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**Re-evaluation of the 32-inch
Commercial Size Limit**

by

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ABSTRACT

Intrinsic growth parameters of female and male halibut, and the length-specific selectivity of the commercial setline fishery, were estimated by fitting a simple model to catch composition data collected in Areas 2B and 3A in 1990 and 1991. Area-specific schedules of female maturity as a function of length were estimated using data collected during the 1980s. Yield per recruit and spawning biomass per recruit of halibut in Area 2B and 3A were calculated using the new estimates of growth, selectivity, and maturity. The results showed the current 32-inch commercial size limit to be appropriate. (At time of publication in mid-1995, it is clear that halibut life history parameters have changed considerably since 1990. The size limit is therefore being reviewed again.)

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INTRODUCTION

Since 1973 the Commission has set a coastwide minimum size limit of 32 in (81 cm) for commercial halibut landings. This size limit was based on a study by Myhre (1974), who calculated yield per recruit for various ages of recruitment to the commercial fishery assuming a release mortality in the vicinity of 25% and a full-recruitment instantaneous fishing mortality rate in the range 0.2–0.4. The calculations were done using a single deterministic growth schedule for both sexes coastwide and a single age-specific selectivity schedule for longline gear.

In the work reported here, we have updated our estimates of growth, selectivity, and maturity schedules, and we have calculated in much greater detail the effect of alternative size limits. Our specific aims in this work were:

- (i) to perform the calculations for females and males separately, because females grow substantially faster than males.
- (ii) to perform the calculations with average growth schedules estimated for each regulatory area, because fish in Alaska grow faster than fish in Canada and the lower U.S.
- (iii) to perform the calculations with length-specific selectivity schedules estimated for each regulatory area, because fish in Canada and the lower U.S. recruit at a smaller size than fish in Alaska.
- (iv) to perform the calculations with updated estimates of average growth, because growth rates appear to have decreased in recent years, especially in Alaska.
- (v) to perform the calculations allowing for the large variance in size at age observed in halibut.
- (vi) to calculate the effect of alternative size limits and fishing mortality rates on female spawning biomass per recruit as well as yield per recruit.

Our re-estimation of life history parameters and re-evaluation of the size limit are reported below. The results generally support continuation of the 32-inch size limit, and the Commission has followed that advice. At time of publication in mid-1995, however, it is clear that a further dramatic reduction in halibut growth has occurred, as well as a shift of the maturity schedule to smaller sizes. The appropriateness of the 32-inch size limit is therefore in question again, and the staff will very soon conduct a new analysis.

ESTIMATION OF GROWTH AND SELECTIVITY PARAMETERS

Effects of size-selective fishing

It is not a straightforward matter to estimate growth and selectivity parameters from catch data because size selection affects the observed size at age both directly and indirectly. The direct effect is obvious: large fish are more vulnerable to setline gear than small fish, for example, so the mean size at age in setline catches is larger than in the stock as a whole. The indirect effect is less obvious: the mean size at age in the stock is lower than it would be in the absence of a fishery because the larger fish are more vulnerable and therefore relatively less numerous than they would be in the absence of a fishery.

Both of these effects are illustrated in Figure 1 with growth and selectivity parameters that (as will be explained below) are appropriate for female halibut in Area 3A. Vulnerability to the NMFS trawl survey increases sharply from about 40 cm to 65 cm, then decreases gradually (Figure 1a). Vulnerability to the commercial setline fishery increases gradually from about 50 to 100 cm and does not decrease thereafter. The intrinsic (unfished) growth schedule is approximately linear, and the intrinsic standard deviation of length at age increases moderately with age (Figure 1b). Full-recruitment fishing mortality in the setline fishery is assumed to be 0.3, the approximate average during the 1980s. With these parameters, the commercial setline fishery reduces the true mean length at age in the stock considerably among the older age groups. The observed mean length at age *in the catch* is quite different for different gears. The trawl survey catch shows a mean length at age much lower than the true (fished) value among the older age groups. On the other hand, the mean length at age in the setline catch is not so different from the true mean length at age in the (fished) stock, and the observed standard deviation of length at age is hardly affected by gear type or level of exploitation.

Just as the distribution of size at age in trawl and setline catches can be predicted from the underlying growth, mortality and selectivity parameters, so can the underlying growth and selectivity parameters be estimated from the observed distribution of size at age in trawl and setline catches. Deriso and Parma (1988) developed a model and estimation theory for the case in which variance in length at age results from independent stochastic variation in growth increments. They extended the analysis to include variation among individuals in one growth parameter and fitted the model to commercial halibut data from Areas 2A and 2B, data which did not distinguish females and males and did not include fish below the commercial size limit (Parma and Deriso 1990).

Model specification

In the present study, a similar model has been fitted to setline and trawl data from research cruises in Areas 2B and 3A in which the sexes were distinguished and all sublegals were recorded, so the parameter estimates are better defined by the data. The setline data are from simulated commercial operations on charter cruises in 1989 and the trawl data from the NMFS Gulf of Alaska survey in 1990, which included a number of stations in Canadian waters fished under Commission auspices. The main features of the model fitted to these data were:

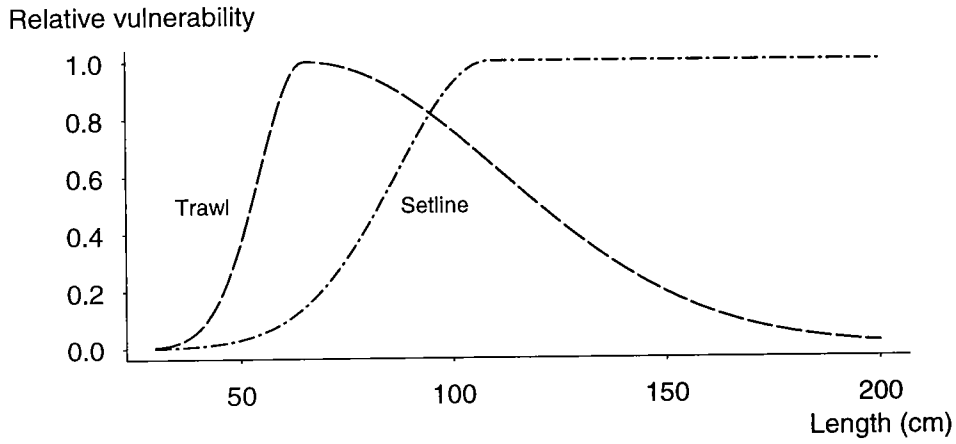


Figure 1a. Length-specific selectivity of setlines and trawls (Area 3).

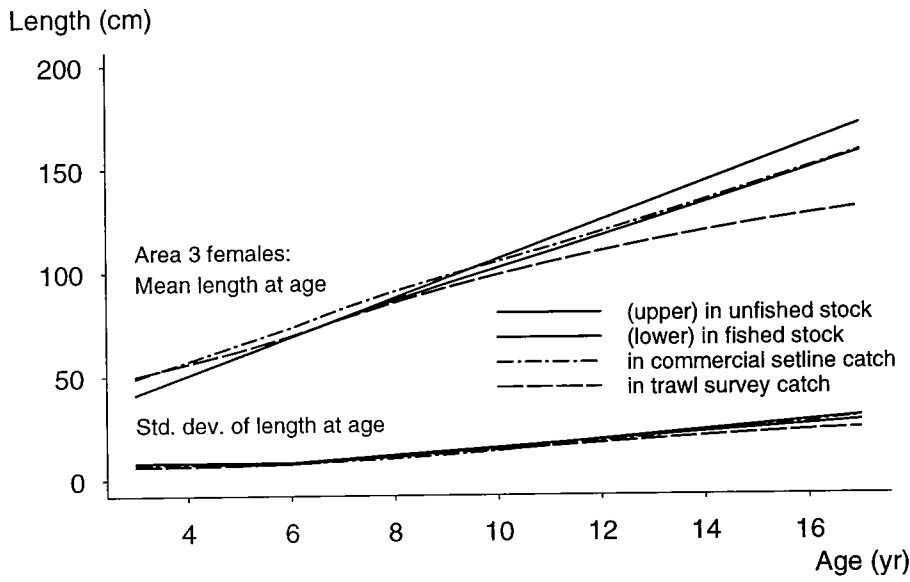


Figure 1b. Effect of size selection on length at age in the stock and the catch.

(i) Average length at age in the unfished stock was a linear function of age, with separate functions for males and females. Previous studies (McCaughran 1981, 1987) have shown that growth is approximately linear after the first few years of life. With x denoting length and t age, the growth function was:

$$E(x_t) = a + b \cdot t$$

(ii) The standard deviation of length at age in the unfished stock was a linear function of age (and therefore of mean length), with separate functions for males and females:

$$V(x_t) = (c + d \cdot t)^2$$

At lower ages the standard deviation of length is flat, so the value at age 6 was used for all younger age groups (3, 4, and 5 in model fits).

(iii) Fish grew in echelon, meaning that a fish which was one standard deviation above the mean length at age three, was one standard deviation above the (unfished) mean length at age fourteen. This was a simplification of the Parma-Deriso (1990) model in that all of the variance in length at age was ascribed to variation among fish in deterministic growth parameters, and none to stochastic variation in growth increments. It was adopted after initial trials with the Parma-Deriso model because it involved much less computation and because in the case of linear growth it is nearly impossible to distinguish the two sources of variance anyhow.

(iv) The length-specific selectivity of fishing gear was represented by two half-normals with a common peak, allowing for vulnerability to increase to the maximum at one rate and then decrease at some other rate (or not decrease at all) beyond the maximum. Separate functions were of course fitted for setline and trawl gear, but a single function was assumed to apply to both females and males. Let $S(x)$ denote relative vulnerability at length x , x_f the (smallest) length at full vulnerability, k_l the slope coefficient on the left (ascending) side of the curve, and k_r the slope coefficient on the right side beyond x_f . Then the selectivity function was:

$$S(x) = \exp(-k_l(x - x_f)^2) \text{ for } x \leq x_f$$

and

$$S(x) = \exp(-k_r(x - x_f)^2) \text{ for } x > x_f$$

(v) The relative abundance in the sea of the age groups present in the catches in 1989 and 1990, and the sequence of fishing mortality rates that they had sustained during the 1980's, were taken from the 1992 stock assessment. (In fact a smoother was run through the CAGEAN estimates of initial year-class strength to capture the trend in recruitment rather than the exact values of the estimates, and an average of the recruitment and fishing mortality series from Areas 2B and 3A were used because the trends were very similar.)

(vi) Natural mortality was taken to be 0.2.

