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# 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 1980-1986 catch-at-age data. Fishing mortality was moderately higher in 1986 than in 1985, due to a decrease in stock size and an increase in harvest. Projected stock biomass in 1987 and 1988 should be slightly lower than the estimated levels in 1985 and 1986. Using results from cohort analysis, estimates of MSY ranged from 7,700 to 12,000 metric tons (mt), with an average of 10,100 mt. The recommended fishing mortality rate for fully recruited fish was 0.30. At this level of fishing effort, average yield in 1988 and 1989 (an estimate of ABC) would be 12,500 mt. Using results of catch-at-age analysis, estimates of MSY ranged from 7,800 to 12,200 mt, with an average of 10,200 mt. At a recommended fishing mortality rate of 0.30 for fully recruited fish, average yield in 1988 and 1989 would be 11,700 mt. Because each of the two stock reconstruction techniques has advantages and disadvantages, we recommend calculating ABC as the average of the two ABC estimates. This combined estimate of the 1988 ABC is 12,100 mt.


## Introduction

This report represents an update of the widow rockfish (Sebastes entomelas) status report submitted in August 1986 (Hightower and Lenarz 1986). Included is (1) a review of the 1986 report and of recent events in the fishery, (2) estimates of the current status of the stock, (3) and recommendations for harvest in 1988.

## Summary of previous assessment

The estimate of acceptable biological catch (ABC) for 1987 was 12,400 metric tons (mt), an increase of 3,100 mt over the 1986 ABC. The increase was due in part to an increase in estimated mean recruitment, but primarily to an upward revision in the estimated size of the 1978-1980 year classes. Estimates of total stock biomass and spawning biomass were relatively stable from 1984 through 1987.

## Recent History of the fishery

Landings in 1986 were slightly higher than in 1985, due primarily to increased landings in the northern part of the Columbia INPFC area (Table 1, Figure 1). As in earlier years, the change in landings should not be attributed to a change in stock size, but rather to the difficulty of using regulations to remove OY exactly. The fishery proceeded at a somewhat slower pace in 1986 than in 1985, due in part to good fishing for pink shrimp (Pandalus jordani).

The 1980 year class dominated the catch numerically in 1986, 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 1986 catch (71 percent by number) was comprised of fish less than age 9, the age at full maturity (Figure 3). A shift in the age distribution toward older fish is likely as the 1977-1980 year classes move through the fishery. As of 1986, peak catches have occurred for all year classes through 1978.

The OY for 1987 was set at 12,500 mt, which was the October 1986 estimate of ABC. The original estimate of 12,400 mt (Hightower and

Table 1. Landings (metric tons) of widow rockfish by area and year from 1979 through 1986.

| Area | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|---|
| INPFC Vancouver | 329 | 143 | 1,991 | 3,969 | 1,596 | 594 | 446 | 557 |
| Northern Columbia | 432 | 9,426 | 7,969 | 4,625 | 2,490 | 2,086 | 2,128 | 3,508 |
| Nelson Island | 1,680 | 3,192 | 2,056 | 489 | 0 | 0 | 0 | 0 |
| Newport Deeps | 0 | 0 | 272 | 4,953 | 1,337 | 2,147 | 1,688 | 1,983 |
| Heceta-Coq. | 214 | 2,589 | 9,973 | 1,487 | 792 | 1,600 | 1,305 | 679 |
| Southern Col. | 1,894 | 5,781 | 12,301 | 6,929 | 2,129 | 3,747 | 2,993 | 2,662 |
| INPFC Columbia | 2,326 | 15,207 | 20,270 | 11,554 | 4,619 | 5,833 | 5,120 | 6,170 |
| INPFC Eureka | 2,166 | 4,736 | 3,430 | 3,993 | 2,442 | 2,256 | 2,313 | 1,632 |
| INPFC Monterey -Conception | 120 | 304 | 2,000 | 6,997 | 1,554 | 988 | 977 | 971 |
| Total | 4,941 | 20,390 | 27,691 | 26,513 | 10,211 | 9,671 | 8,856 | 9,329 |

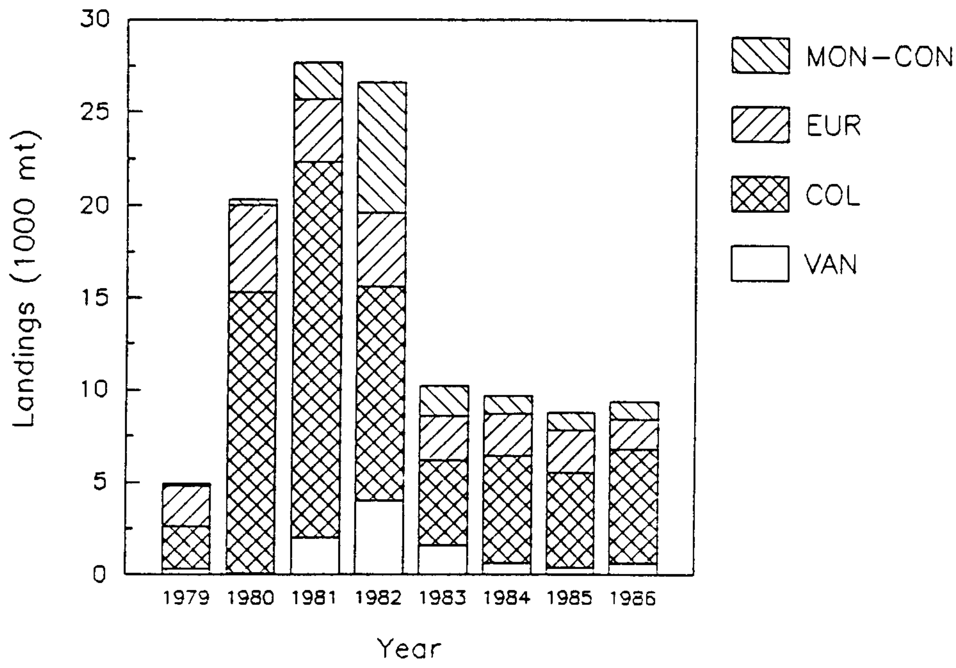


Figure 1. Landings of widow rockfish by INPFC area from 1979 through 1986.

Table 2. Estimates of the number of widow rockfish landed by year class (millions) from 1980 through 1986.

| Year Class | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| 65+ | 1.856 | 1.409 | 2.945 | 1.357 | 0.810 | 0.473 | 0.504 |
| 66 | 0.567 | 0.579 | 0.826 | 0.191 | 0.116 | 0.062 | 0.056 |
| 67 | 0.855 | 0.853 | 1.093 | 0.279 | 0.144 | 0.073 | 0.060 |
| 68 | 1.675 | 1.356 | 1.403 | 0.365 | 0.237 | 0.093 | 0.076 |
| 69 | 2.237 | 2.194 | 1.647 | 0.364 | 0.338 | 0.067 | 0.070 |
| 70 | 5.590 | 5.633 | 3.849 | 0.690 | 0.744 | 0.400 | 0.317 |
| 71 | 3.580 | 5.130 | 1.960 | 0.391 | 0.392 | 0.173 | 0.064 |
| 72 | 0.904 | 1.483 | 0.727 | 0.222 | 0.102 | 0.047 | 0.017 |
| 73 | 0.460 | 0.885 | 0.933 | 0.272 | 0.170 | 0.037 | 0.037 |
| 74 | 0.454 | 1.626 | 1.513 | 0.322 | 0.189 | 0.148 | 0.162 |
| 75 | 0.300 | 2.219 | 1.924 | 0.620 | 0.471 | 0.268 | 0.243 |
| 76 | 0.001 | 0.690 | 1.512 | 0.705 | 0.576 | 0.292 | 0.166 |
| 77 | 0.000 | 0.899 | 2.599 | 2.484 | 3.046 | 1.801 | 1.318 |
| 78 | | 0.000 | 0.510 | 2.272 | 3.338 | 3.786 | 2.259 |
| 79 | | | 0.015 | 0.334 | 0.516 | 1.402 | 1.644 |
| 80 | | | | 0.015 | 0.026 | 0.920 | 2.827 |
| 81 | | | | | 0.002 | 0.053 | 0.656 |
| 82 | | | | | | 0.001 | 0.022 |
| 83 | | | | | | | 0.000 |

