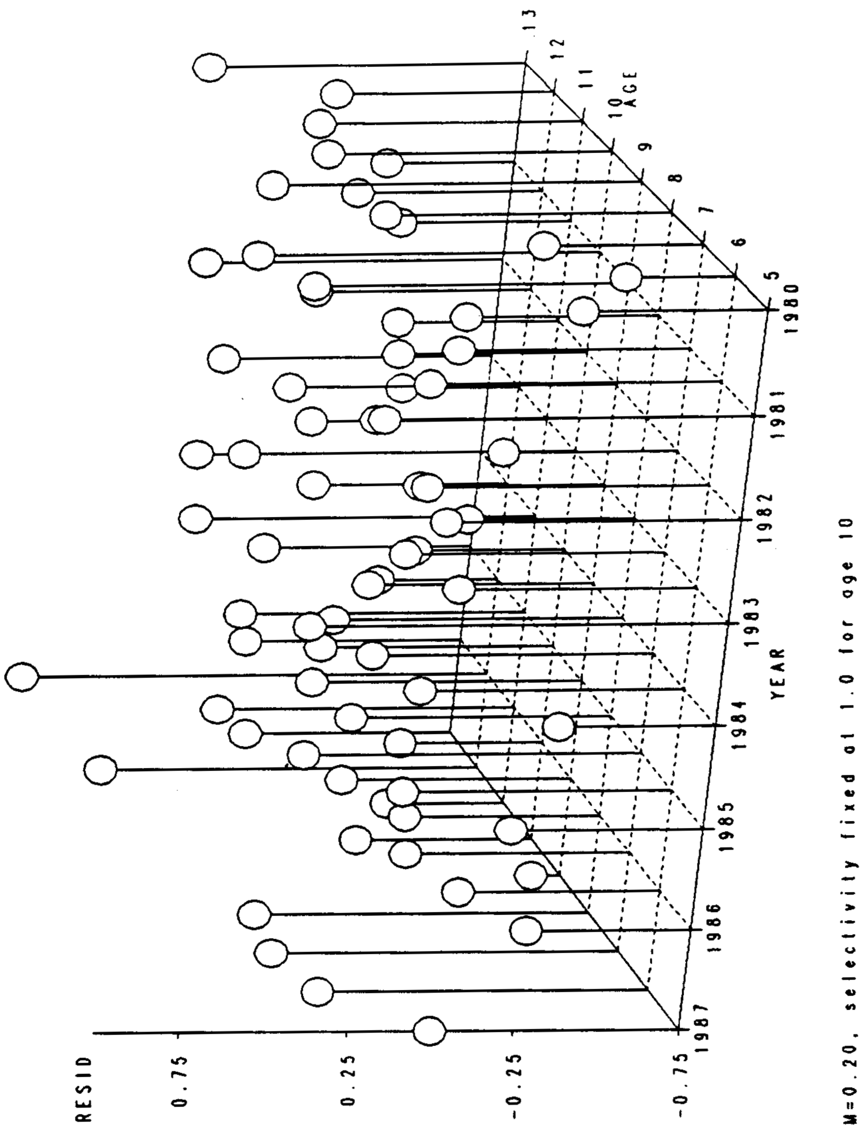
In summary, we feel that the apparent changes in selectivity lend support to our approach of using both cohort and catch-at-age analysis in the assessment. Until the additional data and improved assessment techniques are available, we believe a conservative harvesting policy (such as outlined in the assessment) is necessary.

References

Sen, A. R. 1984. Sampling commercial rockfish landings in California. U. S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFC-45.



App. Figure 7. **Residuals (log [observed catch] - log [predicted catch]) from the least-squares fit using CAGEAN to the 1980-1987 catch-at-age data, with M = 0.15.**



App. Figure 8. **Residuals (log [observed catch] - log [predicted catch]) from the least-squares fit using CAGEAN to the 1980-1987 catch-at-age data, with M = 0.20.**

App. Table 2. Residuals (log(observed catch)-log(predicted catch)) from the least-squares fit using CAGEAN to the 1980-1987 catch-at-age data, with M=0.15.

	Year							
Age	1980	1981	1982	1983	1984	1985	1986	1987
5	-.20635	.34886	.12045	.47447	-.30002	-.18674	-.26109	.00021
6	-.43148	.11111	.07846	-.05579	.03191	.05920	-.13792	.26151
7	-.27955	-.06304	-.23551	.02702	.09959	.28543	-.05440	.32530
8	.10520	-.17633	.06890	-.23849	.14092	.06095	-.13537	.29618
9	.35965	.19432	.24697	-.17239	-.04508	.09991	-.02593	-.65503
10	.11353	.27553	-.17917	.28300	-.27869	-.01276	-.30336	-.19709
11	.06043	-.24482	-.25899	-.00294	.32040	.15278	.18320	-.38835
12	-.09056	-.18001	-.06462	-.35043	-.11337	-.35631	.73128	.44947
13+	.25489	-.30911	.21357	.14727	.20232	-.04815	-.02615	-.06360

App. Table 3. Residuals (log(observed catch)-log(predicted catch)) from the least-squares fit using CAGEAN to the 1980-1987 catch-at-age data, with M=0.20.