The model therefore contained 14 parameters to be estimated for each area (2B and 3A): four growth parameters for females, four for males, three parameters for length-specific selectivity of setline gear, and three for the length-specific selectivity of the NMFS trawl survey. This sounds like a large number of parameters, but as explained

above the growth parameters are in fact quite well determined by the mean and variance of length at age in the catches, and the left limbs of the selectivity functions are quite well determined by the length distribution of the catches (and the calculated underlying length distribution of the stock). The only parameter that is not very well determined is the slope coefficient on the right side of the trawl selectivity function. Owing to the scarcity of very large fish in the catches by trawl gear, the right side of the selectivity function can be raised or lowered without much affecting the fit of the model to the bulk of the data. Only a few days of trawling were done in Area 2B, so the estimate of trawl selectivity as a whole in this area is weak.

Fitting procedures

Least-squares parameter estimates were obtained by fitting the model numerically to all of the following data (starting at age 5 for setline catches and at age 3 for trawl catches):

- (i) Mean and variance of length at age of females and males in setline and trawl catches.
- (ii) Age distribution of females and males in setline and trawl catches.
- (iii) Length distribution of females and males in setline and trawl catches.
- (iv) Proportion of females at each length in setline and trawl catches.
- (v) CAGEAN estimates of age-specific selectivity (relative to the age-specific selectivities implied by the length-specific selectivities estimated by the model in conjunction with the calculated sex and length composition of each age group).

For most of these data sets, the model fit was similar to a data smoother run through the data, so it was possible to obtain good estimates of the residual variance of each data set about the model fit and re-weight the component sums of squares accordingly. In a few cases, however, the weights were adjusted to influence the fit. In particular, it was necessary to add weight to the age-specific selectivities in Area 3A to obtain a fit that agreed reasonably well with CAGEAN. (The CAGEAN age-specific selectivities, in conjunction with the growth parameter estimates, predict more small females in the setline catch than were observed. Disregarding the CAGEAN age-specific selectivities would shift the Area 3A length-specific setline selectivity upward, but only by a few centimeters.)

Results

Parameter estimates are listed in Table 1, and the fit of the model to the various data sets is shown in Figures 2-6 for Area 3A and in Figures 7-11 for Area 2B.

The model predictions are in good agreement with the data from both areas. That is, the model fit shows the same general features as the data in all respects: size at age, age composition, length composition, and sex composition. This result indicates that recruitment to the setline fishery and the NMFS trawl survey is largely determined by size selection.

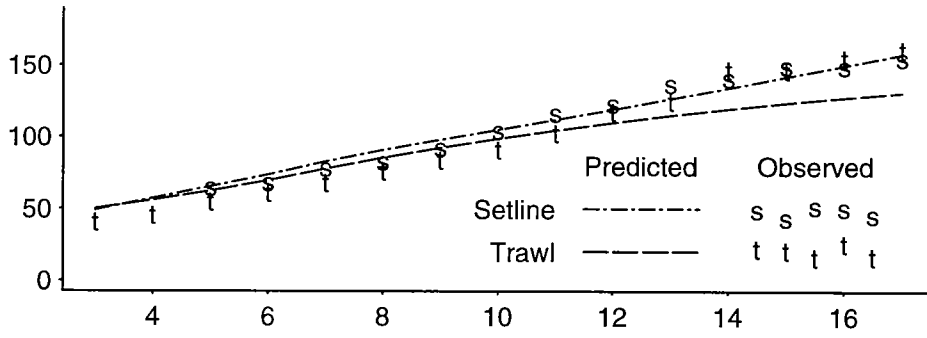
The model predictions are also in good agreement with CAGEAN estimates of age-specific selectivity, although as mentioned above this required some extra effort. It was considered important to achieve that agreement, however, because the CAGEAN estimates are very stable and are based on many years of very large data sets collected from the fishery as a whole, whereas the setline data used in this study came from only a few trips.

The model fits indicate quite conclusively that setline selectivity does not decrease with length beyond some point; i.e., setline selectivity is asymptotic. For trawl selectivity the overall model fits are not conclusive on this point, but a comparison of the length compositions of trawl and setline catches of only large fish showed that at least in Area 3A, vulnerability did decrease with size.

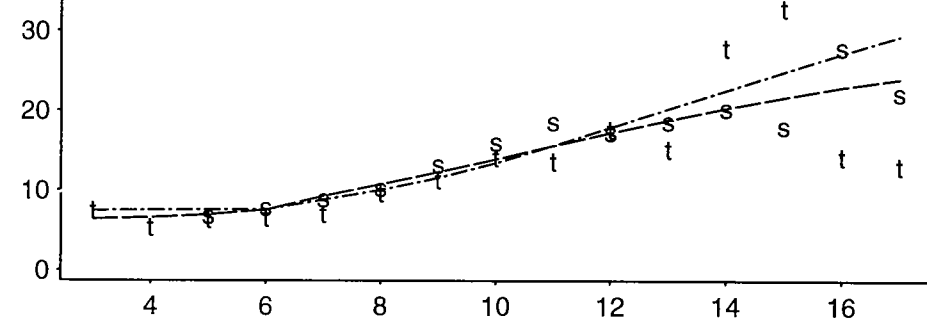
Table 1. Estimates of halibut growth and selectivity parameters.

| Parameter | Symbol | Area 3A | Area 2B |
|--|--------|----------|----------|
| Female mean length at age | | | |
| Intercept | a | 13.23 | 34.99 |
| Slope | b | 9.27 | 6.43 |
| Female standard deviation of length at age | | | |
| Intercept | c | -2.27 | -6.26 |
| slope | d | 1.75 | 2.17 |
| Male mean length at age | | | |
| Intercept | a | 31.16 | 38.93 |
| Slope | b | 5.03 | 4.39 |
| Male standard deviation of length at age | | | |
| Intercept | c | 1.73 | -0.38 |
| Slope | d | 0.65 | 0.60 |
| Setline selectivity | | | |
| Slope of left limb | k_l | 0.001013 | 0.002436 |
| (Length at 50% recruitment) | — | 82.72 | 79.18 |
| Length at full recruitment | x_f | 108.88 | 96.05 |
| Slope of right limb | k_r | 0 | 0 |
| Trawl selectivity | | | |
| Slope of left limb | k_l | 0.004465 | 0.019063 |
| (Lower length at 50% recruitment) | — | 52.58 | 65.06 |
| Length at full recruitment | x_f | 65.04 | 71.09 |
| Slope of right limb | k_r | 0.000229 | 0.004798 |
| (Upper length at 50% recruitment) | — | 120.00 | 83.11 |

Mean length at age



Std. dev. of length at age



Relative age frequencies

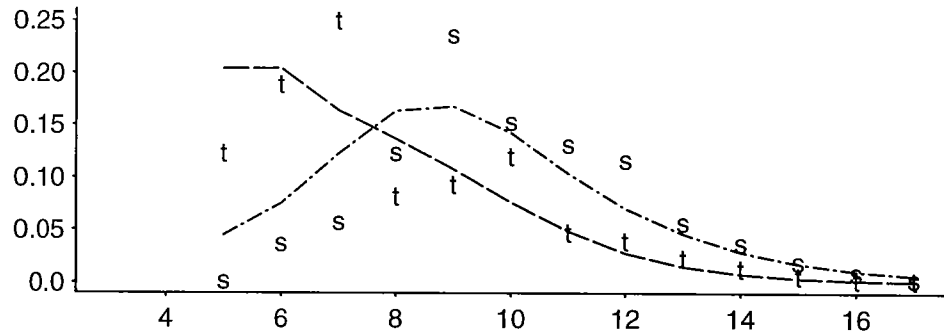


Figure 2. Predicted and observed features of female catches in Area 3.

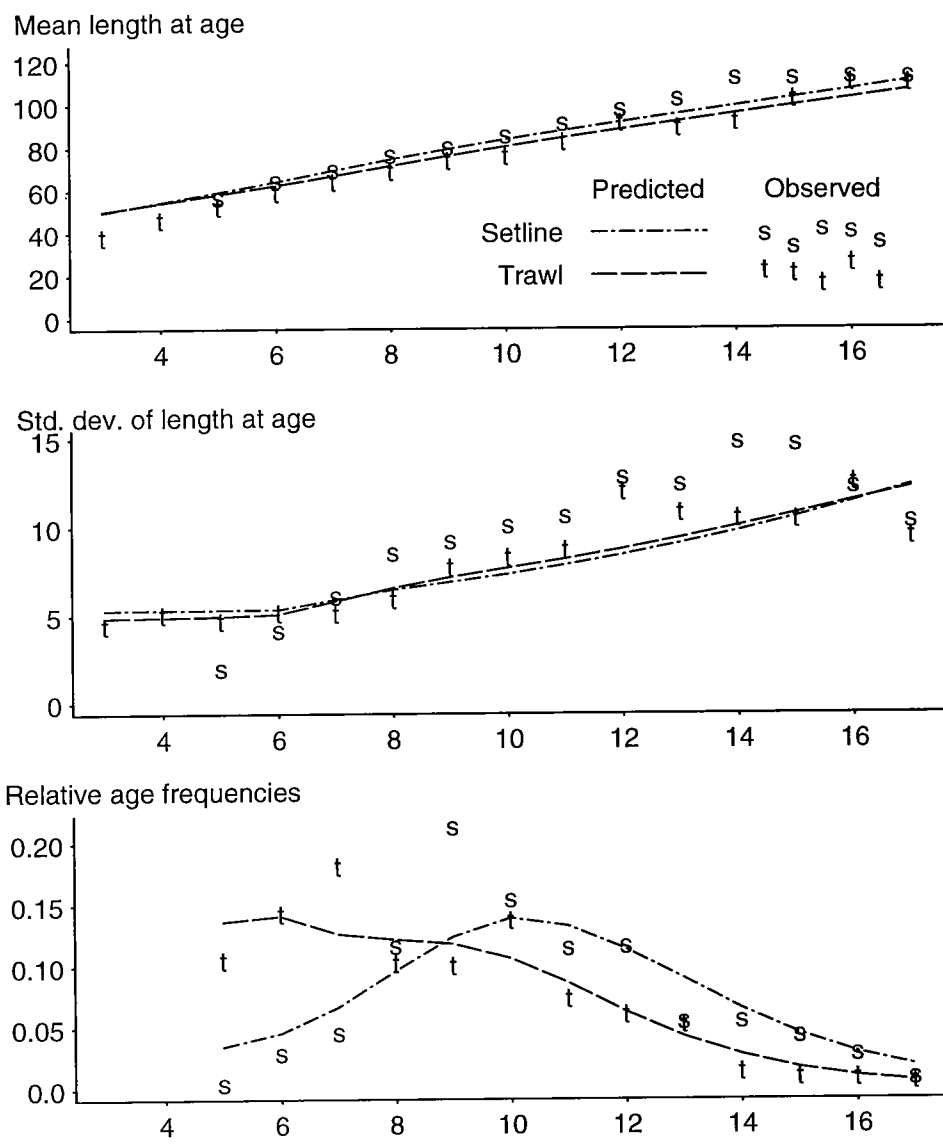


Figure 3. Predicted and observed features of male catches in Area 3.