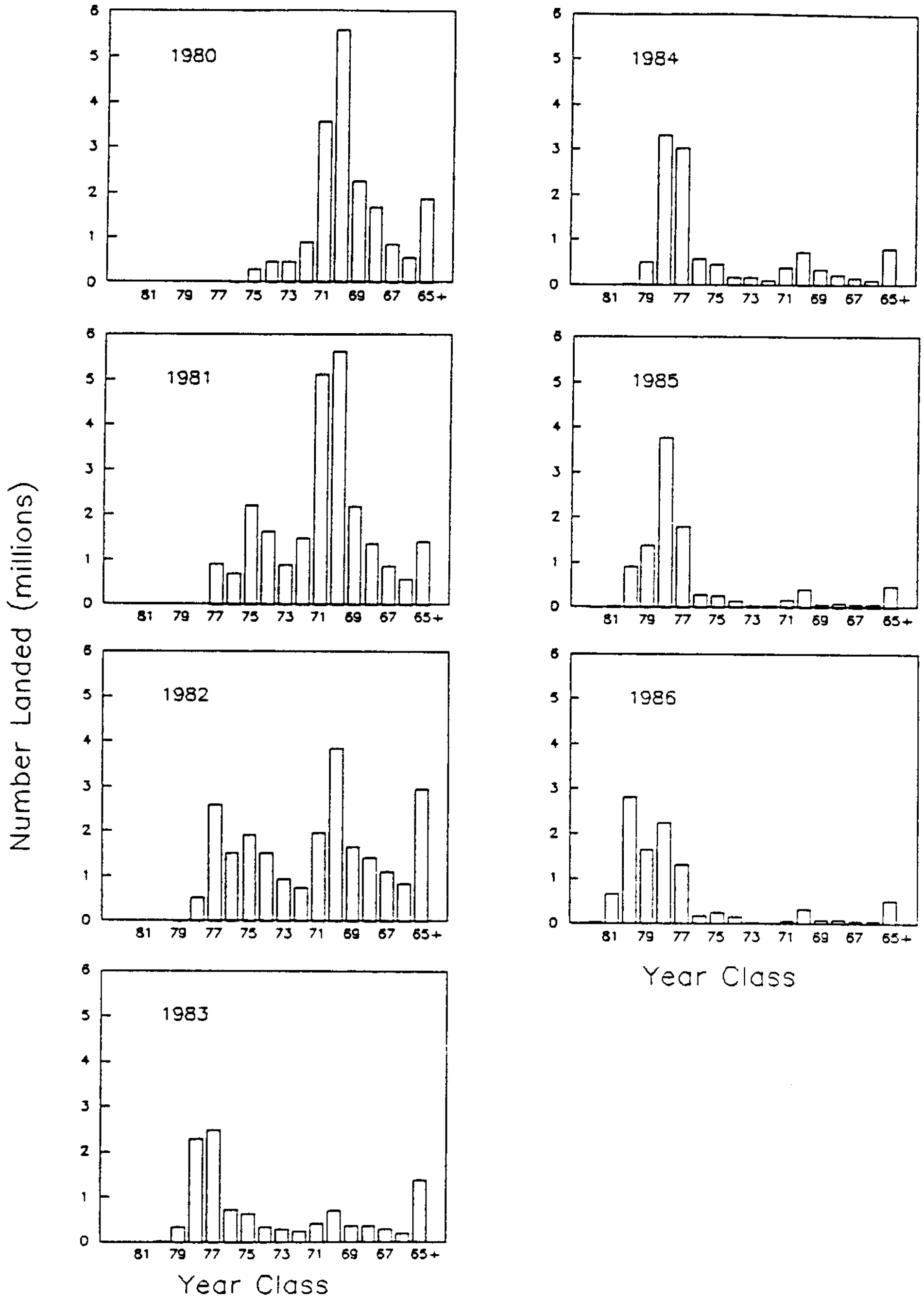


Figure 2. Total numbers of widow rockfish from each cohort in Washington, Oregon, and California landings from 1980 through 1986.

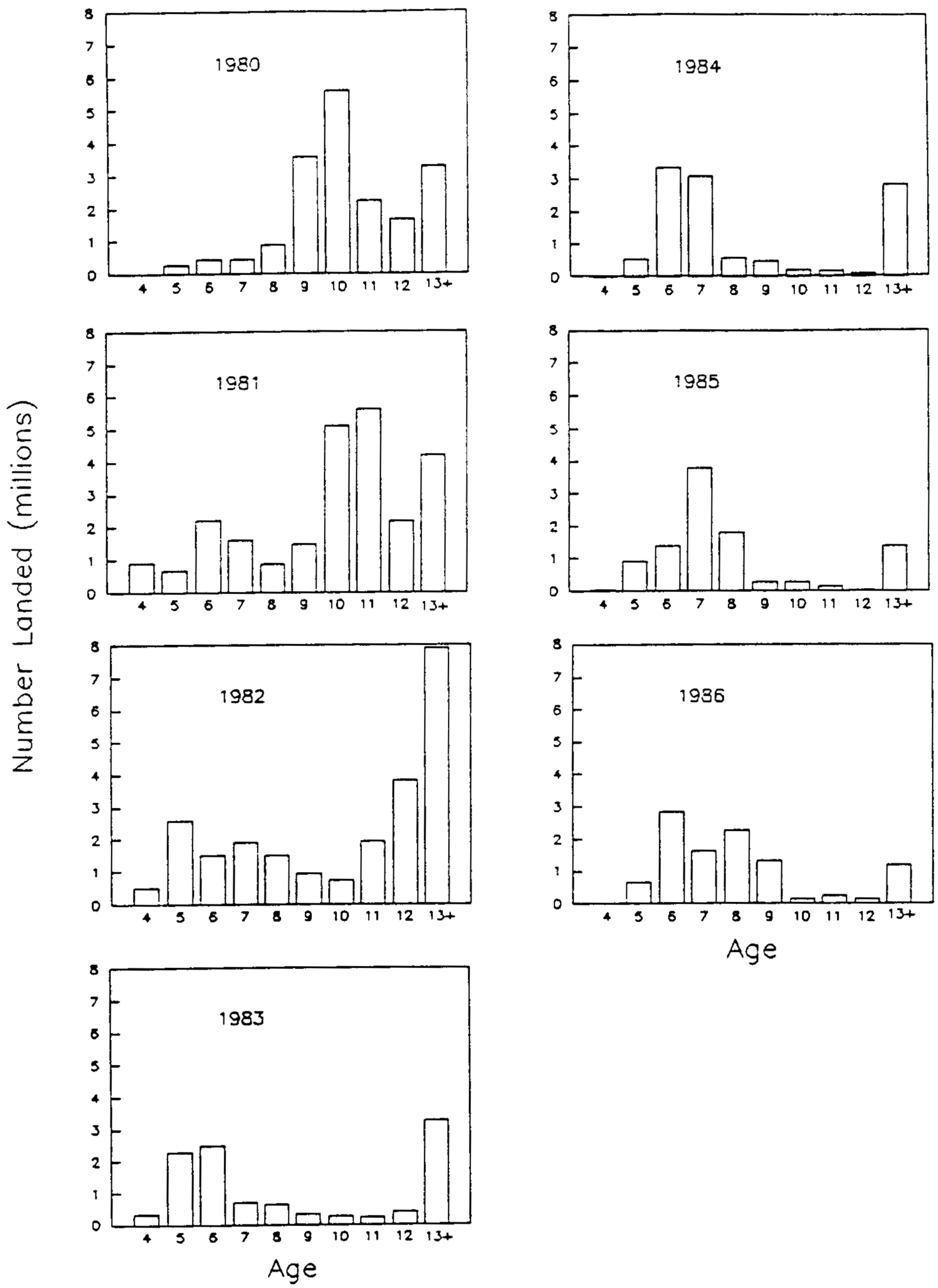


Figure 3. Total numbers of widow rockfish from each age group in Washington, Oregon, and California landings from 1980 through 1986.