	Year							
Age	1980	1981	1982	1983	1984	1985	1986	1987
5	-.21470	.33074	.11453	.48665	-.28593	-.17733	-.25701	-.00119
6	-.42966	.11144	.08547	-.04232	.04141	.06167	-.13949	.25513
7	-.27715	-.05923	-.22930	.03319	.10192	.27872	-.06336	.31456
8	.11226	-.16817	.07281	-.24147	.13767	.05129	-.14628	.28598
9	.37136	.21263	.25421	-.17949	-.05276	.09059	-.03262	-.66079
10	.12202	.30341	-.16409	.28133	-.28354	-.01792	-.30091	-.19182
11	.06698	-.21988	-.24512	-.00643	.32130	.15229	.19264	-.37388
12	-.06744	-.16689	-.06959	-.37662	-.12758	-.36535	.73185	.45517
13+	.24991	-.34280	.19852	.10966	.16364	-.08208	-.05303	-.08368

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Tiburon Laboratory
Southwest Fisheries Center
3150 Paradise Drive
Tiburon, California 94920

October 17, 1988   F/SWC3:JEH

MEMORANDUM FOR: James W. Glock
Pacific Fishery Management Council

FROM: F/SWC3 - Joseph E. Hightower

SUBJECT: Supplemental Information Regarding 1988 Widow Rockfish Status of Stock Document

After further review of the draft widow rockfish status of stock document, Bill Lenarz and I discovered that the biomass at MSY (B[MSY]) estimates were incorrect. The values were based on the wrong fishing mortality rate; the correct values (Table A, enclosed) are moderately higher. The final version of the status of stock document contains the correct B[MSY] values.

Also enclosed are the two tables of biomass estimates that we discussed at the October meeting of the Groundfish Managment Team (Tables B-C). The table values represent estimates of the widow rockfish biomass that would be expected in years 1989-1993, assuming a constant harvest of 9,000 to 15,000 mt. The status of stock document contained the tables of fishing mortality rates (Table 10) that correspond to these biomass estimates. The biomass estimates are easier to interpret, however, so we wanted to make them available as well.

The two tables represent projections based on results from cohort and catch-at-age analysis. Estimates of current stock biomass differ considerably for the two approaches, and unfortunately, we have insufficient data to choose between the two sets of results. Our discussion at the GMT meeting focused on the catch-at-age analysis results because harvests that are acceptable for that more pessimistic case should not result in overfishing.

We concluded at the GMT meeting that, based on the catch-at-age analysis results, biomass would reach the MSY level within five years if a harvest of 11,000 or 12,000 mt. was maintained through 1992. For that reason, the GMT supported a 1989 ABC of 12,400 mt., which is the calculated value using the same ABC

Table a. Estimates of maximum sustainable yield (MSY) and biomass at MSY (B[MSY]) obtained from cohort and catch-at-age analysis at two levels of natural mortality (M) and using two assumptions about the stock-recruitment relationship.

Assessment technique	M	Stock-recruitment relationship	Mean recruit. (millions)	MSY (000 mt)	B[MSY] (000 mt)
Cohort	0.15	Constant	29.6	13.31	87.8
		Beverton-Holt		8.23	54.3
	0.20	Constant	34.2	12.66	83.3
		Beverton-Holt		8.61	56.6
	Average			10.7	70.5
Catch-at-age	0.15	Constant	20.8	8.64	66.1
		Beverton-Holt		5.93	45.4
	0.20	Constant	31.1	11.40	72.5
		Beverton-Holt		7.49	47.6
	Average			8.4	57.9

Table b. Estimates of widow rockfish biomass (ages 5+, thousands of metric tons (mt)) in 1989-1992 based on results of cohort analysis, assuming a constant harvest of 9,000 to 15,000 mt, a natural mortality rate (M) of 0.15 or 0.20, and one of three recruitment scenarios (mean observed recruitment, following the pattern observed in the juvenile rockfish survey, or following a Beverton-Holt stock recruitment curve).