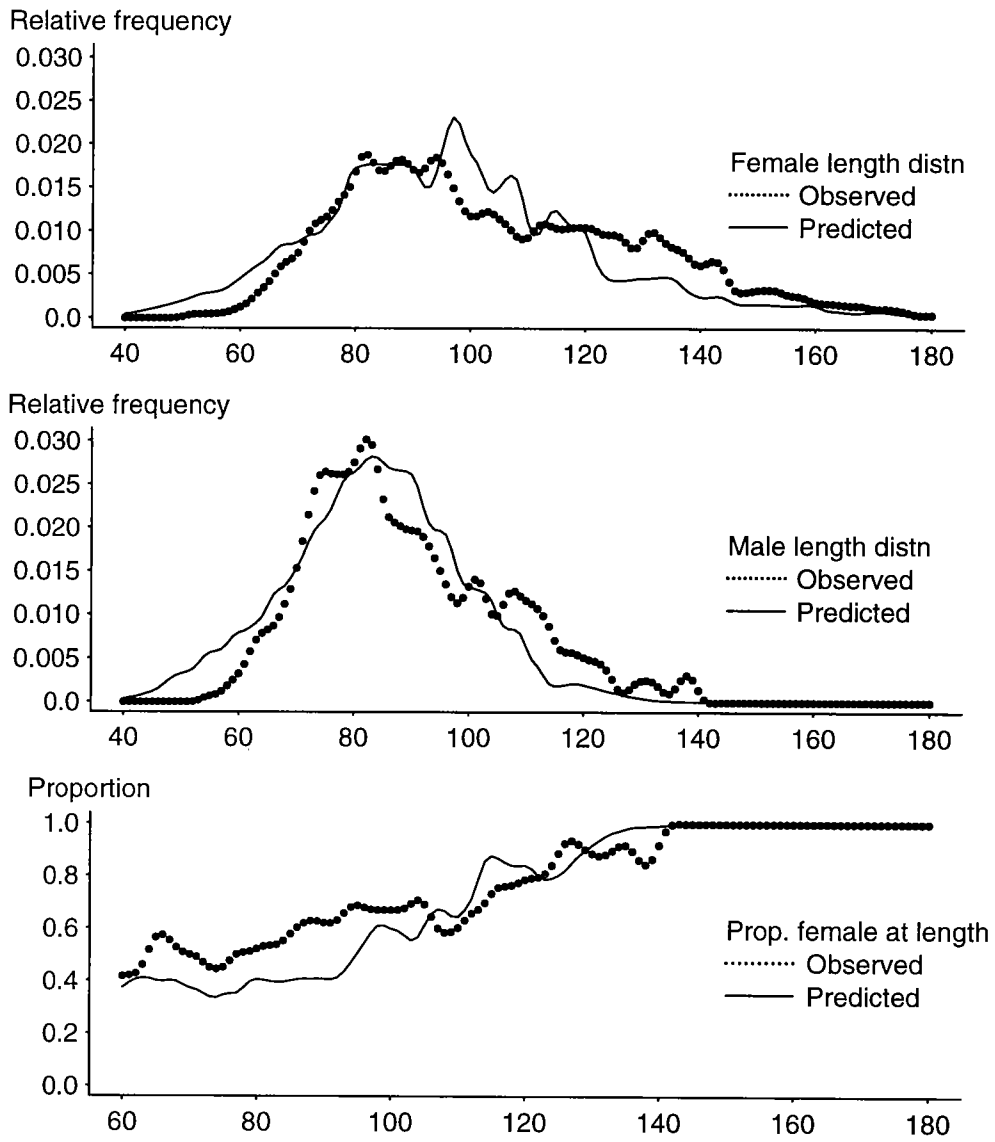


Figure 4. Predicted and observed features of setline catches in Area 3.

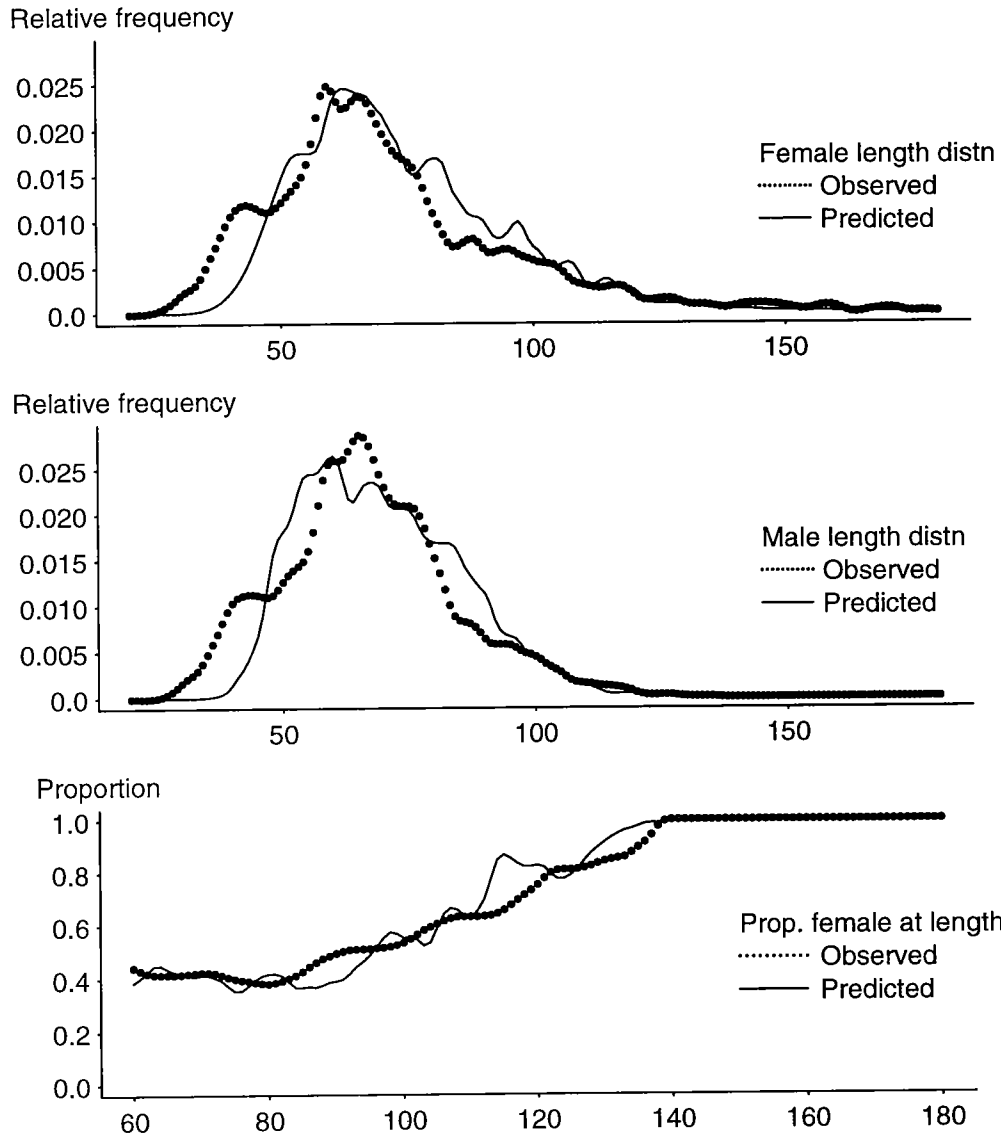


Figure 5. Predicted and observed features of trawl catches in Area 3.

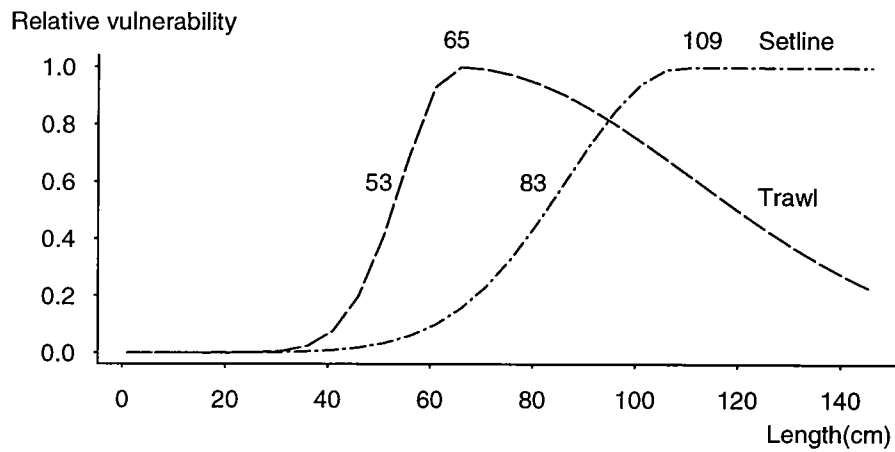


Figure 6a. Estimated length-specific selectivity curves in Area 3.
(Numbers on graphs indicate lengths of 50% and 100% recruitment to each gear.)

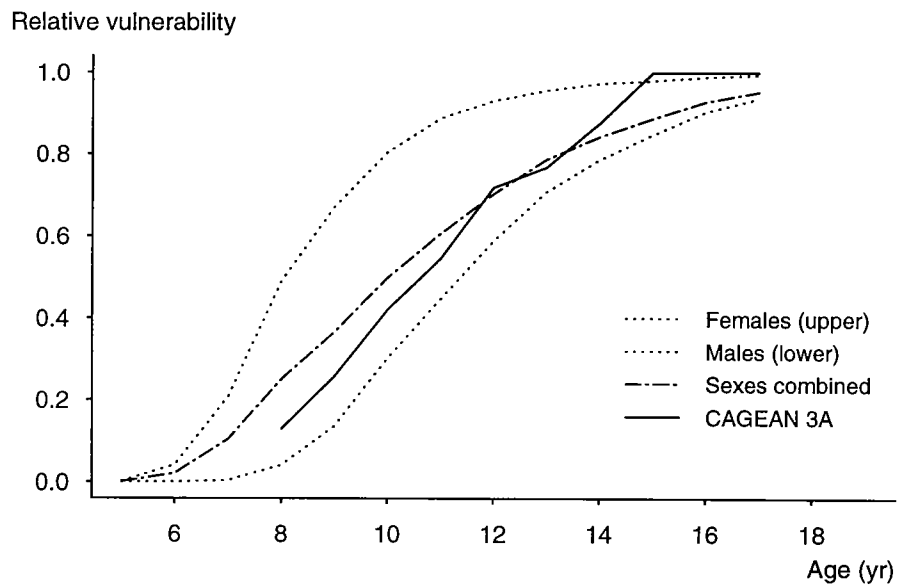


Figure 6b. Age-specific selectivities predicted by the model, and those estimated by CAGEAN.