Lenarz 1986) was based on projected 1986 landings of 9,600 mt. In response to a Council request, a revised estimate of ABC (12,500 mt) was obtained by using an updated forecast that 1986 landings would be about 9,300 mt. Preliminary estimates are that 1987 landings will be about 12,500 mt, and that the OY will be reached by October or November.

## Assessment Methodology

The same approaches and assumptions used in the 1986 assessment were used in this assessment. 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.

Cohort analysis (Murphy 1965) and catch-at-age analysis (Deriso et al. 1985) were used to estimate instantaneous rates of fishing mortality (F) and population size (N, in numbers of fish). By comparing the more traditional approach (cohort analysis) to the more recently developed approach using nonlinear least squares (catch-at-age analysis), we were able to determine whether our results were sensitive to the assumptions or methods used in either analysis.

As in the 1986 assessment, cohort analysis was 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 1977 cohorts, we used the same starting value used in the 1985 and 1986 assessments ($F_9(1984)$). This starting value assessment was originally selected by varying $F_9(1984)$ until we produced a decline in average F of about 50 percent from 1982 to 1983 and about 10 percent from 1983 to 1984. Starting F values for cohorts younger than 1977 were obtained by assuming that the ratio of F for ages less than 9 to age 9 was the same in 1986 as in earlier years. For example, the estimate of $F_8(1986)$ was obtained by multiplying $F_9(1986)$ by $\bar{F}_8/\bar{F}_9$, where $\bar{F}_8$ and $\bar{F}_9$ were averages for years 1980-1985. 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 1981-1986. As in earlier assessments, the microcomputer program GENCOH was used for the cohort analysis.

The 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 63 (7 years X 9 ages) to 15 (7 fishing mortality rates plus 8 selectivity estimates (with $s_{10}$ assumed to be 1)).

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 auxilliary 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 Fs for cohort analysis. These assumptions were incorporated into the catch-at-age analysis by using average Fs from cohort analysis as a relative measure of fishing effort (the annual averages shown in Table 3). 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). In our 1986 assessment, we obtained very similar results using lambda values of 0.1 to 10.0; therefore, the 1987 analysis was done using only the lambda value 0.5. The only change in methodology for this assessment was that fish ages 13 and older were included as an additional 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 low recruitment case, we assumed that the 1982 year class was equal in size to the average of the lower 50% of all recruitment estimates ($R_{low}$). The size of the 1983 year class was assumed to be 0, based on a juvenile rockfish survey indicating very poor spawning success off the central California coast. Recruitment of subsequent year classes was assumed to be equal to $\bar{R}$, the average for the 1968 to 1981 cohorts.
2) For the high recruitment case, recruitment was assumed to be equal to $R_{low}$ in 1983 and otherwise equal to $\bar{R}$.
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 1988 were obtained as follows. The two stock reconstruction techniques provided estimates of the number-at-age vector at the beginning of 1986. Estimates of F-at-age in 1986 were used to project the number of fish ages 6 through 13+ present at the start of 1987. Recruitment in 1987 was obtained using the above assumptions about the strength of the 1982 year class. We then solved iteratively for the fishing mortality rates needed to obtain a 1987 harvest of 12,500 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 1988 was obtained using the above assumptions about the strength of the 1983 year class.

We used two approaches to develop harvest recommendations for 1988. The first approach was to maintain F at the level estimated to produce maximum sustained yield (MSY). The second approach was to maintain yield at a constant level.

## Results

Estimates of age-specific Fs for 1980-1985 from cohort and catch-at-age analysis (Tables 3 and 4) were quite similar to the results presented in the 1986 assessment. Preliminary indications are that F increased in 1986, not only because harvest was higher, but also because stock size decreased from 1985 to 1986. The decrease in stock size can be attributed in part to the declining abundance of the strong 1977 and 1978 year classes (Tables 5 and 6), which is only partially offset by the recruitment of the strong 1980 year class. The primary reason, however, for the sharp reduction in biomass indicated by cohort analysis is the substantially lower estimate of the number of fish ages 13 and older (Table 5). Although this may be an artifact of the method used to estimate $N_{13+}$ (see below), both approaches indicate a decline from 1985 to 1986, with a gradual further decline predicted through 1988 (Table 7). For the years 1980 through 1987, estimates of stock biomass and spawning stock (for ages 5+) were generally quite similar to estimates from the 1986 assessment (Table 7). At the start of 1986, stock biomass and spawning stock were about 55 and 35 percent, respectively, of the estimated levels in 1980.

Estimates of recruitment at age 5 were generally similar to estimates from the 1986 assessment, except that result of both stock reconstruction techniques indicated that the strength of the 1980 year class was underestimated in the 1986 report (Figure 4). Based on cohort analysis, average recruitment was about 25.5 and 32.5 million age-5 fish for $M=0.15$ and 0.20, respectively. Estimates of average recruitment from catch-at-age analysis were 26.1 and 33.4 million age-5 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. The current cohort analysis predicts only slightly reduced vulnerability for older fish, due apparently to the relatively large estimated landings in 1986 of 11- and 12-year-old fish (Table 2). 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 $F_{12}(1986)$ produces a low estimate of $N_{13+}(1986)$, 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. As mentioned earlier, the low estimate for $N_{13+}(1986)$ causes 1986 biomass and spawning stock estimates from cohort analysis to drop sharply (Table 7).

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. The disadvantage is that if a change in fishing patterns occurred in 1986, 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

Table 3. Estimates of F for widow rockfish by age and year obtained by cohort analysis.

M=0.15

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | Ave |
|---|---|---|---|---|---|---|---|---|
| 5 | 0.030 | 0.102 | 0.097 | 0.063 | 0.025 | 0.022 | 0.027 | 0.052 |
| 6 | 0.073 | 0.297 | 0.318 | 0.120 | 0.119 | 0.082 | 0.081 | 0.156 |
| 7 | 0.108 | 0.379 | 0.428 | 0.227 | 0.200 | 0.182 | 0.123 | 0.235 |
| 8 | 0.201 | 0.295 | 0.686 | 0.224 | 0.277 | 0.165 | 0.149 | 0.285 |
| 9 | 0.227 | 0.551 | 0.542 | 0.281 | 0.250 | 0.208 | 0.166 | 0.318 |
| 10 | 0.227 | 0.551 | 0.542 | 0.281 | 0.250 | 0.208 | 0.166 | 0.318 |
| 11 | 0.215 | 0.355 | 0.396 | 0.296 | 0.268 | 0.298 | 0.279 | 0.301 |
| 12 | 0.195 | 0.319 | 0.412 | 0.120 | 0.203 | 0.082 | 0.584 | 0.274 |
| Ave | 0.160 | 0.356 | 0.428 | 0.202 | 0.199 | 0.156 | 0.197 | |

