RECONSTRUCTION OF STOCK HISTORY AND DEVELOPMENT OF REHABILITATION STRATEGIES FOR PACIFIC OCEAN PERCH IN QUEEN CHARLOTTE SOUND, CANADA

by

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Abstract

Pacific ocean perch (Sebastes alutus) have undergone considerable over-exploitation in Queen Charlotte Sound, British Columbia, largely as a result of excessive removals by foreign fleets in the 1965-1974 period. A new catch-at-age model is used to reconstruct the history of this stock through simultaneous analysis for all cohorts present in the time series of catch data. The reconstruction extends from 1963-1977 and estimates that intensive fishing pressure reduced the stock from an initial size of 82,000 t to only 13,000 t by 1977. Numbers of fish at each age are estimated for the period of the data, together with estimates of fishing mortality. The reconstructed stock status and the stochastic stock-recruit relation estimated by this analysis are used as inputs for a model to simulate stock behaviour over 30-year periods, under various exploitation strategies. Results indicate that rehabilitation will be achieved only at fishing intensities about one third of the terminal 1977 fishing mortality (F=0.06). The stochastic nature of recruitment to this stock indicates up to a 50% probability of further stock declines at levels of fishing mortality as low as one half the 1977 value (F=0.1).

Key words: Catch-at-age model, stock management, rockfish, Queen Charlotte Sound.

Introduction

Pacific ocean perch (Sebastes alutus) are found along the edge of the continental shelf throughout the temperate region of the nortneastern Pacific Ocean and have been of commercial importance to North American trawl fleets since 1946 (Alverson and Westrheim 1961). This importance has fostered considerable research into the biology and population dynamics of the species. While some characteristics of its life history are well established (Gunderson 1977), recent application of sectioning and breaking/burning techniques to otoliths has led to a major reassessment of some of the basic population parameters for this fish (Beamish 1979, Archibald et al. 1981). In particular, estimated rates of natural mortality have decreased by as much as 50-65% from previous estimates and maximum life span estimates have doubled. Numerous fish have been aged at more than 70 years, including one at 85 years, and instanteous natural mortality (M) is probably 0.05 or lower (Archibald et al. 1981; Shaw and Archibald 1981). The general review of Pacific ocean perch and its fisheries prompted by these results included the application of a sequential population model developed by D. Fournier (Fournier and Archibald 1982). This paper presents the results of this reconstruction analysis and also the results of a simulation analysis of future stock behaviour and rehabilitation trajectories under a variety of exploitation strategies. The subject stock is from Goose Island Gully in Queen Charlotte Sound (Fig. 1).

Pacific ocean perch undergo a seasonal bathymetric migration in Goose Island Gully, spending the winter and spawning in deeper water

(>275 m), then moving to shallower water (180-220 m) in summer (Ketchen 1981). It is an ovoviviparous species with insemination of females occurring in September-October and larval release the following January-March (Gunderson 1971; Westrheim 1975), although this may occur as late as June in northern waters. The species is characterized by highly variable levels of recruitment (Gunderson 1977) and relatively slow growth, with very little increase in length beyond age 25 years (Archibald et al. 1981). In addition there is a positive correlation of depth and age of fish; the proportion of older fish in the catch increasing with depth. Further biological information on this species is available from Gunderson (1971, 1977) and Westrheim (1973, 1975).

The fishery for Pacific ocean perch in Queen Charlotte Sound did not become well-developed until the mid-1950s when both U.S. and Canadian trawlers began operating in relatively deep water (>200 m). About 1960 the Soviet and Japanese trawl fisheries for the species began in the Bering Sea (Westrheim et al. 1972) and by the autumn of 1965 Soviet vessels had started fishing in Queen Charlotte Sound. They were joined by a Japanese fleet in 1966 and foreign removals were heavy through 1969. Except for a brief period of fairly intensive exploitation by the Japanese fleet between 1973 and 1975, the fishery in Queen Charlotte Sound declined during the 1970s with estimated annual removals dropping from a high of 22,121 t in 1966 to 1,949 t in 1977 (Ketchen 1981).

Throughout the history of this fishery, most of the catch came from Goose Island Gully (Fig. 1) (Ketchen 1980, 1981). Several studies indicated that by the mid-to-late 1970s the stock in Goose Island Gully was substantially depleted (Gunderson et al. 1976; Gunderson 1977; Ketchen 1981). These studies were largely based on relative changes in catch-per-unit-effort (CPUE). In order to decide upon an effective rehabilitation strategy, more quantitative answers are required concerning the present status of the stock and the probable effects of various management strategies.

Methods

Data Series Available for Analysis

Catch-at-age data were available for the Goose Island Gully stock from 1963 to 1977. These data were available only for the domestic catch and were assumed to be representative of the total all-nation catch. Estimates of total catch by weight each year were obtained from Ketchen (1980, 1981). The catch-at-age analysis requires catch data in terms of numbers of fish, hence Ketchen's weight estimates were converted to numbers based on the length-weight relationship for Pacific ocean perch (Westrheim and Snytko 1974) and the size distribution of the domestic catch for each year of the data series (groundfish data files, Pacific Biological Station, Nanaimo, B.C.). Information on the total effort expended on Pacific ocean perch in Goose Island Gully was derived from the estimated total catch and the standardized Canadian CPUE for that year, assuming that foreign vessels fished with an efficiency at least equal to that of the standard Canadian vessel (Ketchen 1981). This input information is shown on Table 1.

The ageing techniques noted earlier have indicated that Sebastes alutus and many other Sebastes spp. may have considerably greater life spans than previously estimated. All ages in the data series available for our analysis were estimated by surface-reading otoliths and the ages for older fish were underestimated. From additional comparisons of surface readings and sectioned or broken/burnt readings of otoliths from Queen Charlotte Sound, it was determined that there was no appreciable bias in surface ageing data up to and including age 16. Surface readings past age 17 were not reliable, however, and generally underestimated "true" (sectioned, broken/burnt) ages by 4 years or more. Even before the application of these techniques other authors had expressed doubts about the accuracy of surface ages beyond 16 (Westrheim 1973; Gunderson 1977). Because the only information provided by a surface age over 17 years was that the individual belonged to an older age-group, these ages were combined in the input data.

Catch-at-age model

The catch-at-age model used to analyze the data series for Pacific ocean perch is described in detail by Fournier and Archibald (1982). Briefly, this model attempts to reconstruct population histories, and is similar to other sequential analyses (cohort analysis, virtual population analysis), but extracts additional information by analyzing all cohorts simultaneously. The major strengths of this model are: (1) it correctly addresses the stochastic error in both the input data and the biological processes described; and, (2) it utilizes the underlying regularities in the instantaneous mortality rates. For this paper, only the assignment of instantaneous mortalities and the estimation of a stock-recruit relationship will be discussed in detail; otherwise the reader is referred to Fournier and Archibald (1982).