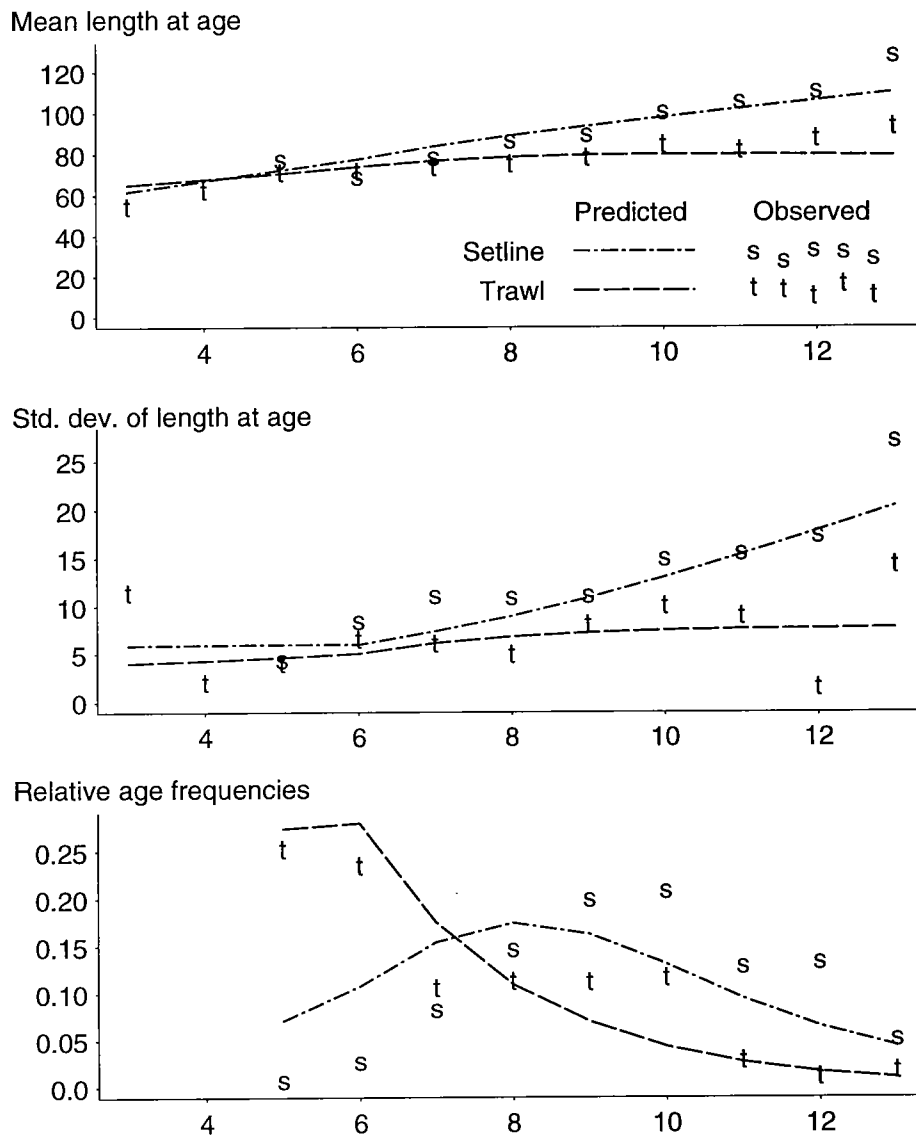
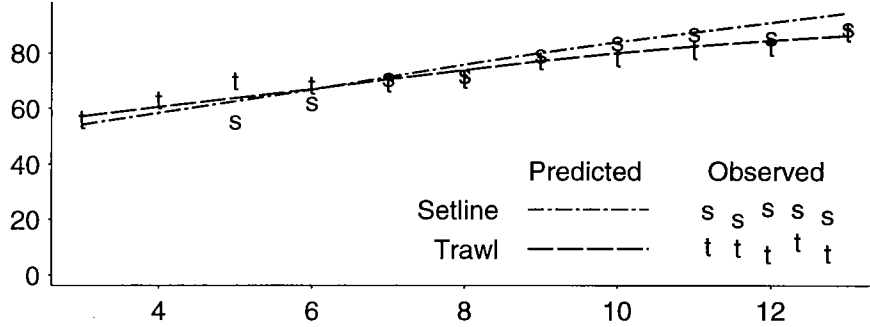
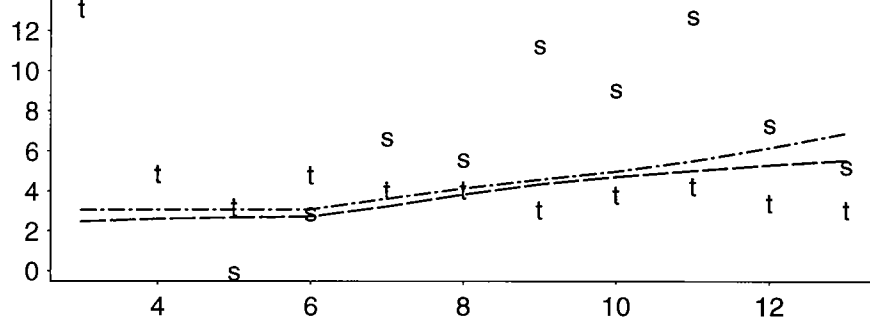


Figure 7. Predicted and observed features of female catches in Area 2B.

Mean length at age



Std. dev. of length at age



Relative age frequencies

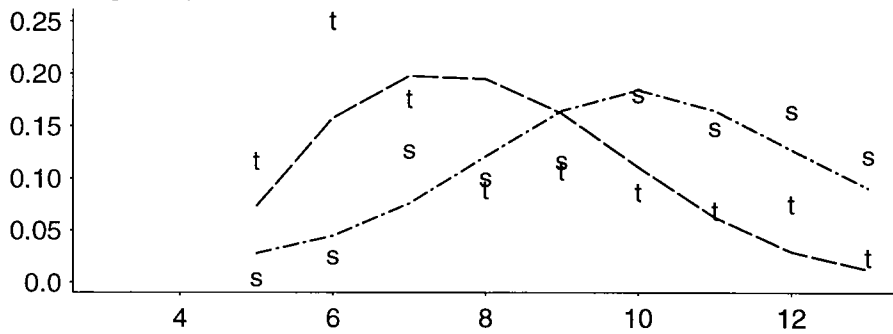


Figure 8. Predicted and observed features of male catches in Area 2B.

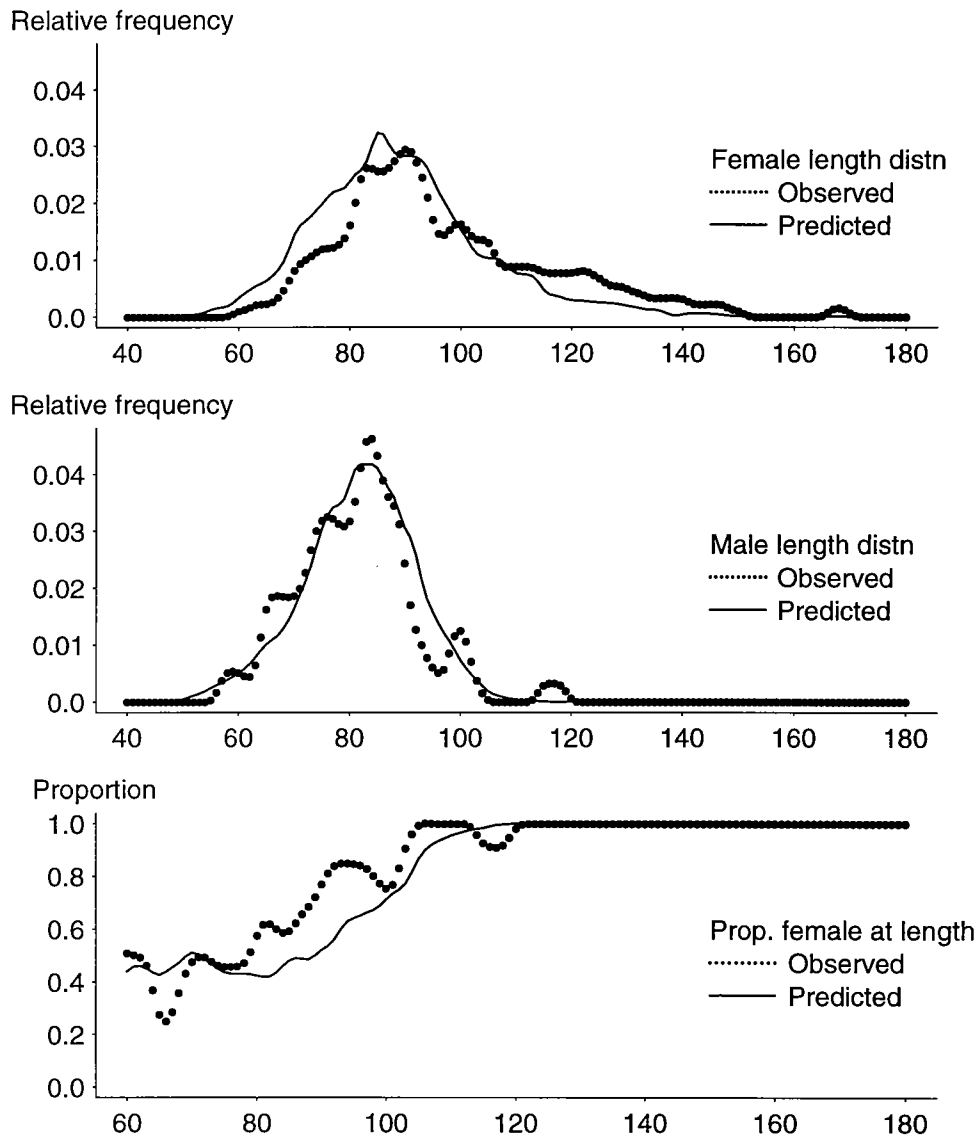


Figure 9. Predicted and observed features of setline catches in Area 2B.