M=0.20

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | Ave |
|---|---|---|---|---|---|---|---|---|
| 5 | 0.026 | 0.091 | 0.089 | 0.061 | 0.025 | 0.023 | 0.030 | 0.049 |
| 6 | 0.066 | 0.270 | 0.294 | 0.115 | 0.120 | 0.087 | 0.092 | 0.149 |
| 7 | 0.096 | 0.350 | 0.398 | 0.217 | 0.201 | 0.193 | 0.140 | 0.228 |
| 8 | 0.182 | 0.270 | 0.643 | 0.214 | 0.277 | 0.175 | 0.169 | 0.276 |
| 9 | 0.206 | 0.509 | 0.506 | 0.269 | 0.250 | 0.220 | 0.188 | 0.307 |
| 10 | 0.206 | 0.509 | 0.506 | 0.269 | 0.250 | 0.220 | 0.188 | 0.307 |
| 11 | 0.200 | 0.330 | 0.371 | 0.283 | 0.268 | 0.316 | 0.318 | 0.298 |
| 12 | 0.190 | 0.307 | 0.395 | 0.117 | 0.203 | 0.086 | 0.685 | 0.283 |
| Ave | 0.146 | 0.330 | 0.400 | 0.193 | 0.199 | 0.165 | 0.226 | |

Table 4. Estimates of F for widow rockfish by age and year, obtained by catch-at-age analysis with lambda=0.5.

M=0.15

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | Ave |
|---|---|---|---|---|---|---|---|---|
| 5 | 0.035 | 0.080 | 0.101 | 0.046 | 0.041 | 0.033 | 0.038 | 0.053 |
| 6 | 0.100 | 0.227 | 0.286 | 0.131 | 0.115 | 0.093 | 0.108 | 0.151 |
| 7 | 0.147 | 0.336 | 0.423 | 0.194 | 0.170 | 0.138 | 0.159 | 0.224 |
| 8 | 0.161 | 0.368 | 0.463 | 0.213 | 0.187 | 0.151 | 0.175 | 0.245 |
| 9 | 0.189 | 0.431 | 0.543 | 0.250 | 0.219 | 0.178 | 0.205 | 0.288 |
| 10 | 0.185 | 0.421 | 0.531 | 0.244 | 0.214 | 0.173 | 0.200 | 0.281 |
| 11 | 0.180 | 0.410 | 0.517 | 0.237 | 0.208 | 0.169 | 0.195 | 0.274 |
| 12 | 0.125 | 0.285 | 0.359 | 0.165 | 0.145 | 0.117 | 0.135 | 0.190 |
| 13+ | 0.082 | 0.187 | 0.235 | 0.108 | 0.095 | 0.077 | 0.089 | 0.125 |
| Ave | 0.134 | 0.305 | 0.384 | 0.177 | 0.155 | 0.126 | 0.145 | |

M=0.20

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | Ave |
|---|---|---|---|---|---|---|---|---|
| 5 | 0.031 | 0.072 | 0.093 | 0.044 | 0.041 | 0.035 | 0.043 | 0.051 |
| 6 | 0.088 | 0.206 | 0.266 | 0.126 | 0.116 | 0.099 | 0.122 | 0.146 |
| 7 | 0.132 | 0.307 | 0.395 | 0.188 | 0.172 | 0.148 | 0.182 | 0.218 |
| 8 | 0.145 | 0.338 | 0.435 | 0.206 | 0.190 | 0.163 | 0.200 | 0.240 |
| 9 | 0.170 | 0.396 | 0.509 | 0.242 | 0.222 | 0.191 | 0.235 | 0.281 |
| 10 | 0.165 | 0.386 | 0.497 | 0.236 | 0.217 | 0.186 | 0.229 | 0.274 |
| 11 | 0.160 | 0.374 | 0.481 | 0.229 | 0.210 | 0.180 | 0.222 | 0.265 |
| 12 | 0.112 | 0.261 | 0.336 | 0.159 | 0.147 | 0.126 | 0.155 | 0.185 |
| 13+ | 0.080 | 0.186 | 0.240 | 0.114 | 0.105 | 0.090 | 0.111 | 0.132 |
| Ave | 0.120 | 0.281 | 0.361 | 0.172 | 0.158 | 0.135 | 0.166 | |

Table 5. 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 |
|---|---|---|---|---|---|---|---|
| 5 | 11.1 | 7.7 | 30.2 | 39.6 | 22.9 | 46.4 | 26.5 |
| 6 | 6.9 | 9.3 | 5.9 | 23.6 | 32.0 | 19.2 | 39.1 |
| 7 | 4.8 | 5.5 | 5.9 | 3.7 | 18.0 | 24.4 | 15.3 |
| 8 | 5.3 | 3.7 | 3.3 | 3.3 | 2.6 | 12.7 | 17.5 |
| 9 | 18.9 | 3.7 | 2.4 | 1.4 | 2.3 | 1.7 | 9.3 |
| 10 | 29.5 | 13.0 | 1.9 | 1.2 | 0.9 | 1.5 | 1.2 |
| 11 | 12.4 | 20.2 | 6.4 | 0.9 | 0.8 | 0.6 | 1.1 |
| 12 | 10.2 | 8.6 | 12.2 | 3.7 | 0.6 | 0.5 | 0.4 |
| 13+ | 19.9 | 16.5 | 25.1 | 30.9 | 16.3 | 19.0 | 2.9 |

M=0.20

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| 5 | 12.9 | 8.7 | 33.7 | 42.3 | 23.1 | 44.3 | 24.5 |
| 6 | 7.9 | 10.3 | 6.5 | 25.2 | 32.6 | 18.5 | 35.4 |
| 7 | 5.5 | 6.0 | 6.4 | 4.0 | 18.4 | 23.7 | 13.8 |
| 8 | 6.0 | 4.1 | 3.5 | 3.5 | 2.6 | 12.3 | 16.0 |
| 9 | 21.1 | 4.1 | 2.6 | 1.5 | 2.3 | 1.6 | 8.4 |
| 10 | 33.0 | 14.1 | 2.0 | 1.3 | 0.9 | 1.5 | 1.1 |
| 11 | 13.6 | 22.0 | 6.9 | 1.0 | 0.8 | 0.6 | 1.0 |
| 12 | 10.6 | 9.1 | 12.9 | 3.9 | 0.6 | 0.5 | 0.4 |
| 13+ | 20.8 | 17.4 | 26.6 | 32.4 | 16.6 | 18.6 | 2.6 |

Table 6. Estimates of population size (millions of fish) of widow rockfish by age and year, obtained by catch-at-age analysis with lambda=0.5.

M=0.15

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| 5 | 11.4 | 7.8 | 29.1 | 43.3 | 17.9 | 33.1 | 19.0 |
| 6 | 7.8 | 9.4 | 6.2 | 22.7 | 35.6 | 14.8 | 27.5 |
| 7 | 4.6 | 6.1 | 6.5 | 4.0 | 17.1 | 27.3 | 11.6 |
| 8 | 5.4 | 3.4 | 3.7 | 3.7 | 2.8 | 12.4 | 20.5 |
| 9 | 17.1 | 4.0 | 2.0 | 2.0 | 2.5 | 2.0 | 9.2 |
| 10 | 33.3 | 12.2 | 2.2 | 1.0 | 1.4 | 1.8 | 1.5 |
| 11 | 14.4 | 23.8 | 6.9 | 1.1 | 0.7 | 0.9 | 1.3 |
| 12 | 15.3 | 10.4 | 13.6 | 3.5 | 0.8 | 0.5 | 0.7 |
| 13+ | 34.3 | 38.8 | 34.5 | 31.6 | 27.0 | 21.7 | 17.7 |