Instantaneous natural mortality was assumed to be constant for all age-groups and all years (see Results). Instantaneous fishing mortality (F) was more complicated to parameterize and was treated as a sum of three terms (all logarithms to the base e):

$$\log F_{ij} = [b_1\, j(s) + b_2\, j(s)^2] + [\log q_i + \log E_i] + [D_i] \qquad 1.1$$

where $j(s) = -1 + 2(1 - s^{j-1})/(1-s^{r-1})$, with $0<s<1$, $1 \le j \le r$ 1.2

F_{ij} = fishing mortality of age-group j in year i,

b_1, b_2, s = parameters that determine the shape of the curve of F over age,

q_i = catchability in year i,

E_i = effort in year i

The term D_i represents the deviation from the general level of F (set by q_i and E_i) in year i, and r is the number of age-groups (24, ages 6-29, inclusive). For the case where the fishing mortality is made age-independent for the last t age classes, expression 1.2 is modified to

$$j(s) = -1+2\,(1-s^{j-1})/(1-s^{r-t}) \qquad 1 \le j < r-t+1$$

$$j(s) = 1 \qquad r-t+1 \le j \le r,\ 0<s<1$$

This parameterization results in a curve describing generic fishing mortality over age that retains its shape from year to year (no i index in the first part of equation 1.1). This curve is moved up or down each year in response to the fishing effort and catchability for that year (the second part of equation 1.1). The D_i term accounts for the fact that the effort information is not perfect thus the average level of F is allowed some variation about the level determined by the effort and catchability. This variation however, is limited by the fact that a penalty function involving D_i is subtracted from the log-likelihood function the program is trying to maximize. The shape of the generic F curve is determined by the three parameters b_1, b_2, and s which are varied by the program in its attempt to fit the data. This shape is essentially a parabola that is rescaled in a nonlinear fashion by the function $j(s)$.

In order to describe future stock behaviour under various management strategies, future recruitment must be estimated. Although nothing is known about environmental factors affecting Pacific ocean perch recruitment, the catch-at-age model can estimate the relationship between parental stock size (fecundity) and subsequent recruitment. For simplicity, a Ricker-type relationship was assumed (Ricker 1975) although any other desired relationship could easily be substituted:

$$R_{i+6} = \alpha P_i e^{-\delta P_i} e^{\varepsilon_i} \qquad 1.3$$

where R_{i+6} is the number of recruits (6-yr-olds) entering the stock in year $i+6$, α and δ are parameters of the curve, and ε_i are normally distributed random variables with mean zero and variance σ^2. The stock fecundity in year i (P_i) was calculated as follows:

$$P_i = \sum_j f_j N_{ij} \qquad 1.4$$

where f_j is the fecundity of age j fish (Table 2) and N_{ij} is the number of fish of age j in year i

The assumption of a specific sex ratio is unnecessary as the stock fecundity is only used as a relative index. Necessary assumptions are that neither the age-specific fecundity nor the sex ratio change with time and that the sex ratio (whatever it is) remains constant for all ages. The inclusion of the ε_i term in equation 1.3 takes into account the stochastic nature of the recruitment process and is discussed further in the next section.

Forward Simulations

In order to determine the best management strategy for Pacific ocean perch in Goose Island Gully, a simple simulation model was built which predicts the behaviour of the ocean perch stock under a variety of harvesting strategies. The simulations began in 1977 with the population numbers and age structure that resulted from the catch-at-age analysis. Important components of the simulation are: (1) the assignment of mortalities, (2) the calculation of numbers in the population and in the catch, (3) the conversion of numbers to weight, and (4) the estimation of recruitment.

Natural mortality was assumed to be independent of age and year. Fishing mortality was allowed to vary between simulation runs so that different harvesting strategies could be examined, but was held constant for the duration of each run. The distribution of fishing mortality over age was equal to the 1977 F-at-age relationship as calculated by the reconstruction, i.e., to produce any desired F level for simulation, the F for each age-group in 1977 was multiplied by a constant, 0.5, 1.0, 1.5, etc. This method assumes the recruitment pattern to the fishery does not change over the time period simulated (in our case, 30 years into the future).

Change in numbers of fish in the population over time was assumed to follow the usual exponential decline:

$$N_{i+1,j+1} = N_{ij}\, e^{-Z_{ij}} \qquad 1.5$$

where

$$Z_{ij} = F_{ij} + M \qquad 1.6$$

which is the total instantaneous mortality of age j fish in year i

The proportion of total deaths that contribute to the yield was calculated using the standard catch equation (Ricker 1975):

$$C_{ij} = \frac{N_{ij} F_{ij}}{Z_{ij}} (1 - e^{-Z_{ij}}) \qquad 1.7$$

where C_{ij} is the catch of age j fish in year i.

The simulation model deals separately with age groups 6-28 inclusive and combines older fish into a 29-year and over category. This is simply a bookkeeping device and does not affect the results because M and F are assumed to be constant for these older fish. The bookkeeping is done as follows:

$$N_{i+1,\geq 29} = (N_{i,\geq 29})(e^{-Z_{i,\geq 29}}) + (N_{i,28})(e^{-Z_{i,28}}) \qquad 1.8$$

where $N_{i+1,\geq 29}$ is the number of fish of age ≥ 29 years in year $i+1$

After the numbers of fish were calculated for both the population and the catch, these numbers were converted to weight by multiplying by the average weight-at-age. Since there are no direct weight-at-age data for Pacific ocean perch off the British Columbia coast, length-at-age (Archibald et al. 1981) and length-weight information (Westrheim and Thomson 1971) were used to estimate average weights-at-age (Table 2).

At present, the only predictor available for Pacific ocean perch recruitment is parental stock fecundity; the relationship between these two variables was estimated by the reconstruction analysis. Parental stock fecundity was calculated from the numbers at age and the age-specific fecundity information (Table 2). Once again, the assumption of a specific sex ratio is unimportant as long as it is the same as that used in the reconstruction analysis.

The foregoing would be sufficient to account for future recruitment if parental stock fecundity were the only factor influencing recruitment. Environmental factors undoubtedly play a major role and this is clearly seen in the very large year classes that occur once every decade or so (presumably as a result of favourable environmental conditions), with the intervening year classes being comparatively weak. The variation about predicted recruitment due to environmental influences would therefore appear to be log-normal and this can be partly taken into account by introducing stochastic variation, in the manner of equation 1.3. In the reconstruction analysis, the variance about the estimated stock-recruit curve was approximately 0.3 and this value was used for the variance about ε_i in the stochastic simulations. Of course, each stochastic run will be different since different random values of ε_i will be used as input. For presentation purposes the average of 30 simulation runs, each going for 30 years into the future, was used. The overall result is that recruitment is slightly higher than if the stochastic element was not included.