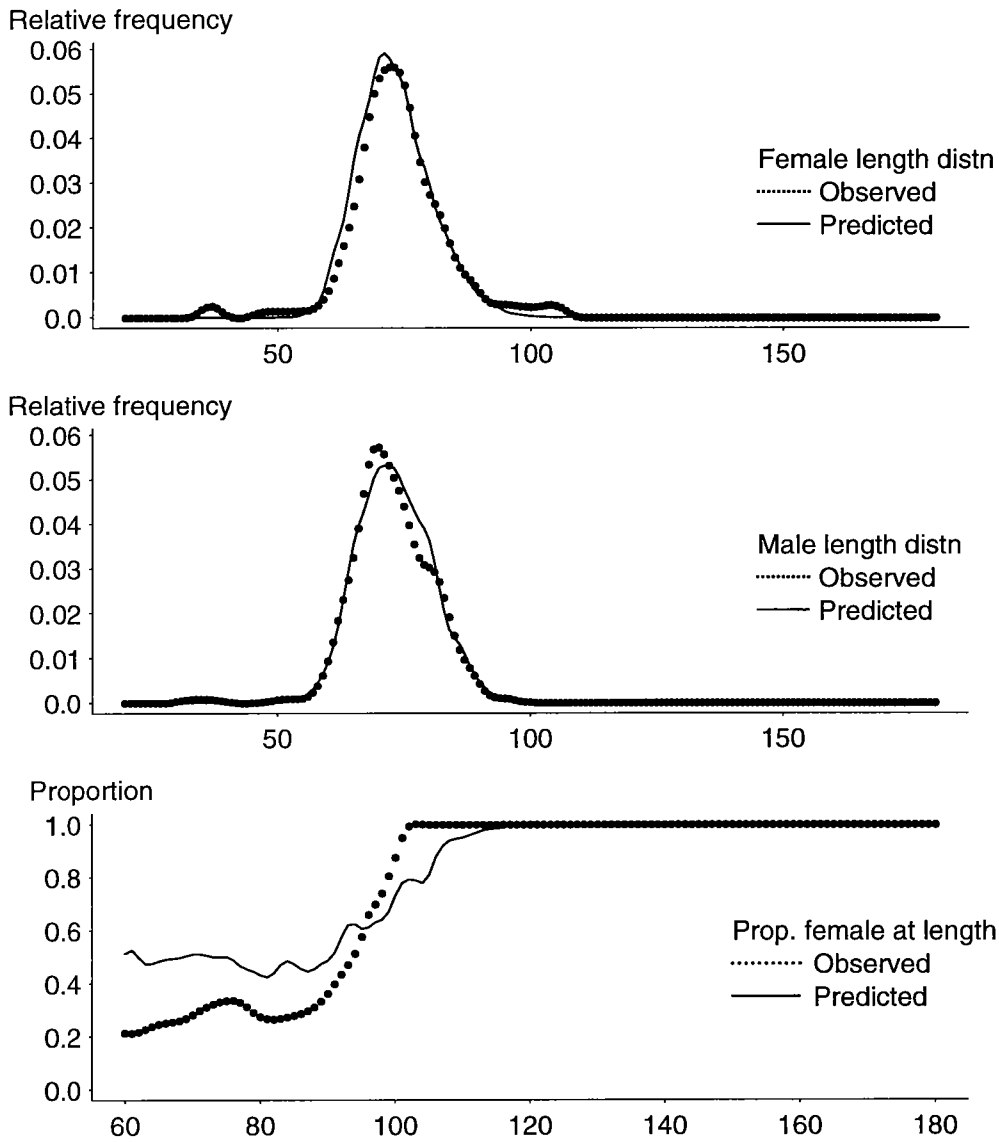


Figure 10. Predicted and observed features of trawl catches in Area 2B.

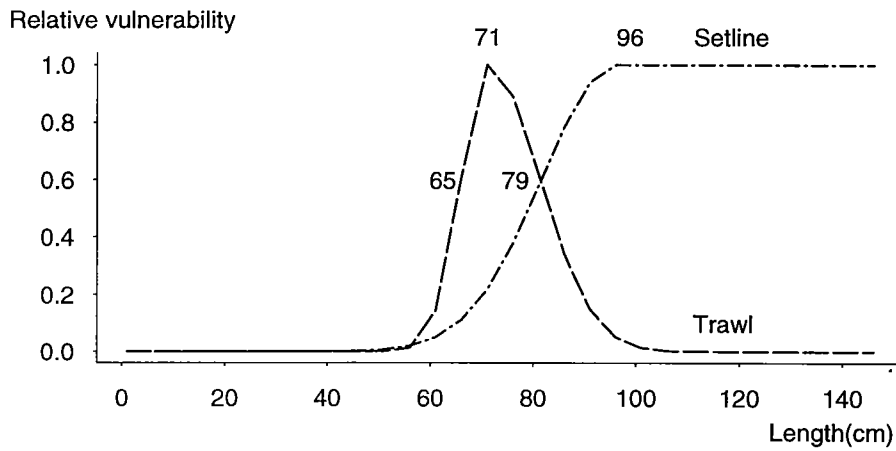


Figure 11a. Estimated length-specific selectivity curves in Area 2B.
(Numbers on graphs indicate lengths of 50% and 100% recruitment to each gear.)

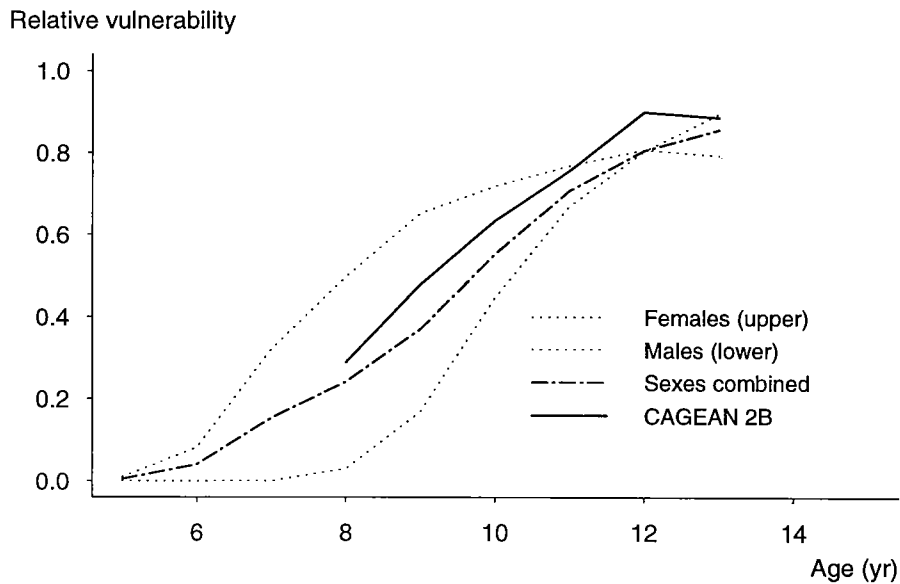


Figure 11b. Age-specific selectivities predicted by the model, and those estimated by CAGEAN.

ESTIMATION OF MATURITY AS A FUNCTION OF LENGTH

The purpose of this project was to estimate area-specific schedules of female maturity as a function of fish length using data collected during the 1980s. In addition, earlier data collected since 1960 were analyzed in order to explore possible changes in maturity over time.

Data available

Maturity observations were made during many research cruises conducted by IPHC. Maturity status was determined on board by visual examination of the gonads, as explained in St-Pierre (1984). The reliability of the method was evaluated by Schmitt (1985), who found that visual determinations of maturity were in good agreement with those made by applying serological techniques, when both winter and summer samples were analyzed. Only data collected in the months of March through September were used in the present study; winter samples were excluded because maturity fractions may be biased due to spatial segregation of immature and mature females during the spawning season. Preliminary exploration of the data indicated that the proportion of females mature at each size tends to be larger in winter than in summer samples; this is in agreement with observations made in previous studies (Schmitt and Skud 1978). A summary of the number of data available by year and regulatory area is shown in Table 2. Data were pooled by regulatory area, and three periods (1960-1969, 1970-1979, and 1980-1984) were analyzed separately.

Methods

The analysis was conducted using the statistical package GLIM (Generalized Linear Interactive Modelling, Aitkin et al. 1989). The maturity status was treated as a binomial response variable, with value 1 for mature and 0 for immature. The expected probability that a female of length l was mature, $p(l)$, was assumed to be a linear function of length, on the logit scale, so that

$$\ln \left[\frac{p(l)}{1-p(l)} \right] = a + bl$$

The error was assumed to be binomially distributed. The length at which 50% of the females are mature is given by

$$L_{0.5} = -\frac{a}{b}$$

Confidence intervals for $L_{0.5}$ were approximated by computing the profile deviance,

$$-2\ell(L_{0.5}) : -2 \text{ times the log-likelihood conditioned on } L_{0.5}$$

The 95% confidence interval consisted of those values of $L_{0.5}$ for which $-2\ell(L_{0.5})$ was within $\chi_{0.05,1}^2$ units of its minimum value.

Results and discussion

The logistic model provided a good fit to the data on proportion of females mature as a function of size (Figure 12). Length at 50% maturity tended to be smaller in

Table 2. Number of data by year and regulatory area.

| Year | 2B | 2C | 3A | 3B | 4 |
|------|------|------|------|------|------|
| 1960 | 1155 | 1014 | | | |
| 1961 | | | 69 | 100 | 54 |
| 1962 | | | 20 | 5 | 7 |
| 1963 | | | 2173 | | |
| 1964 | | | 564 | 2533 | 1689 |
| 1965 | 589 | | | 383 | 305 |
| 1966 | 711 | 13 | 18 | | |
| 1967 | | | | | 4000 |
| 1968 | 184 | | | | 36 |
| 1969 | | | | | 36 |
| 1971 | 3 | | 459 | | |
| 1972 | 468 | | | 446 | |
| 1973 | 155 | | | | |
| 1975 | | | 102 | | 209 |
| 1976 | 118 | | | | 559 |
| 1977 | | | 222 | | |
| 1978 | | | 189 | | |
| 1979 | | 484 | | | |
| 1980 | 262 | | 737 | 735 | |
| 1981 | 211 | | 1105 | 782 | 36 |
| 1982 | 107 | 452 | 713 | 702 | 53 |
| 1983 | 91 | | 359 | | |
| 1984 | 2 | | | | 459 |

the southern regulatory areas than in Areas 3B and 4 (Table 3). Likelihood-based confidence intervals for $L_{0.5}$ were always extremely narrow, about 1 to 1.5 cm around the point estimate, so they were not included in the table. On the other hand, when samples collected in different locations and dates within the same period were compared, variability of the maturity fractions among the different samples was substantial, with the sigmoid trends shifting by up to 10 cm on the x-axis (Figure 13). This small-scale temporal and spatial heterogeneity was averaged out when the data were pooled.

Comparisons of data collected in different periods indicate some changes in the maturity schedule over time (Figure 14). In Areas 3A, 3B and 4, females tended to mature at a somewhat larger size in the 1980s than in the 1970s and 1960s. The opposite pattern was evident in Area 2B, and no trend was apparent in Area 2C. Changes of the same sign were found by Schmitt and Skud (1978), who also used data collected during the 1950s in their comparisons. These changes are relatively minor, and probably reflect that maturity is a function of both size and age, and so size-specific schedules of maturity change following changes in growth rate.