M=0.20

| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| 5 | 13.2 | 8.8 | 32.2 | 46.1 | 18.1 | 31.9 | 17.3 |
| 6 | 8.9 | 10.5 | 6.7 | 24.0 | 36.1 | 14.3 | 25.2 |
| 7 | 5.2 | 6.7 | 7.0 | 4.2 | 17.3 | 26.3 | 10.6 |
| 8 | 6.1 | 3.8 | 4.0 | 3.9 | 2.9 | 11.9 | 18.6 |
| 9 | 19.2 | 4.3 | 2.2 | 2.1 | 2.6 | 1.9 | 8.3 |
| 10 | 37.7 | 13.3 | 2.4 | 1.1 | 1.4 | 1.7 | 1.3 |
| 11 | 16.5 | 26.1 | 7.4 | 1.2 | 0.7 | 0.9 | 1.1 |
| 12 | 17.4 | 11.5 | 14.7 | 3.7 | 0.8 | 0.5 | 0.6 |
| 13+ | 36.3 | 40.2 | 34.6 | 30.9 | 25.2 | 19.1 | 14.6 |

Table 7. Estimates from cohort (GENCOH) and catch-at-age (CAGEAN) analysis of widow rockfish biomass and spawning stock (thousands of metric tons) from 1980 through 1988. Estimates for 1987 and 1988 from the current assessment (87 GENCOH and 87 CAGEAN) are averages for three recruitment cases, using projected number-at-age vectors. Similar projections were made for 1986 and 1987 in the 1986 assessment (86 GENCOH).

Biomass

| Year | M=0.15 | | | M=0.20 | | |
|---|---|---|---|---|---|---|
| | 86 GENCOH | 87 GENCOH | 87 CAGEAN | 86 GENCOH | 87 GENCOH | 87 CAGEAN |
| 1980 | 147.5 | 129.2 | 164.2 | 164.4 | 141.2 | 182.2 |
| 1981 | 99.6 | 96.4 | 138.5 | 108.0 | 104.1 | 148.3 |
| 1982 | 92.8 | 93.9 | 111.7 | 99.4 | 100.8 | 116.8 |
| 1984 | 76.1 | 76.7 | 93.9 | 77.5 | 77.9 | 91.8 |
| 1985 | 88.4 | 98.4 | 96.1 | 86.0 | 95.3 | 89.7 |
| 1986 | 87.4 | 80.3 | 94.2 | 83.7 | 73.0 | 83.1 |
| 1987 | 83.3 | 80.8 | 89.8 | 73.8 | 72.5 | 78.5 |
| 1988 | | 74.0 | 79.6 | | 65.9 | 68.2 |

Spawning stock

| Year | M=0.15 | | | M=0.20 | | |
|---|---|---|---|---|---|---|
| | 86 GENCOH | 87 GENCOH | 87 CAGEAN | 86 GENCOH | 87 GENCOH | 87 CAGEAN |
| 1980 | 134.9 | 116.6 | 151.1 | 150.0 | 126.9 | 167.2 |
| 1981 | 88.5 | 85.3 | 127.1 | 95.7 | 91.8 | 135.6 |
| 1982 | 75.7 | 75.9 | 93.8 | 80.6 | 80.8 | 97.1 |
| 1983 | 67.6 | 67.4 | 69.5 | 71.3 | 71.1 | 69.6 |
| 1984 | 45.8 | 46.6 | 64.3 | 46.7 | 47.3 | 61.1 |
| 1985 | 60.6 | 61.4 | 66.4 | 59.0 | 59.8 | 61.1 |
| 1986 | 60.0 | 42.5 | 65.6 | 55.8 | 38.6 | 57.0 |
| 1987 | 59.7 | 51.3 | 66.2 | 48.1 | 44.0 | 54.7 |
| 1988 | | 52.0 | 60.2 | | 43.0 | 47.2 |

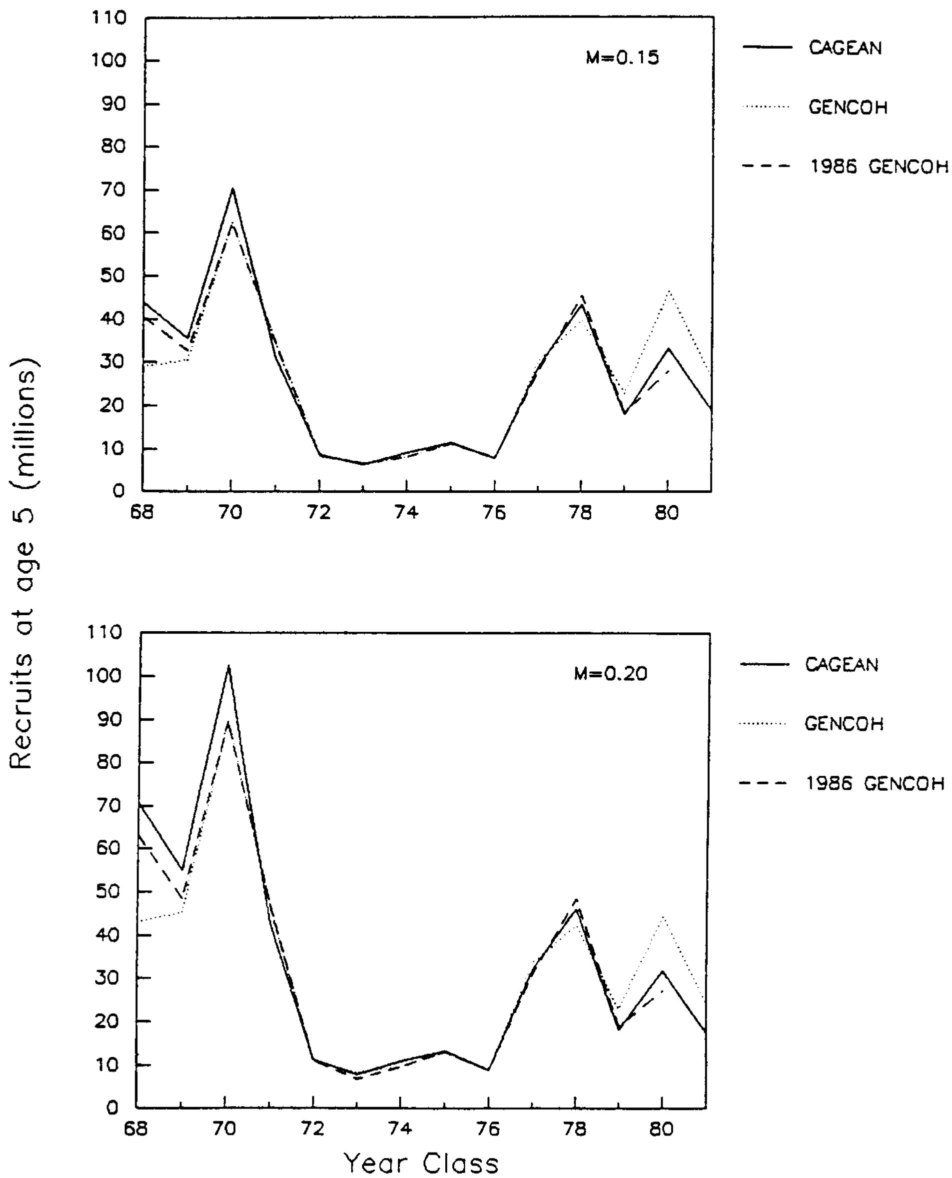


Figure 4. Estimates of widow rockfish recruitment at age 5 obtained from cohort (GENCOH) and catch-at-age analysis (CAGEAN). Estimates from the 1986 assessment (1986 GENCOH) are included for comparison.