The stochastic model for calculating recruitment is able to predict only the average of all possible situations and not any specific result. By its very nature, a stochastic model cannot give an exact prediction but it can provide probabilities associated with certain events. For example, with stochastic runs we could say that there is only a 10% chance the stock will fall below its current level after 30 years of fishing at a particular intensity. A first approximation at a management strategy can thus be derived from the average of a number of stochastic runs and subsequently refined by examining the individual runs to determine the probabilities associated with certain important events (e.g., long intervals between strong year classes).

Results

Catch-at-age analysis

The initial catch-at-age analysis was carried out with no grouping of older age classes, time-independent catchability, and a Ricker-type, stock-recruit relation assumed. Subsequent runs examined the effects of grouping the older age classes and of allowing catchability to vary over time. For each run, instantaneous natural mortality (M) was fixed and the program allowed to maximize the log-likelihood function for that value of M. The goodness of fit for the various runs is measured by the log-likelihood function with its sign changed. Thus a smaller value of the objective function denotes a better fit to the observed data.

Relevant results of the initial catch-at-age analysis are shown in Fig. 2 (a,b). The best fit to the data occurred at an M value of 0.3 (Fig. 2a), an impossibly high value for Pacific ocean perch given the longevity of the species. In Fig. 2b fishing mortality is shown as a function of age for the M=0.3 reconstruction. Fishing mortality increased steadily with age and full recruitment to the fishery did not occur until after age 24. Such late full recruitment is also an unreasonable result because the small amount of evidence available for the species indicates full recruitment occurs somewhere between ages 15 and 16, or lower (Gunderson 1977; B. M. Leaman, unpublished data).

The ageing errors in the data probably are responsible for the program choosing a high value for natural mortality and a late age for full recruitment. To compensate for the ageing errors among older fish, individuals of 17 years and older in the input data were grouped together. The analysis of these data resulted in a more reasonable solution: the best fit occurred at M=0.1 (Fig. 2c) and full recruitment was at 16 years (Fig. 2d). Before proceeding to examine the effects of time-dependent catchability, this reconstruction was modified slightly to include additional biological considerations. Although the objective function value was a minimum at M=0.1, there was very little difference in quality of fit as long as M was less than 0.2 (Fig. 2c). Archibald et al. (1981) indicated that the most probable value of M for Pacific ocean perch was around 0.05 and this value was chosen for use in subsequent reconstructions. Also, note in Fig. 2d that the fishing mortality for older fish drops to less than one-half the maximum value at age 16. Although F probably drops slightly due to the age stratification over depth (older fish apparently moving to deeper water and thus out of the major fishing ground), we felt it unlikely that the drop was this extreme. To limit this decrease in F, fishing mortality was made age independent for fish more than 18 years old and the resulting objective function value dropped from 269 to 258 (M=0.05). This change successfully limited the drop in F for older fish (refer to Fig. 3a)

The effects of allowing the catchability to vary over time were examined by including the time-dependent option for catchability in the reconstruction. A substantial improvement in the fit resulted: the value of the objective function dropped from 258 to 240. Full recruitment occurred at age 15 (Fig. 3a) and catchability increased nearly five-fold between 1963 and 1977 (Table 3). Although there are no data to directly substantiate the increase in catchability that the model implies, this increase does confirm suspicions about the effort underestimating fishing mortality in recent years. This increase in catchability has not been a result of increasing boat or net size since those factors were accounted for in the initial calculation of effort (Ketchen 1981). Rather, the apparent increase in catchability was probably due to reduced population abundance and possibly to increased time spent by fishermen searching for the remaining schools. If fishing success on schools were unchanged, then catchability would increase automatically with decreased abundance.

This final reconstruction (objective function value = 240) was accepted as producing the best fit to the data, and the full results are presented in Table 3 and Fig. 3. It is apparent that catches have declined steadily since 1966, but the average annual fishing mortality (averaged over fish more than 8 years old) has remained high, around 0.3 (Fig. 3b). The estimated biomass of Pacific ocean perch in Goose Island Gully declined dramatically from 82,000 t in 1963 to about 13,000 t in 1977 (Fig. 3c).

Because the catch-at-age data came only from domestic landings and most of the catch in the 1960s was taken by foreign vessels, the reader may well wonder about the possible bias, if the two catches had different age compositions. Certainly, one would expect the foreign vessels to generally catch older fish as they operated in deeper water than the domestic fleet (Ketchen 1980). However, since all fish 17 years and older were grouped together in the catch-at-age data, this would tend to decrease the difference between the two. Also, when the input catch-at-age data were modified in an attempt to take this possible difference into account [through the known age stratification of the species over depth and the distribution of foreign fishing vessels (Ketchen 1980)], the fit to the data was no better. This may be explained in part by the problem of extrapolating these age composition data (obtained through bottom trawling) to the midwater fishing patterns of the foreign fleets.

Forward Simulation

The simulations to predict future stock behaviour of Pacific ocean perch under various harvesting strategies were started using the 1977 population information shown in Table 3 and Fig. 3. The average results of 30 stochastic runs (variance=0.3) simulated for 30 years into the future for each of five levels of average fishing mortality are presented in Fig. 4. Without fishing (F=0.0), the stock reached 50,000 t after 30 years. Fishing at an average level of 0.1 (which is one-half of the 1977 F level) kept the stock size approximately constant and produced slightly less than 1,000 t of yield each year. Fishing at levels higher than 0.1 (taking more than 1,000 t/yr in the first few years past 1977), resulted in a steadily decreasing stock size.

To examine the equilibrium levels of stock size and yield at each level of fishing mortality, the simulations were run beyond 30 years to allow the stock to reach equilibrium (usually requiring 100 years or more). The equilibrium levels thus attained are shown in Fig. 5. With no fishing, the equilibrium stock biomass was 78,000 t which is about the same as the estimated stock size in 1965 just before the foreign fleets started fishing in Goose Island Gully. At the other extreme, fishing at an average intensity of 0.1 resulted in an equilibrium stock biomass of only 10,000 t. Above F=0.1, the stock did not reach equilibrium (at least not within 200 years) but continually declined. Maximum equilibrium yield was estimated to be 1,800 t/yr and occurred at an F value of 0.06 or about one-third of the 1977 F level.

Discussion

The analysis presented in this paper represents our best estimate of the history of the Pacific ocean perch stock in Goose Island Gully with the data available for the period 1963-1977. Given the fact that most of these data are past history and are not likely to be improved beyond what Ketchen (1980, 1981) has already done, it is doubtful a more conclusive reconstruction can be achieved.

The stock reconstruction analysis indicates that by 1977 the biomass had dropped to one-sixth of its 1963 value or from 82,000 t to 13,000 t. The only other absolute estimates of the size of the Goose Island Gully stock are from biomass surveys. Harling and Davenport (1977) estimated 64,000 t in 1965 and 23,000 t in 1977. More recently (in Stocker 1981), a review of their survey methodology indicated these estimates could be as low as 22,000 t in 1965 and 8,200 t in 1977. In both cases, the decline in abundance over time was not thought to be as great as that estimated in the present study.