Table 3. Parameter values of the female maturity function with respect to length estimated for each regulatory area and period.

| Period | Area | $L_{0.5}$ | b |
|--------|------|-----------|--------|
| 1980's | 2B | 111.17 | 0.0996 |
| | 2C | 120.36 | 0.1537 |
| | 3A | 125.42 | 0.1239 |
| | 3B | 134.89 | 0.1279 |
| | 4 | 135.98 | 0.1306 |
| 1970's | 2B | 115.04 | 0.0076 |
| | 2C | — | — |
| | 3A | 124.40 | 0.0110 |
| | 3B | 130.34 | 0.0314 |
| | 4 | 122.68 | 0.0831 |
| 1960's | 2B | 120.44 | 0.1262 |
| | 2C | 120.86 | 0.1452 |
| | 3A | 119.91 | 0.1406 |
| | 3B | 127.56 | 0.1480 |
| | 4 | 125.07 | 0.1001 |

Table 4. Parameter values of the female maturity function with respect to age estimated for each regulatory area and period.

| Period | Area | $A_{0.5}$ | b |
|--------|------|-----------|--------|
| 1980's | 2B | 10.97 | 0.6696 |
| | 2C | 11.60 | 1.0700 |
| | 3A | 11.50 | 0.7972 |
| | 3B | 11.82 | 0.8876 |
| | 4 | 12.14 | 1.1470 |
| 1970's | 2B | 10.49 | 0.5682 |
| | 2C | — | — |
| | 3A | 10.55 | 1.1530 |
| | 3B | 11.39 | 1.1670 |
| | 4 | 12.24 | 0.8979 |
| 1960's | 2B | 11.77 | 0.6590 |
| | 2C | 12.22 | 0.7715 |
| | 3A | 10.53 | 0.9091 |
| | 3B | 11.32 | 0.9602 |
| | 4 | 13.71 | 0.9503 |

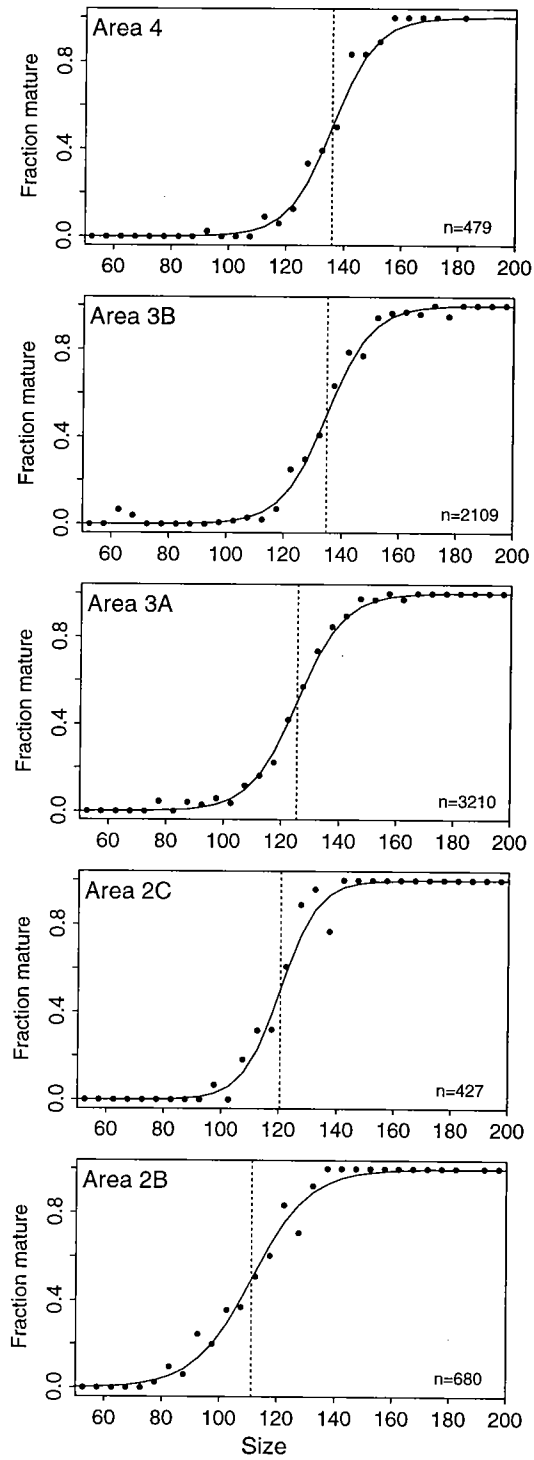


Figure 12. Observed and predicted fractions of females mature as a function of size in each regulatory area, based on data collected during the 1980's. Vertical lines indicate the estimated size at 50% maturity.

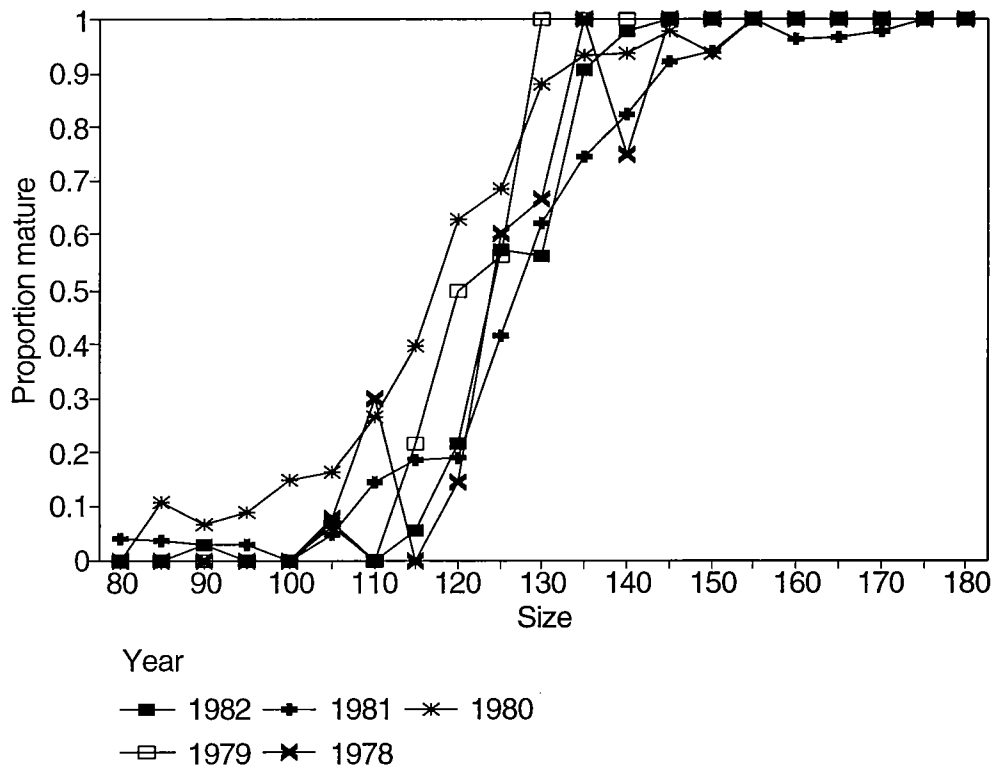


Figure 13. Proportion of females mature as a function of size observed in different cruises conducted in Area 3A in the period 1979-1982.

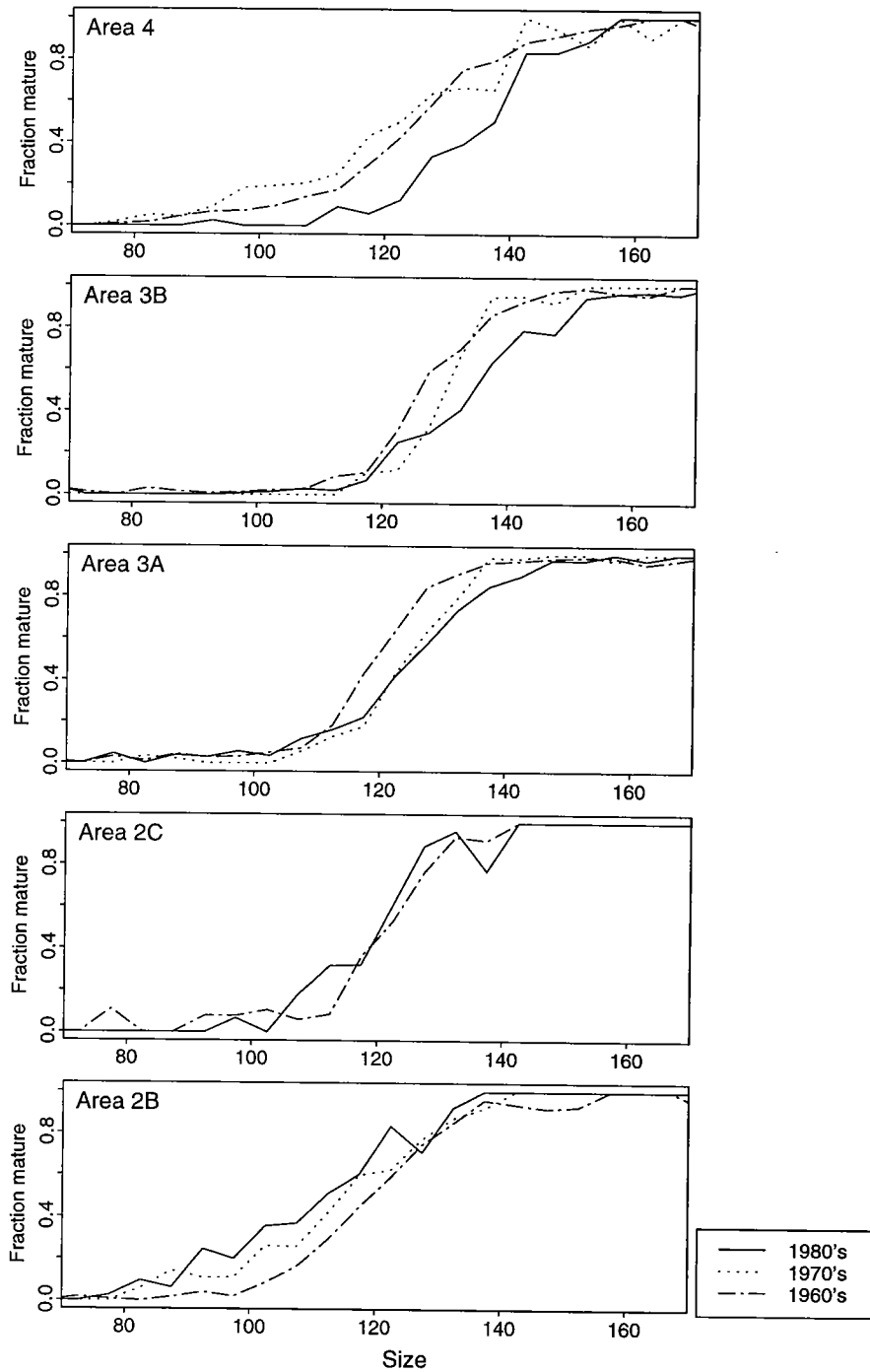


Figure 14. Proportion of females mature as a function of size for the different regulatory areas and periods.