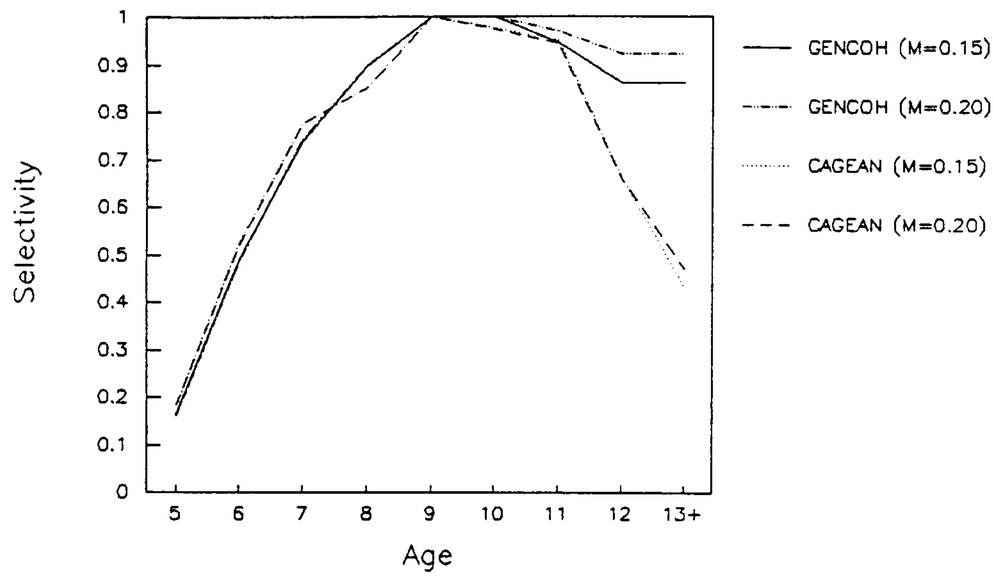


Figure 5. Estimates of age-specific selectivity for widow rockfish obtained by cohort (GENCOH) and catch-at-age analysis (CAGEAN) at two levels of natural mortality.

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).

One effect of the difference in selectivity patterns is that the estimated number of age-13+ fish differs substantially in some years for cohort and catch-at-age analysis (Tables 5 and 6). Results from catch-at-age analysis indicate that $F_{13+}$ is less than $F_{12}$; therefore, estimates of $N_{13+}$ and of stock biomass are generally higher than those from cohort analysis (Figure 6). Estimates of biomass at ages 5-12 are quite similar for the two approaches (Figure 6). Closer agreement in estimates of total biomass could be obtained by using some other assumption to estimate $F_{13+}$ in cohort analysis.

Equilibrium yield curves from cohort and catch-at-age analysis were similar to each other and to curves obtained in the 1986 assessment. As in earlier years, it appears that an F of 0.30 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). Assuming that MSY would be obtained at that level of effort, estimates of MSY from cohort analysis results range from 7,700 to 12,000 mt, with an average of 10,100 mt. Using results of catch-at-age analysis, estimates of MSY ranged from 7,800 to 12,200 mt, with an average of 10,200 mt.

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 effort policy with $F_9$=0.30 to forecast yields from 1988 to 1992, starting from the estimated number-at-age vector for 1988 (Table 8). The average yield would be 12,400-13,100 mt in 1987 and 11,100-11,900 mt in 1988, with an average of 12,500 mt from cohort analysis and 11,700 from catch-at-age analysis. The estimate from cohort analysis is equal to the 1987 ABC and OY, while the estimate from catch-at-age analysis is about 10 percent lower. Both analyses predict that a moderate reduction in landings will be warranted in 1990-1992 when the presumably weak 1983 year class is fully recruited. It appears that the ABC estimate from cohort analysis remains unchanged from the 1986 assessment because the upward revision in the size of the 1980 year class (Figure 4) offset the downward revision in the abundance of age-13+ fish (Table 5).

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 cohort analysis, we determined the levels of fishing mortality needed to produce constant yields of 9,000-15,000 mt (Table 9). Yields of 12,000-13,000 could be taken in 1988 and 1989, although a reduction in harvest would appear to be warranted by 1990.

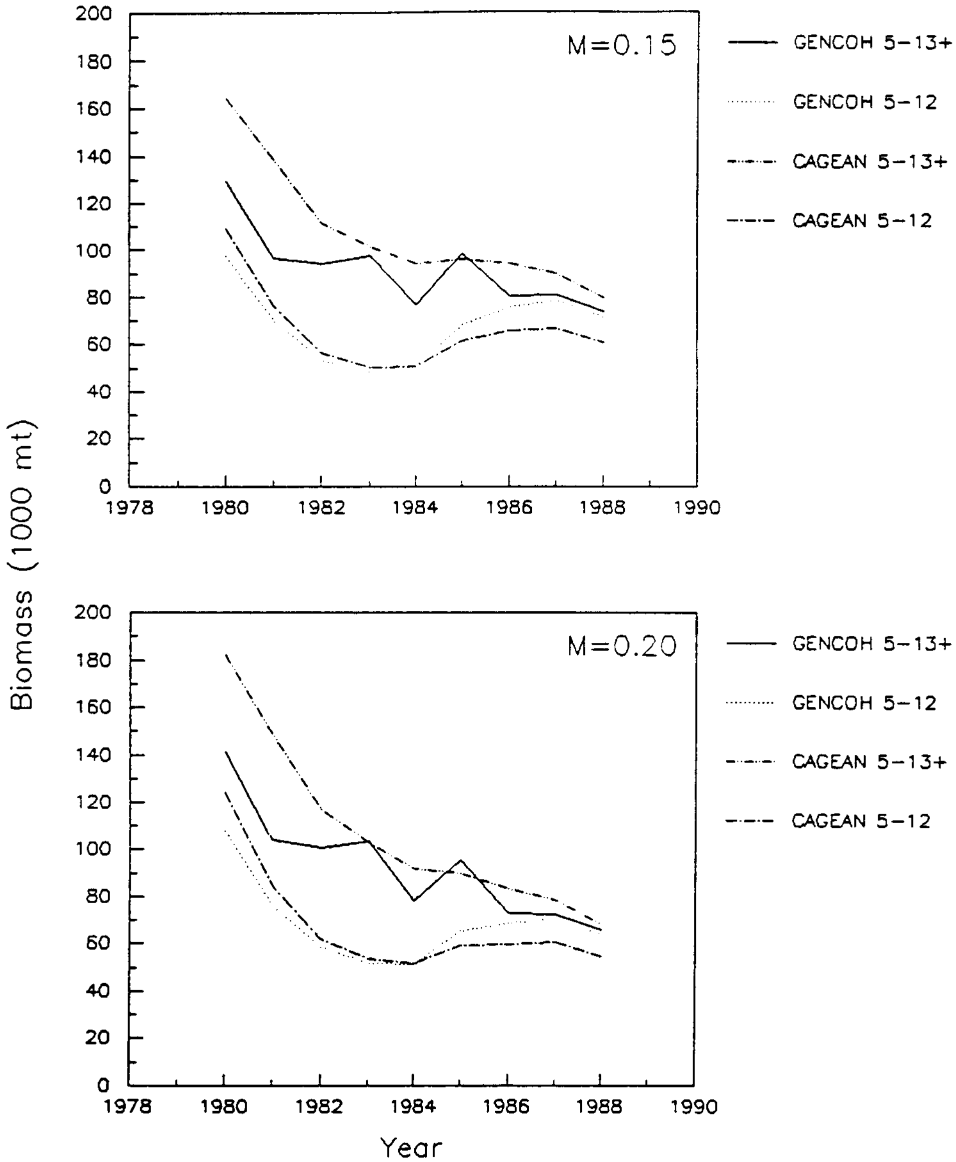


Figure 6. Estimates of widow rockfish biomass obtained by cohort (GENCOH) and catch-at-age analysis (CAGEAN) at two levels of natural mortality.