The same conclusion is drawn from examining indices presented by other investigators for the relative abundance of Goose Island Gully stock. Assuming catch-per-unit-effort (CPUE) to be an index of relative abundance, it was estimated that, by the early-to-mid 1970s, the stock was reduced to one-half its mid-1960s size (Gunderson et al. 1976; Westrheim et al. 1972). Recently Ketchen (1981), working with a more complete data set, estimated the CPUE in 1975 to be about one third of the 1965 value (0.507 t/hour vs. 1.491 t/hour, respectively). The analysis presented here provides evidence for an increase in catchability over time not due simply to increases in vessel or net sizes. This may largely explain why estimates of CPUE appear to have underestimated stock decline.

The historical data used as input for this reconstruction analysis have several deficiencies, chief among which is the impossibility of validating the age composition, sex ratio or foreign fishing-effort estimates used. It is pertinent to note the biases that may result from errors in such estimates. Age composition errors have been dealt with in detail previously; however, the sex composition of catches by non-North American trawlers may have equally strong effects. It is known that Pacific ocean perch undertake annual migrations to wintering grounds outside the mouth of Goose Island Gully and that these migrations are not synchronous between the sexes (Gunderson 1977). Males precede females in their return to the Gully and it is probable that catches by foreign trawlers operating outside the Sound may have contained more females. If this is true, the stock fecundity values for the early 1960s may be relatively underestimated and the constancy of sex ratio used in constructing the stock-recruit relationship may not be true for the entire catch history. Thus, stock fecundity may be underestimated for the early years (1965-1968) of the data set, relative to later years when data quality improved.

While estimates of the total effort applied are probably higher than the actual hours fished, the impact on the analysis is negligible as long as the relationship between the efficiency of foreign and domestic trawlers did not change substantially during the period of coincident fishing. For the purposes of this analysis, total removals can be thought of as coming from the domestic fleet since effort is expressed in equivalent Canadian hours.

Management Implications

The forward simulations presented here have strong management implications, especially considering previous catch history and management recommendations. Although the simulations present an average of potential results, they provide guidance for the development of a stock-reconstruction trajectory.

The simulations indicated that an average fishing mortality of 0.1 (about one-half the 1977 level of F) would maintain the stock at its 1977 level over the next 30 years and allow for an annual yield of just under 1,000 t. This level of harvesting is excessive, however, in that it permits no rebuilding of the stock, and at levels any higher than this the stock fails to reach equilibrium and declines steadily. In addition, due to the stochastic nature of the recruitment function (reflecting normally encountered variation), the stock has a high probability (50%) of dropping below the 1977 level of 13,000 t by the end of 30 years (Fig. 6). Harvesting levels to be considered would thus result from fishing mortalities lower than 0.1.

At an average fishing mortality of 0.06 (one third of the 1977 level) for example, there is only about a 5% chance that the stock will drop below 13,000 t after 30 years (Fig. 6) and it should reach a level of between 20-25,000 t (Fig. 4). The annual yields associated with this trajectory would be approximately 600 t for the first few years after 1977 and about 1,000 t after 30 years. This F=0.06 level of harvesting has the additional advantage of being close to the optimum, allowing the stock to stabilize at approximately 37,000 t (slightly less than one-half the estimated virgin biomass), with an annual yield of about 5% of the stock or 1,800 t (Fig. 5). This harvest strategy is even more conservative than those recommended previously. For example, Gunderson (1977) stated that the Queen Charlotte Sound stock should not be harvested at a rate greater than F=0.1 and that annual catches should not exceed 10% of the standing stock. Since he estimated M to lie in the

0.1-0.2 range, F was probably higher than 0.1 and the suggested exploitation strategy was less conservative than assumed. It is apparent that remedial action to counter the decline in Pacific ocean perch stock abundance in Queen Charlotte Sound is necessary and that it will probably be a minimum of a decade before substantive improvements will be detectable. Although the yield associated with this action is low relative to the mid 1960s, it is approximately two-thirds of the 1981 total allowable catch. The reduction in total effort resulting from withdrawal of all foreign fishing effort after April 1981 should render this reconstruction strategy more feasible, without major economic dislocation.

Finally, it should be noted that this paper deals with the rehabilitation of a stock in which the maximum percentage of older (>17 years) fish was about 32%. There are several stocks of this and other Sebastes spp. wherein the percentages of such older fish are estimated to be more than 80%; for unexploited or lightly exploited stocks the majority of fish may be in excess of 30 years (Archibald et al. 1981). The existence of such longevity may have profound consequences on the development of optimal exploitation strategies for this group.

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Table 1. Catch-at-age data for the Pacific ocean perch fishery in Goose Island Gully, 1963-1977; values are the percentage of fish of that age in that year's catch sample. Total catch by weight and total effort data are from Ketchen (1981). The estimation of total catch by number is described in the text.

Age	Year														
	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
6				0.4	0.4	2.5	0.9	4.1	1.1	0.5	0.1	0.9	1.7	1.7	1.5
7	1.2		0.3	0.2		2.1	2.3	2.4	3.9	1.5	0.4	0.3	0.7	2.1	4.1
8	1.6	1.8	0.4	0.4	0.1	2.4	5.0	7.8	2.6	5.1	1.8	2.8	0.4	1.4	3.8
9	2.3	1.2	2.5	1.1	1.3	2.6	7.6	20.9	8.8	6.3	6.3	6.7	5.0	1.4	4.4
10	7.0	4.0	5.1	2.7	3.9	3.0	5.2	6.8	22.5	15.3	9.1	10.8	11.1	6.5	5.4
11	21.0	4.8	6.7	5.3	6.3	4.2	4.5	4.5	9.1	19.5	20.7	16.4	14.8	11.2	12.6
12	17.8	16.5	17.0	8.7	9.7	8.8	4.3	2.3	3.3	7.0	19.5	20.0	22.9	14.6	11.8
13	17.0	19.0	27.2	11.8	13.9	12.6	10.7	4.4	1.9	3.3	6.3	12.4	18.8	21.2	14.7
14	8.0	12.8	13.8	30.3	16.7	10.8	8.6	3.9	4.8	1.8	3.6	5.0	5.5	16.9	15.0
15	4.5	8.0	7.4	13.2	17.3	14.7	10.9	6.5	3.5	4.1	1.9	3.0	3.7	5.0	9.3
16	4.2	3.8	3.7	8.4	8.6	10.9	9.7	5.3	8.5	3.3	4.0	2.5	2.4	3.2	3.3
17	3.8	3.0	3.7	4.6	5.7	7.1	7.8	5.8	6.6	5.4	3.4	3.5	3.0	2.2	1.2
18	3.6	2.7	2.6	2.9	6.2	4.8	6.3	7.9	5.1	4.9	4.1	3.2	2.9	2.9	1.3
19	3.3	6.5	3.1	2.3	3.1	4.1	3.9	3.3	8.2	4.2	4.4	2.9	3.0	2.7	2.4
20	1.7	4.8	1.8	3.0	2.6	2.8	3.1	4.3	2.3	8.9	4.0	3.3	1.7	3.8	2.2
21	1.0	3.5	1.8	1.8	1.7	2.1	2.3	2.0	2.2	3.4	4.8	2.5	1.0	1.7	2.3
22	1.2	3.0	1.1	1.1	0.8	1.6	2.1	1.5	1.4	1.7	1.8	2.2	0.7	0.7	1.4
23	0.4	1.2	0.9	1.0	1.0	1.1	2.3	1.4	1.8	1.3	1.2	1.0	0.6	0.5	1.2
24	0.3	1.7	0.4	0.3	0.6	1.2	1.1	1.6	1.1	1.4	1.4	0.6	0.1	0.1	1.3
25	0.1	0.3	0.3	0.2	0.1	0.2	0.9	1.3	0.1	0.6	1.0			0.1	0.3
26		1.2	0.2	0.1		0.2	0.4	0.6	0.7	0.1					0.4
27		0.2		0.1		0.2		0.6	0.3	0.3					0.1
28				0.1			0.1	0.7	0.1	0.1	0.2				
29								0.1	0.1						
Total catch (x 10^3 t)	3.71	3.45	7.48	20.80	12.10	10.20	6.87	6.49	3.53	5.64	3.76	7.27	4.21	2.44	1.69
Total catch (x 10^6 pieces)	5.13	4.07	9.62	26.60	13.90	12.60	8.76	8.64	4.83	7.64	4.28	9.12	5.42	3.21	2.09
Total effort (x 10^3 hours)	2.55	3.55	5.02	14.40	11.30	9.77	9.01	9.66	6.72	6.81	4.86	9.40	8.30	3.33	2.56