EFFECT OF THE SIZE LIMIT ON YIELD PER RECRUIT AND SPAWNING BIOMASS PER RECRUIT

Methods

Yield per recruit and spawning biomass per recruit were calculated for a range of fishing mortality rates and minimum size limits using the fitted model of sex-specific growth and size selective fishing described above and the length-specific estimates of sexual maturity of females reported above. Yield per recruit was calculated for females and males combined, spawning biomass per recruit for females only. All parameters were estimated separately for each area (2B and 3A). Important features of the model are:

(i) All of the variance in length at age is ascribed to differences among individual fish in growth parameters and none to stochastic variation in realized growth increments. Moreover, fish grow in echelon, meaning that the larger juvenile fish remain the larger fish throughout life. This description of the variance of length at age maximizes the effect of size selective fishing in reducing mean size at age and consequently spawning biomass per recruit.

(ii) Length-specific selectivity of the commercial setline fishery is asymptotic, with the ascending limb described by a half-normal. In both areas the present length at 50% recruitment was estimated to be about 81 cm—the present size limit. Above that length vulnerability increased somewhat more rapidly in Area 2B (reaching 100% around 95 cm) than in Area 3A (where it reaches 100% at about 110 cm).

(iii) Setline discard mortality is taken to be 15%, in line with more recent estimates.

(iv) Natural mortality is taken to be 0.2.

(v) The calculations are carried through age 20 only, with no consideration of the contribution of older fish to yield or spawning. The practical effect of excluding the very oldest fish must be small, and going beyond age 20 would require extrapolating the model beyond the range of the data used to estimate growth parameters.

A critical question in calculating the effect of a change in the size limit is the extent to which the observed length-specific selectivity of the fleet is influenced by the size limit. In British Columbia (Area 2B), for example, it appears that after the size limit was imposed, the fleet shifted its effort away from grounds that produced a substantial proportion of small fish. If the size limit were reduced, these grounds might be fished again, effectively shifting the fleet's length-specific selectivity function downward. In the same way, an increase in the size limit might shift the distribution of effort among grounds in such a way as to shift the selectivity function upward.

There is no objective way to predict how selectivity might shift in response to a change in the size limit, so all of the calculations were done for two extreme cases:

(i) *Fixed selectivity.* The assumption here is that length-specific selectivity would be unaffected by a change in the size limit; i.e., that 50% recruitment to the setline catch would stay at about 80 cm even if the size limit were much higher or much lower. In this case a large reduction in the size limit would not have much effect because the model predicts that the fleet could not catch many fish much below 80 cm anyway. On the other side, a large increase in the size limit would result in a large increase in discard mortality because the model predicts that the fleet could not avoid fish much over 80 cm.

(ii) *Variable selectivity.* The assumption here is that if the size limit changed, the fleet

would change its operations in such a way that the length at 50% recruitment would be equal to the minimum size limit, as it is at present. In this case a reduction in the size limit would increase the mortality and catch of fish under 80 cm (which are predominantly males), and an increase in the size limit would lower the mortality of fish over 80 cm.

Results and discussion

The results are shown in Figures 15-18 for fixed and variable selectivity in Areas 2B and 3A. In each figure, the upper panel shows contours of equal yield per recruit (isopleths) as a proportion of the theoretical maximum, and the lower panel shows contours of equal female spawning biomass per recruit as a proportion of the unfished level. In all figures, the status quo is shown to fall at a size limit of 81 cm and a fishing mortality rate of 0.4, which is midway between the average 0.3 applied during the 1980s and the target 0.5 corresponding to 35% of exploitable biomass.

On the whole, the results indicate that yield per recruit is near the maximum at present. In Area 2B the size limit could be eliminated with no loss in yield per recruit, and an increase in the size limit would probably result in a significant loss in yield per recruit. In Area 3A the situation is reversed: the size limit could be increased (at least to 100 cm) with no loss in yield per recruit, but eliminating the size limit could result in a significant loss.

Spawning biomass per recruit is low at present in all cases—around 10% of the unfished level—mostly because on average female halibut do not mature until reaching quite a large size: 112 cm in Area 2B and 125 cm in Area 3A. Because of this, they sustain about five years of fishing mortality before reaching maturity at present.

The figures show that spawning biomass per recruit is very sensitive to the rate of fishing mortality and not very sensitive to the size limit. The only exception is the case of variable selectivity in Area 2B (Figure 2), where removing the size limit would bring about a further substantial reduction in spawning biomass per recruit.

On the basis of the results presented here, we do not recommend a change in the commercial size limit at this time. We are, however, concerned that the present rate of exploitation is reducing the spawning biomass per recruit to levels that are extremely low relative to the unfished level. This, together with the results of other studies (Parma 1992), was one reason for lowering the target exploitation rate from 35% to 30% in 1994.

Size limits in the sport fishery

At present there is no size limit in the sport fishery except off Oregon. Fish below the commercial size limit account for about half the sport caught fish by number but only about a quarter by weight coastwide. In some areas, however, the sport catch consists mostly of small fish.

Hooking mortality of halibut released by anglers has been estimated to be quite similar to discard mortality in the commercial fishery. The length selectivity of the sport fishery also appears to be quite similar to that of commercial longline gear: there are hardly any fish under 60 cm in the sport catch, the mode is around 80 cm, and large fish are well represented. In terms of the calculations described above, therefore, the sport fishery is about the same as the commercial longline fishery with fixed selectivities and no size limit.

Yield per recruit in this case is slightly higher with no size limit in Area 2B (Figure 15), and is unaffected in Area 3A (Figure 17). Spawning biomass per recruit is also unaffected by removing the size limit. On the basis of the sorts of calculations done here, therefore, there is no reason to impose the size limit on the sport fishery. (If the length selectivity of the commercial fishery were known to be fixed rather than variable, there would be no reason to have a commercial size limit either.)

Another effect to consider is the interception of migrating juveniles by the sport fishery. Because recruitment of halibut in Southeast Alaska, British Columbia, and the lower U.S. consists of juveniles migrating from the west and north, it is likely that the catch of small fish in the sport fishery reduces recruitment in downstream areas. Thus the sport fishery in Alaska probably takes some recruits bound for British Columbia, and the sport fishery in British Columbia probably takes some recruits bound for the lower U.S. This effect is probably small, because almost all the fish in the sport fishery are over 65 cm, and tagging studies have shown that these fish are less migratory than smaller halibut.

Further work is needed on the size selectivity of the sport fishery in each area (including data collection in Southeast Alaska and British Columbia) before it can be concluded positively that a size limit is not needed in the sport fishery.

LITERATURE CITED

- Aitkin, M., D. Anderson, B. Francis, and J. Hinde. 1989. Statistical modelling in GLIM. Oxford University Press, pp 373.
- Deriso, R. B., and A. M. Parma. 1988. Dynamics of age and size for a stochastic population model. *Can. J. Fish. Aquat. Sci.* 45:1054-1068.
- McCaughran, D. A. 1981. Estimating growth parameters for Pacific halibut from mark-recapture data. *Can. J. Fish. Aquat. Sci.* 38:394-398.
- McCaughran, D. A. 1987. Growth in length of Pacific halibut, p. 507-515. *In: Summerfelt, R. C., and G. E. Hall (ed.). The age and growth of fish.* Iowa State University Press, Ames, Iowa.
- Myhre, R. J. 1974. Minimum size and optimum age of entry for Pacific halibut. *Int. Pac. Halibut Comm. Sci. Report No. 55:15p.*
- Parma, A. M. 1992. Retrospective catch-at-age analysis of Pacific halibut: implications on assessment of harvesting policies. *In: Proceedings of the International Symposium on Management of Exploited Populations*, pp. 247-266. Alaska Sea Grant Report 93-02, University of Alaska Fairbanks.
- Parma, A. M., and R. B. Deriso. 1990. Dynamics of age and size composition in a population subject to size-selective mortality: effects of phenotypic variability in growth. *Can. J. Fish. Aquat. Sci.* 47:274-289.
- Schmitt, C. 1985. Evaluation of two methods to determine maturity of female Pacific halibut *Hippoglossus stenolepis*. Unpublished manuscript.
- Schmitt, C. C., and B. E. Skud. 1978. Relation of fecundity to long-term changes in growth, abundance and recruitment. *Int. Pac. Halibut Comm. Sci. Report No. 66: 31p.*
- St-Pierre, G. 1984. Spawning locations and season for Pacific halibut. *Int. Pac. Halibut Comm. Sci. Report No. 70: 45p.*