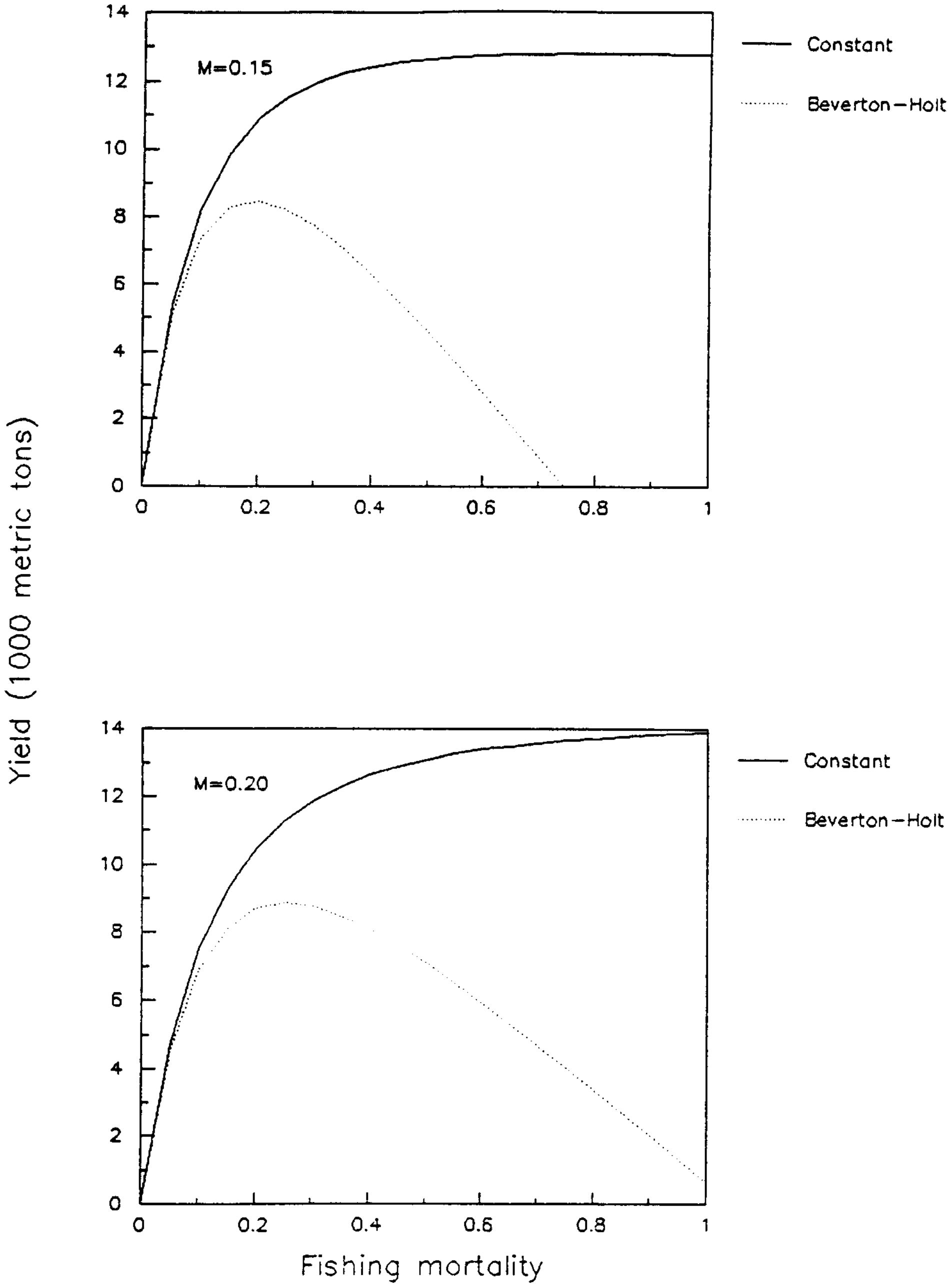


Figure 7. Estimates of equilibrium yield for widow rockfish based on results from cohort analysis.

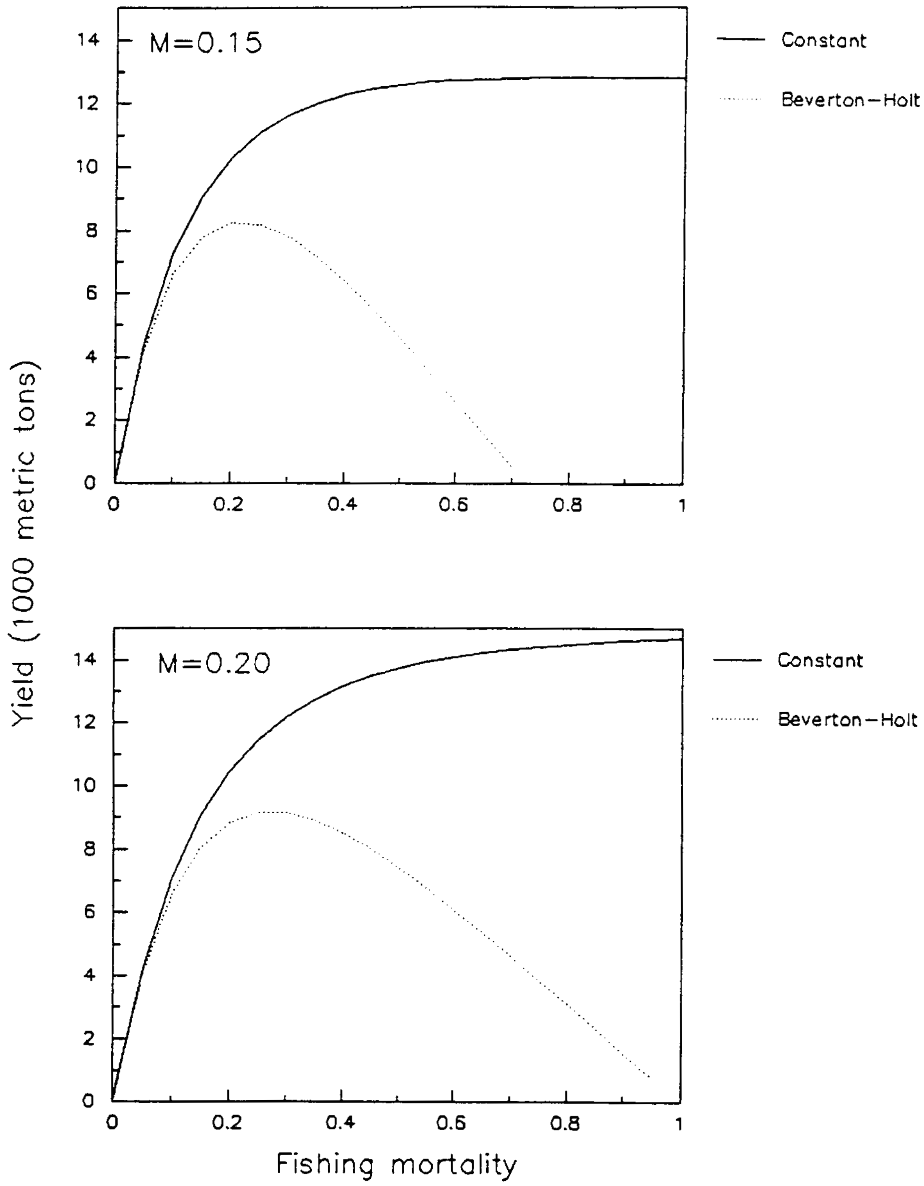


Figure 8. Estimates of equilibrium yield for widow rockfish based on results from catch-at-age analysis.

Table 8. Estimated yield (thousands of metric tons) when F for fully recruited fish is 0.3 for two values of M and three assumptions about recruitment.