Target		Mean observed		Survey		Beverton-Holt		
harvest	Year	M=0.15	M=0.20	M=0.15	M=0.20	M=0.15	M=0.20	Average
9,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	127.1	104.5	132.8	113.5	117.1	97.2	115.4
	1991	129.8	106.3	121.5	98.8	114.4	94.5	110.9
	1992	132.3	108.0	130.6	108.5	113.2	93.1	114.3
	1993	135.9	110.2	138.2	114.3	114.1	93.3	117.7
10,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	126.0	103.5	131.8	112.5	116.0	96.2	114.3
	1991	127.7	104.4	119.5	96.9	112.4	92.5	108.9
	1992	129.3	105.2	127.7	105.7	110.2	90.3	111.4
	1993	132.0	106.6	134.2	110.6	110.2	89.7	113.9
11,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	125.0	102.5	130.8	111.5	115.0	95.2	113.3
	1991	125.7	102.4	117.5	95.0	110.3	90.6	106.9
	1992	126.4	102.4	124.8	103.0	107.2	87.6	108.6
	1993	128.1	102.9	130.2	106.9	106.3	86.1	110.1
12,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	123.9	101.4	129.7	110.5	113.9	94.2	112.3
	1991	123.7	100.5	115.5	93.1	108.3	88.6	105.0
	1992	123.4	99.6	121.8	100.2	104.3	84.8	105.7
	1993	124.1	99.3	126.3	103.2	102.4	82.5	106.3
13,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	122.9	100.4	128.7	109.5	112.9	93.2	111.3
	1991	121.6	98.5	113.5	91.2	106.3	86.7	103.0
	1992	120.4	96.8	118.9	97.4	101.3	82.0	102.8
	1993	120.2	95.7	122.3	99.5	98.5	78.9	102.5
14,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	121.9	99.4	127.7	108.5	111.9	92.2	110.3
	1991	119.6	96.6	111.5	89.3	104.3	84.7	101.0
	1992	117.4	94.0	116.0	94.7	98.4	79.2	100.0
	1993	116.3	92.1	118.3	95.7	94.6	75.2	98.7
15,000	1989	124.1	103.0	101.3	77.7	117.5	98.2	103.6
	1990	120.8	98.4	126.6	107.5	110.8	91.1	109.2
	1991	117.6	94.6	109.5	87.4	102.2	82.8	99.0
	1992	114.4	91.2	113.0	91.9	95.4	76.4	97.1
	1993	112.3	88.4	114.3	92.0	90.6	71.6	94.9

Table c. Estimates of widow rockfish biomass (ages 5+, thousands of metric tons (mt)) in 1989-1992 based on results of catch-at-age analysis, assuming a constant harvest of 9,000 to 15,000 mt, a natural mortality rate (M) of 0.15 or 0.20, and one of three recruitment scenarios (mean observed recruitment, following the pattern observed in the juvenile rockfish survey, or following a Beverton-Holt stock recruitment curve).

Target		Mean observed		Survey		Beverton-Holt		
harvest	Year	M=0.15	M=0.20	M=0.15	M=0.20	M=0.15	M=0.20	Average
9,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	58.4	70.2	63.2	78.5	55.2	71.4	66.2
	1991	58.0	72.4	53.2	66.1	53.2	73.8	62.8
	1992	57.6	74.5	57.5	75.4	51.2	75.7	65.3
	1993	57.5	76.6	59.3	80.2	49.1	77.1	66.6
10,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	57.4	69.2	62.2	77.6	54.2	70.4	65.2
	1991	55.9	70.4	51.2	64.1	51.2	71.8	60.8
	1992	54.6	71.6	54.5	72.6	48.2	72.8	62.4
	1993	53.5	72.9	55.2	76.4	45.2	73.4	62.8
11,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	56.4	68.2	61.1	76.6	53.2	69.4	64.2
	1991	53.9	68.4	49.2	62.2	49.1	69.8	58.8
	1992	51.5	68.7	51.6	69.8	45.1	70.0	59.5
	1993	49.5	69.2	51.1	72.6	41.2	69.7	58.9
12,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	55.3	67.2	60.1	75.6	52.1	68.4	63.1
	1991	51.8	66.5	47.2	60.3	47.1	67.8	56.8
	1992	48.5	65.9	48.6	67.1	42.1	67.1	56.5
	1993	45.5	65.5	46.9	68.8	37.2	66.0	55.0
13,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	54.3	66.2	59.1	74.6	51.1	67.4	62.1
	1991	49.8	64.5	45.2	58.4	45.0	65.9	54.8
	1992	45.5	63.0	45.7	64.3	39.1	64.2	53.6
	1993	41.5	61.9	42.8	64.9	33.3	62.3	51.1
14,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	53.3	65.2	58.1	73.6	50.1	66.4	61.1
	1991	47.7	62.5	43.2	56.5	43.0	63.9	52.8
	1992	42.4	60.1	42.7	61.5	36.1	61.4	50.7
	1993	37.5	58.1	38.7	61.1	29.3	58.6	47.2
15,000	1989	59.8	69.1	44.4	46.1	57.9	69.7	57.8
	1990	52.3	64.2	57.1	72.6	49.1	65.4	60.1
	1991	45.7	60.5	41.2	54.6	41.0	61.9	50.8
	1992	39.4	57.3	39.7	58.7	33.1	58.5	47.8
	1993	33.5	54.4	34.6	57.3	25.3	54.9	43.3

algorithm as in previous widow rockfish assessments. Based on the correct value of B[MSY] (57,900 mt), it appears that biomass in 1989 (57,800 mt) is at the MSY level, but should remain close to that level through 1992 at harvest levels of 11,000-12,000 mt. The GMT reviewed the corrected B[MSY] estimates and biomass projections and believes that a 12,400 mt. ABC for 1989 is still appropriate. ABC estimates for 1990 and beyond will be reevaluated annually as additional data become available.

Please contact me at (415) 556-0565 if you have questions or comments.

Enclosures