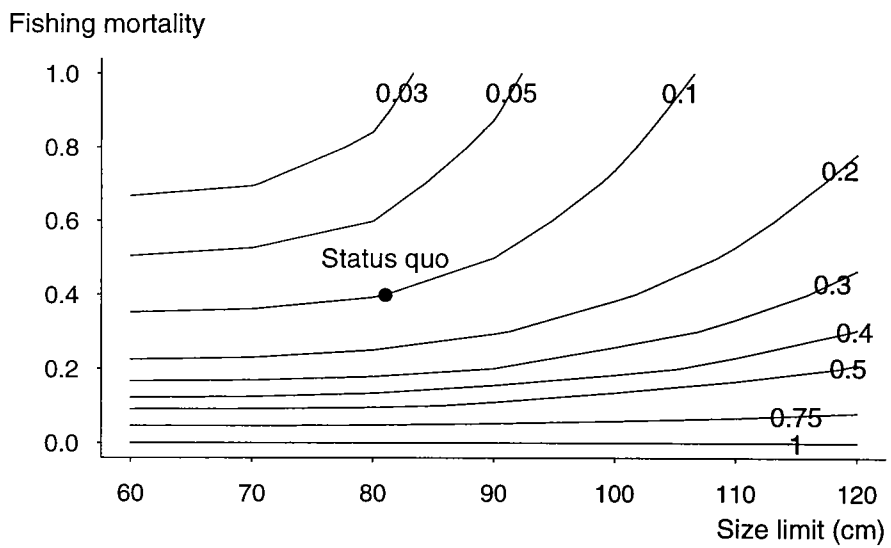
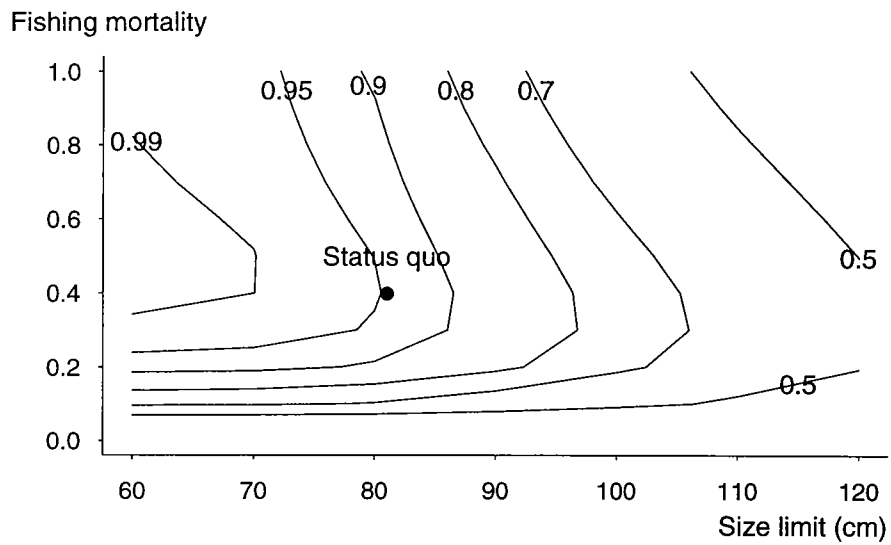
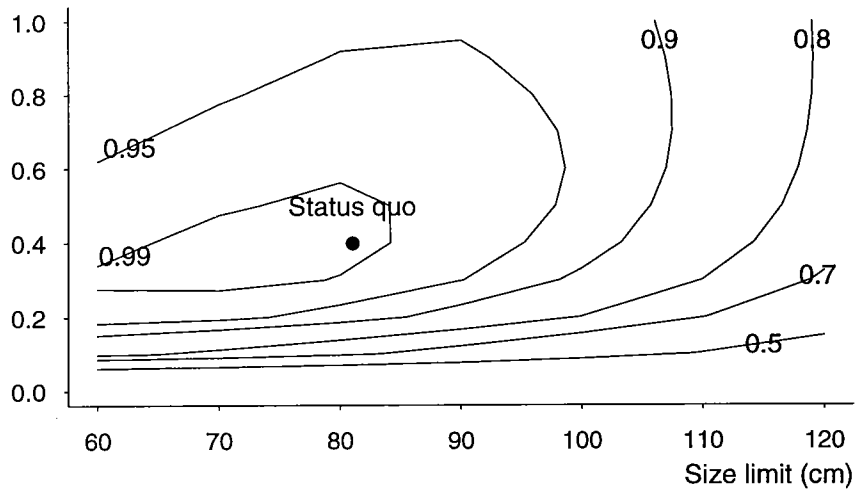


Figure 15. Area 2B female + male yield per recruit (above) and female spawning biomass per recruit (below) assuming fixed setline selectivity.

Fishing mortality



Fishing mortality

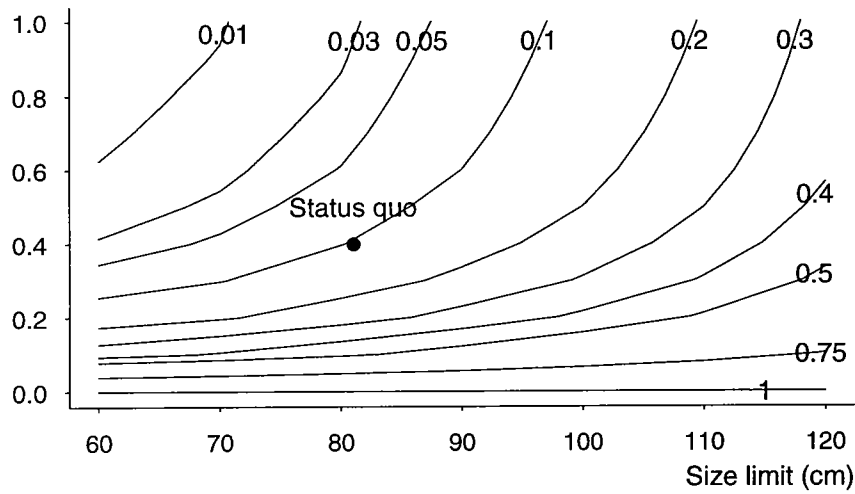


Figure 16. Area 2B female + male yield per recruit (above) and female spawning biomass per recruit (below) assuming variable setline selectivity.

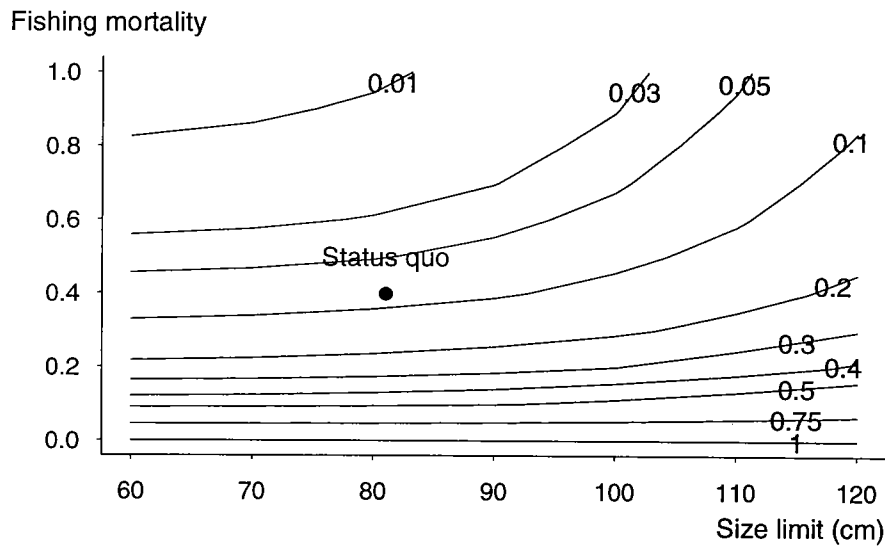
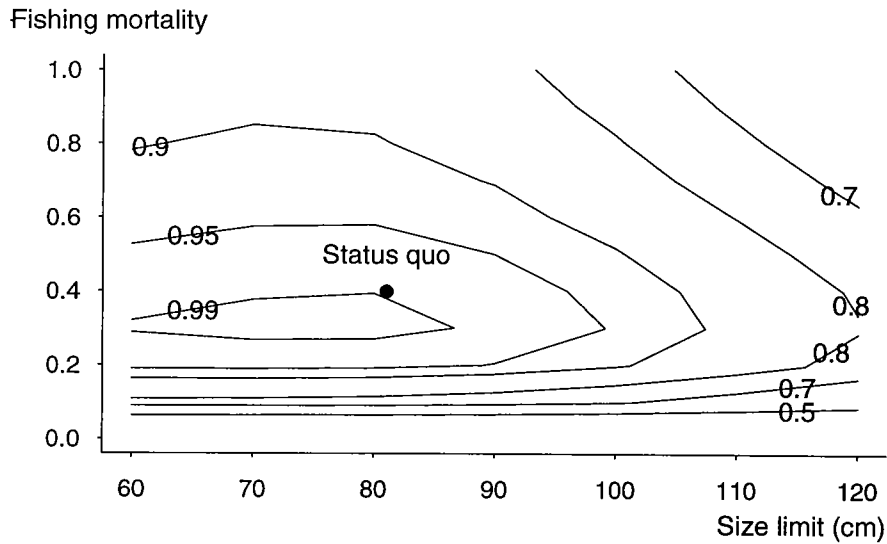
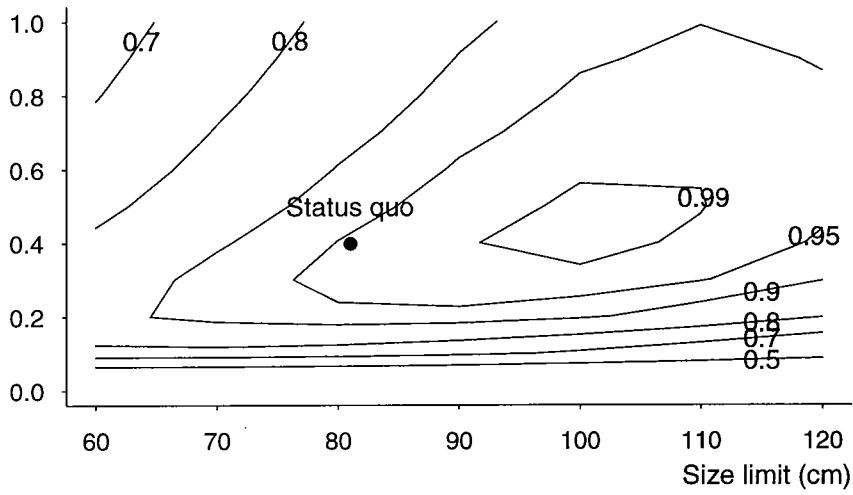


Figure 17. Area 3A female + male yield per recruit (above) and female spawning biomass per recruit (below) assuming fixed setline selectivity.

Fishing mortality



Fishing mortality

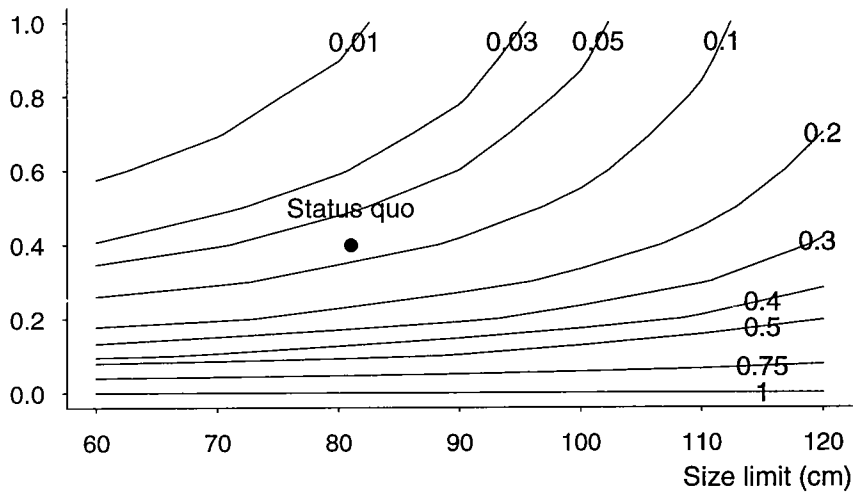


Figure 18. Area 3A female + male yield per recruit (above) and female spawning biomass per recruit (below) assuming variable setline selectivity.