Cohort analysis

| | Recruitment | | | | | | |
|---|---|---|---|---|---|---|---|
| | High | | Low | | Beverton-Holt | | Average |
| Year | M=0.15 | M=0.20 | M=0.15 | M=0.20 | M=0.15 | M=0.20 | |
| 1988 | 14.7 | 12.3 | 13.5 | 10.9 | 14.7 | 12.5 | 13.1 |
| 1989 | 13.5 | 11.3 | 11.6 | 9.3 | 13.7 | 11.9 | 11.9 |
| 1990 | 12.6 | 10.9 | 10.4 | 8.7 | 12.6 | 11.5 | 11.1 |
| 1991 | 12.1 | 10.9 | 10.1 | 8.9 | 11.8 | 11.1 | 10.8 |
| 1992 | 11.9 | 11.1 | 10.4 | 9.7 | 11.0 | 10.7 | 10.8 |
| Average | 13.0 | 11.3 | 11.2 | 9.5 | 12.8 | 11.5 | 11.5 |

Average for 1988 and 1989 (estimate of ABC): 12.5

Catch-at-age analysis

| | Recruitment | | | | | | |
|---|---|---|---|---|---|---|---|
| | High | | Low | | Beverton-Holt | | Average |
| Year | M=0.15 | M=0.20 | M=0.15 | M=0.20 | M=0.15 | M=0.20 | |
| 1988 | 14.1 | 11.6 | 12.7 | 9.7 | 14.2 | 12.0 | 12.4 |
| 1989 | 12.6 | 10.7 | 10.6 | 8.1 | 13.1 | 11.5 | 11.1 |
| 1990 | 11.6 | 10.3 | 9.5 | 7.9 | 11.9 | 11.1 | 10.4 |
| 1991 | 11.3 | 10.6 | 9.4 | 8.6 | 11.3 | 11.0 | 10.4 |
| 1992 | 11.2 | 11.0 | 9.8 | 9.5 | 10.9 | 10.9 | 10.6 |
| Average | 12.2 | 10.8 | 10.4 | 8.8 | 12.3 | 11.3 | 11.0 |

Average for 1988 and 1989 (estimate of ABC): 11.7

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

| | | Recruitment | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Target | | High | | Low | | 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 | 1988 | 0.17 | 0.21 | 0.19 | 0.24 | 0.17 | 0.21 | 0.20 |
| | 1989 | 0.17 | 0.22 | 0.21 | 0.28 | 0.17 | 0.20 | 0.21 |
| | 1990 | 0.17 | 0.21 | 0.22 | 0.29 | 0.17 | 0.20 | 0.21 |
| | 1991 | 0.17 | 0.21 | 0.22 | 0.29 | 0.17 | 0.20 | 0.21 |
| | 1992 | 0.17 | 0.20 | 0.21 | 0.27 | 0.18 | 0.20 | 0.21 |
| 10,000 | 1988 | 0.20 | 0.24 | 0.21 | 0.27 | 0.20 | 0.23 | 0.23 |
| | 1989 | 0.20 | 0.25 | 0.24 | 0.32 | 0.19 | 0.23 | 0.24 |
| | 1990 | 0.20 | 0.25 | 0.25 | 0.35 | 0.20 | 0.24 | 0.25 |
| | 1991 | 0.20 | 0.25 | 0.26 | 0.35 | 0.20 | 0.24 | 0.25 |
| | 1992 | 0.20 | 0.24 | 0.26 | 0.33 | 0.21 | 0.24 | 0.25 |
| 11,000 | 1988 | 0.22 | 0.27 | 0.24 | 0.30 | 0.22 | 0.26 | 0.25 |
| | 1989 | 0.22 | 0.28 | 0.27 | 0.37 | 0.22 | 0.27 | 0.27 |
| | 1990 | 0.23 | 0.29 | 0.30 | 0.41 | 0.23 | 0.27 | 0.29 |
| | 1991 | 0.23 | 0.29 | 0.31 | 0.43 | 0.24 | 0.28 | 0.30 |
| | 1992 | 0.23 | 0.29 | 0.31 | 0.40 | 0.25 | 0.29 | 0.29 |
| 12,000 | 1988 | 0.24 | 0.29 | 0.26 | 0.33 | 0.24 | 0.29 | 0.28 |
| | 1989 | 0.25 | 0.32 | 0.30 | 0.42 | 0.25 | 0.30 | 0.31 |
| | 1990 | 0.26 | 0.34 | 0.34 | 0.49 | 0.26 | 0.31 | 0.33 |
| | 1991 | 0.27 | 0.35 | 0.37 | 0.52 | 0.28 | 0.33 | 0.35 |
| | 1992 | 0.28 | 0.35 | 0.38 | 0.50 | 0.30 | 0.35 | 0.36 |
| 13,000 | 1988 | 0.26 | 0.32 | 0.29 | 0.37 | 0.26 | 0.31 | 0.30 |
| | 1989 | 0.28 | 0.36 | 0.34 | 0.48 | 0.27 | 0.33 | 0.34 |
| | 1990 | 0.30 | 0.39 | 0.40 | 0.58 | 0.30 | 0.36 | 0.39 |
| | 1991 | 0.32 | 0.41 | 0.44 | 0.63 | 0.32 | 0.39 | 0.42 |
| | 1992 | 0.33 | 0.42 | 0.46 | 0.62 | 0.36 | 0.42 | 0.43 |
| 14,000 | 1988 | 0.28 | 0.35 | 0.31 | 0.40 | 0.28 | 0.34 | 0.33 |
| | 1989 | 0.31 | 0.40 | 0.38 | 0.54 | 0.30 | 0.37 | 0.38 |
| | 1990 | 0.34 | 0.44 | 0.46 | 0.68 | 0.33 | 0.41 | 0.44 |
| | 1991 | 0.37 | 0.48 | 0.52 | 0.77 | 0.37 | 0.45 | 0.49 |
| | 1992 | 0.39 | 0.50 | 0.56 | 0.79 | 0.43 | 0.51 | 0.53 |
| 15,000 | 1988 | 0.31 | 0.38 | 0.34 | 0.43 | 0.31 | 0.37 | 0.36 |
| | 1989 | 0.34 | 0.44 | 0.42 | 0.61 | 0.34 | 0.41 | 0.43 |
| | 1990 | 0.38 | 0.51 | 0.53 | 0.81 | 0.38 | 0.47 | 0.51 |
| | 1991 | 0.42 | 0.57 | 0.63 | 0.95 | 0.44 | 0.53 | 0.59 |
| | 1992 | 0.46 | 0.61 | 0.70 | 1.01 | 0.52 | 0.63 | 0.66 |

## Discussion

Estimates of F-at-age and population size were generally similar for cohort analysis and catch-at-age analysis. A reasonable level of agreement would be expected since the same year-to-year changes in F were induced in both analyses. These additional assumptions were required in order to stabilize the estimates. Because the assumptions were based on our understanding of stock dynamics and of regulations controlling effort in the developing fishery, the resulting estimates should be more reliable than if no additional assumptions were made.

Estimates of long-term average productivity (average recruitment levels and MSY) from the 1986 and 1987 assessments were in close agreement. In addition, biomass estimates show an encouraging degree of stability from year to year, as have recent estimates of ABC. In the current assessment, both stock reconstruction techniques indicate that total biomass (ages 5+) has declined more or less steadily from 1980 to 1987. Biomass of fish ages 5-12 has been relatively stable after 1985, due to the strength of the 1977-1980 year classes. If, as expected, the 1983 year class is weak, a reduction in ABC to about 10,000 mt appears likely for 1989 or 1990. Better estimates will be possible once the size of the 1983 year class can be estimated from catch data.

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