Table 2. Estimated age-specific fecundities (after Gunderson 1977) and average weights-at-age for the Pacific ocean perch stock in Goose Island Gully.

Ages	Fecundity (x 10^3 eggs/female)							
6-13 (respectively)	0	0	0	0	0	45.7	55.7	67.3
14-21 (respectively)	78.6	90.1	100.4	111.5	122.1	133.5	142.2	151.3
22-≥29 (respectively)	158.9	166.9	175.2	175.2	175.2	175.2	175.2	175.2

Ages	Average weight (kilograms/fish)							
6-13 (respectively)	0.485	0.529	0.572	0.614	0.654	0.694	0.732	0.770
14-21 (respectively)	0.806	0.841	0.876	0.909	0.942	0.973	1.00	1.03
22-≥29 (respectively)	1.06	1.09	1.12	1.15	1.17	1.20	1.22	1.30

Table 3. Estimated number at age for the stock reconstruction with time-dependent catchability, fishing mortality (F) held constant for the last 12 age-groups, stock-recruit option included, and natural mortality held at 0.05. Average F values are averaged over fish ≥ 9 years Age 17 fish in 1963 actually represent fish of age ≥ 17 years and this combined age-group can be followed through the fishery. Coefficients for the estimated Ricker stock-recruit curve were $\alpha = 0.0883$ and $\delta = 9.01 \times 10^{-5}$.

Age	Estimated number at age in each year (x 10^4)														
	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
6	450	250	319	522	1054	1055	798	613	401	295	122	173	285	416	287
7	704	427	237	302	488	990	989	748	574	378	276	115	160	266	390
8	1002	666	404	223	277	452	913	913	687	534	347	257	103	146	246
9	1097	943	628	377	198	250	405	821	812	627	474	316	220	91	132
10	1447	1023	882	576	318	173	214	349	695	717	529	420	251	183	79
11	2195	1334	948	792	451	262	139	174	275	587	564	448	299	192	150
12	1331	1994	1222	829	568	349	195	105	126	220	422	453	280	207	147
13	909	1191	1804	1039	540	409	239	136	69	95	144	320	245	174	147
14	464	803	1065	1496	622	366	260	156	83	49	57	104	153	139	115
15	276	406	713	869	848	405	222	163	90	57	28	40	46	81	88
16	437	241	360	580	487	547	243	138	93	62	32	20	17	24	51
17	1363	383	215	296	337	323	339	155	81	65	36	23	9	9	16
18		1211	345	180	184	235	213	229	98	60	41	27	12	5	6
19			1103	297	123	138	168	155	158	76	41	32	16	8	4
20				951	203	92	98	122	107	123	52	32	19	10	6
21					650	152	65	71	84	83	84	41	19	12	8
22						485	108	48	49	65	57	66	24	12	9
23							346	79	33	38	45	44	38	16	9
24								252	54	26	26	35	26	25	11
25									174	42	18	21	20	17	18
26										135	29	14	12	13	12

Table 3 (cont'd)

Age	Estimated number at age in each year (x 10^4)														
	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
27											93	23	8	8	10
28												72	13	5	6
$\geq$29													42	35	27
Average F each year	.057	.047	.104	.351	.258	.305	.283	.341	.216	.345	.211	.521	.395	.273	.202
Catchability (x 10^{-4})	1.03	1.15	1.28	1.42	1.59	1.77	1.97	2.19	2.44	2.72	3.03	3.37	3.76	4.19	4.66

List of figures

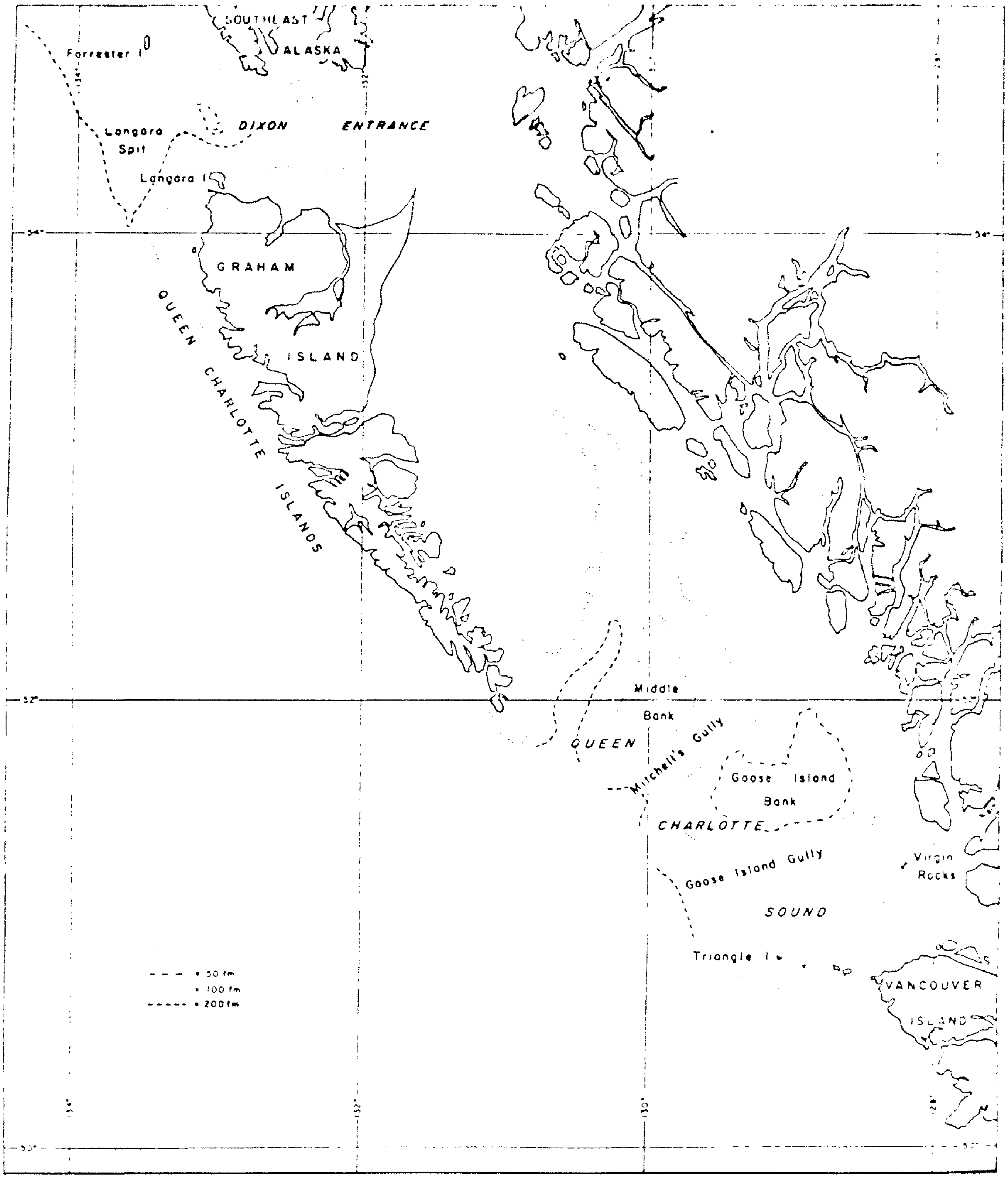

SOUTHEAST
ALASKA
Forrester I
DIXON
ENTRANCE
Langara
Spit
Langara I
GRAHAM
ISLAND
QUEEN CHARLOTTE ISLANDS
Middle
Bank
QUEEN
Mitchell's Gully
Goose Island
Bank
CHARLOTTE
Goose Island Gully
Virgin
Rocks
SOUND
Triangle I
VANCOUVER
ISLAND
54°
52°
50°
134°
132°
130°
128°
= 50 fm
= 100 fm
= 200 fm

Fig. 1

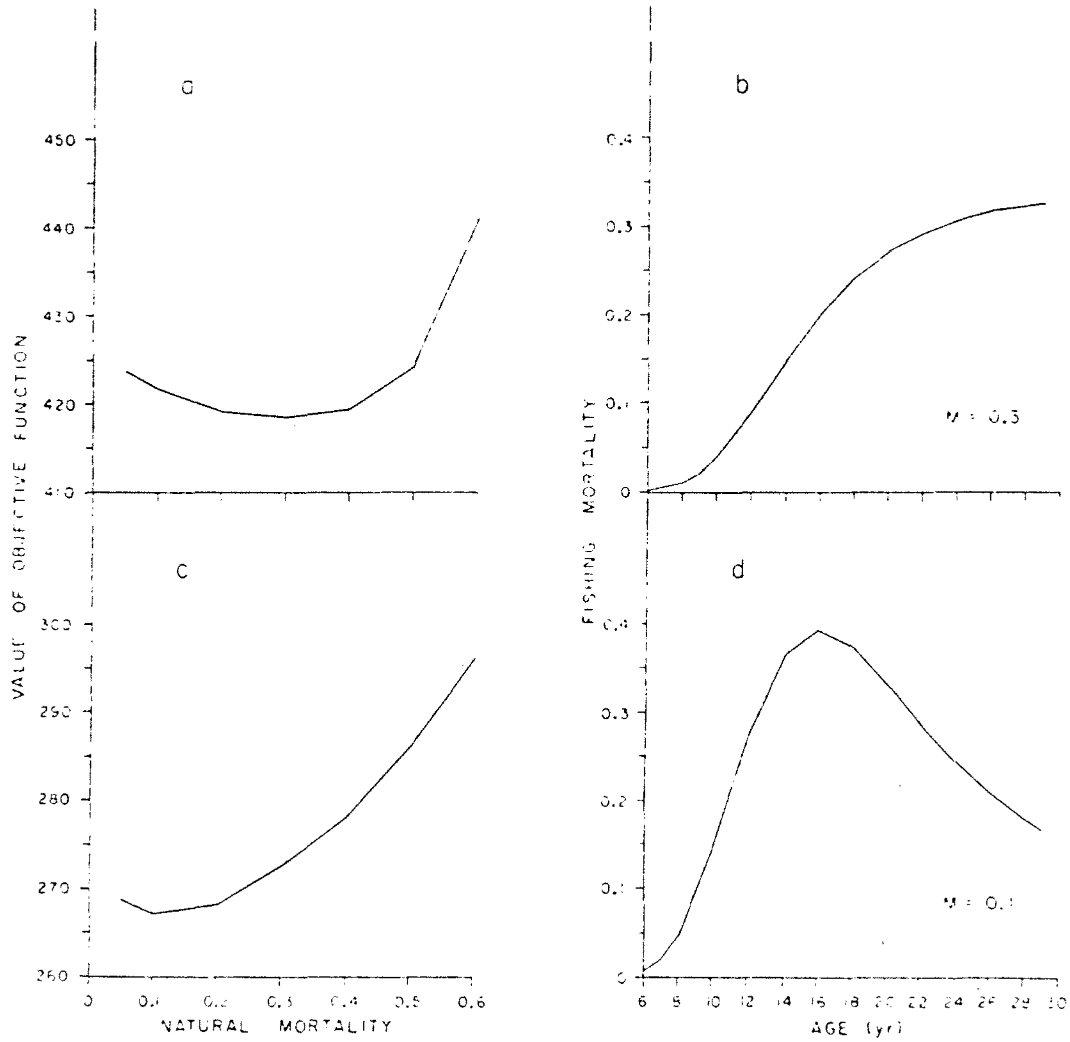

a
b
c
d
450
440
430
420
300
290
280
270
260
0.3
0.2
0
0.4
0.3
0.2
VALUE OF OBJECTIVE FUNCTION
FISHING MORTALITY
M = 0.3
0.6
NATURAL MORTALITY
AGE (yr)

Fig. 2.

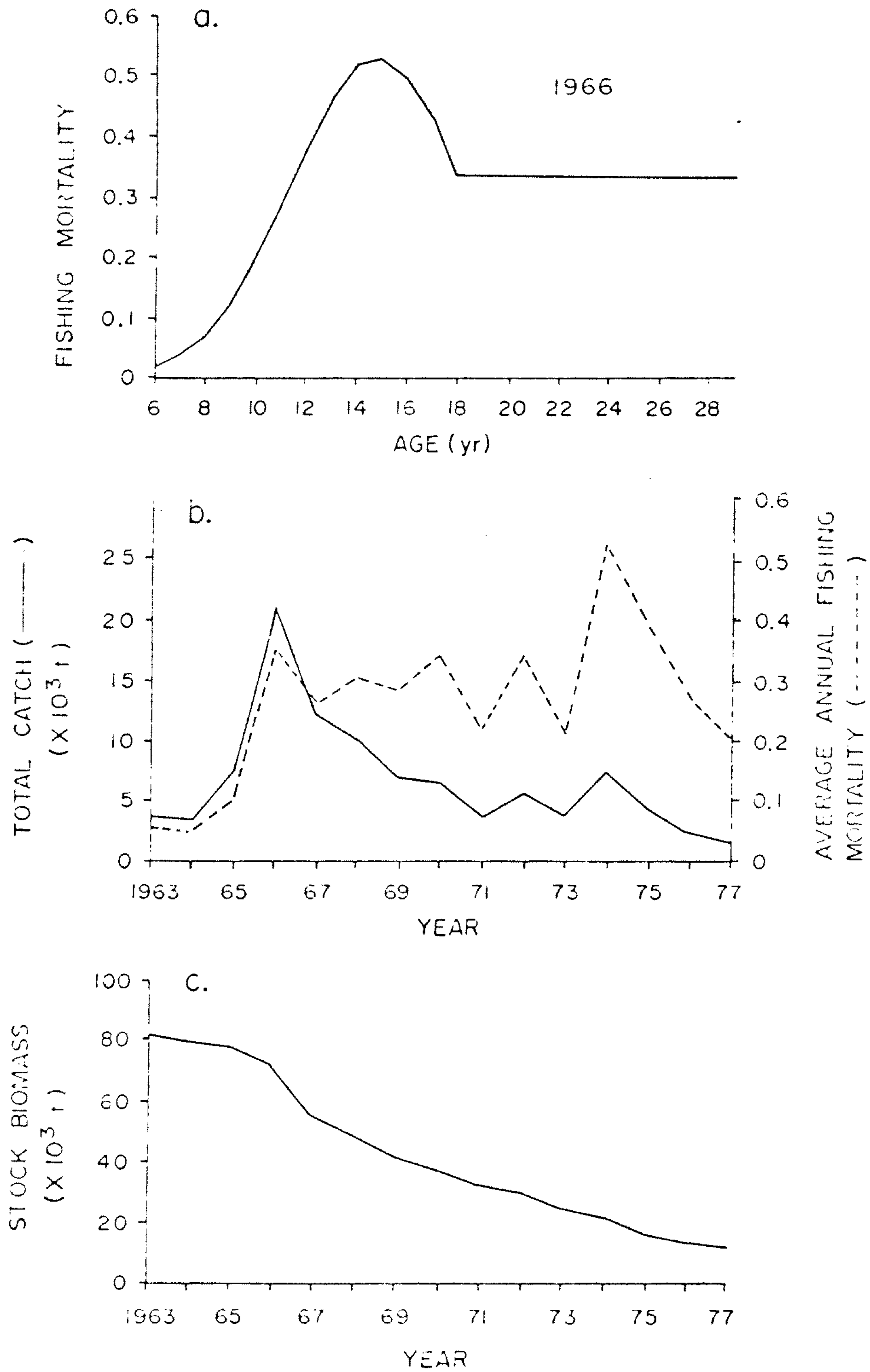
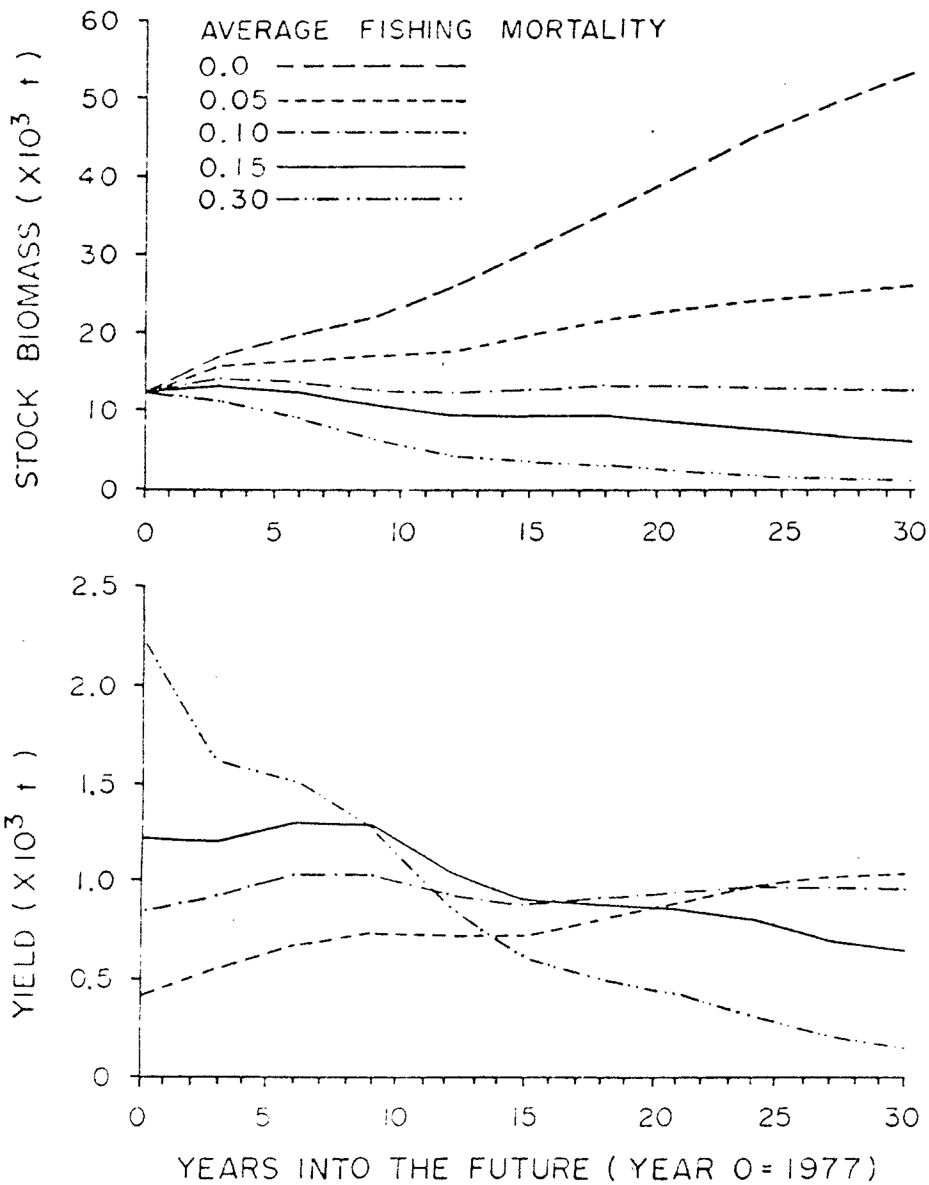

a.
1966
FISHING MORTALITY
0.6
0.5
0.4
0.3
0.2
0.1
0
6
8
10
12
14
16
18
20
22
24
26
28
AGE (yr)
b.
TOTAL CATCH (———)
(X 10^3 t)
25
20
15
10
5
0
AVERAGE ANNUAL FISHING MORTALITY (- - - - -)
0.6
0.5
0.4
0.3
0.2
0.1
0
1963
65
67
69
71
73
75
77
YEAR
c.
STOCK BIOMASS
(X 10^3 t)
100
80
60
40
20
0
1963
65
67
69
71
73
75
77
YEAR

Fig. 3.



AVERAGE FISHING MORTALITY
0.0
0.05
0.10
0.15
0.30
STOCK BIOMASS (X10^3 t)
60
50
40
30
20
10
0
0
5
10
15
20
25
30
YIELD (X10^3 t)
2.5
2.0
1.5
1.0
0.5
0
YEARS INTO THE FUTURE (YEAR 0 = 1977)

Fig. 4.

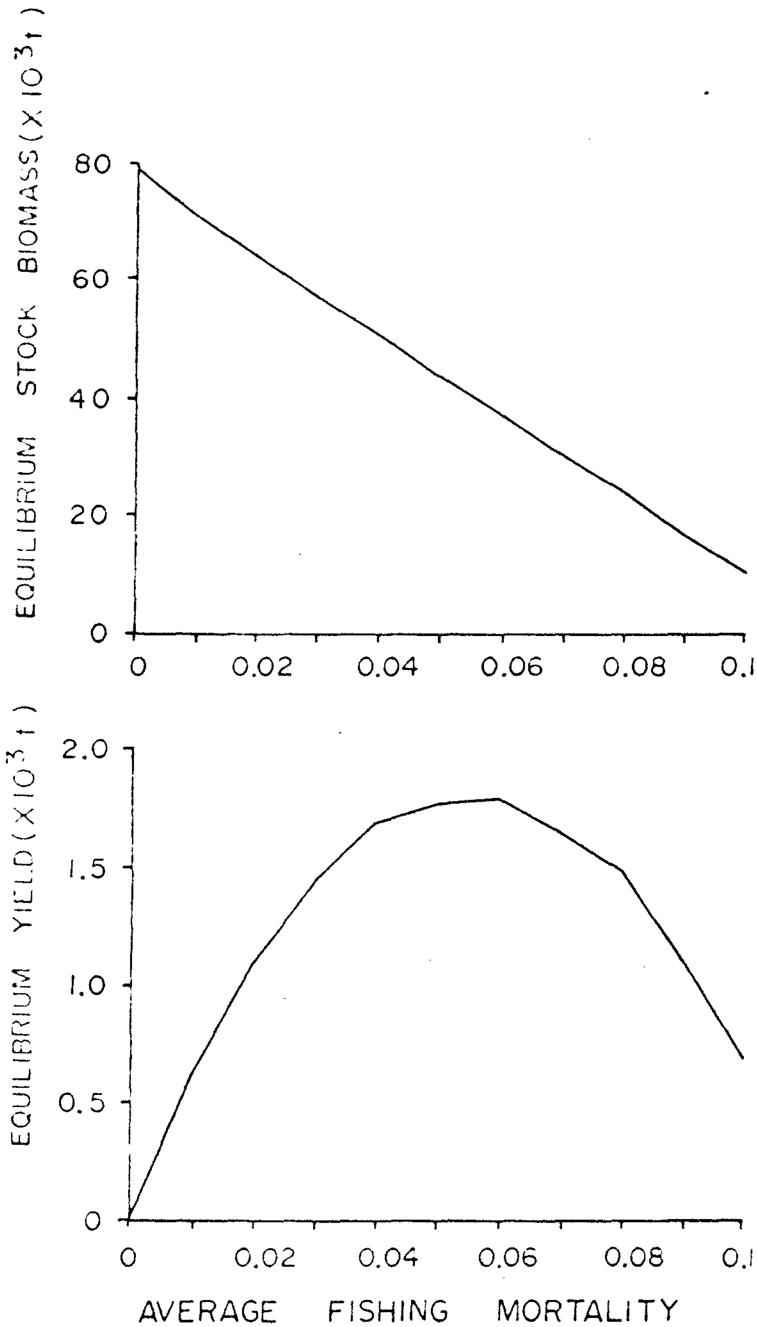

EQUILIBRIUM STOCK BIOMASS (X 10^3 t)
80
60
40
20
0
0
0.02
0.04
0.06
0.08
0.1
EQUILIBRIUM YIELD (X 10^3 t)
2.0
1.5
1.0
0.5
0
0
0.02
0.04
0.06
0.08
0.1
AVERAGE FISHING MORTALITY

Fig. 5.

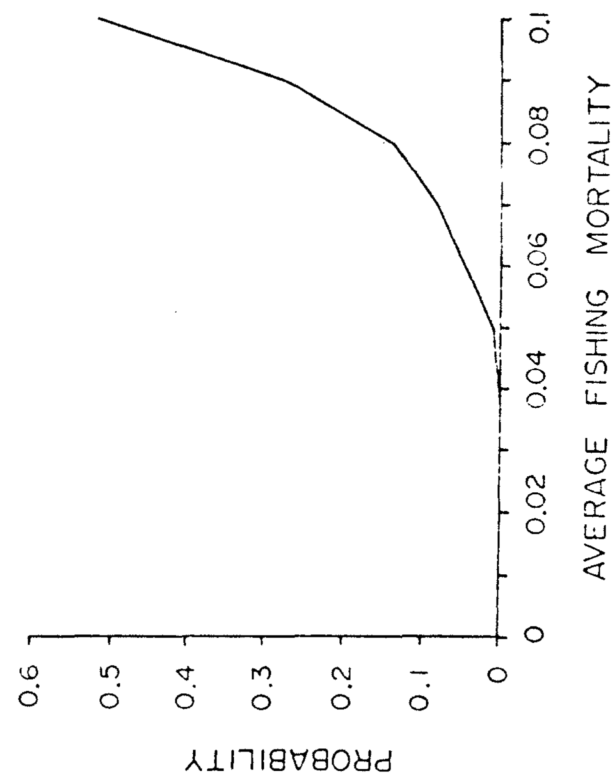

PROBABILITY
0
0.1
0.2
0.3
0.4
0.5
0.6
AVERAGE FISHING MORTALITY
0
0.02
0.04
0.06
0.08
0.1

Fig. 6.