STATUS AND FUTURE PROSPECTS FOR THE PACIFIC OCEAN PERCH RESOURCE IN WATERS OFF WASHINGTON AND OREGON AS ASSESSED IN 1998

by

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EXECUTIVE SUMMARY

This assessment applies to Pacific ocean perch (*Sebastes alutus*) for the US Vancouver and Columbia area combined. Catches are characterized by large removals during the mid-1960s by foreign vessels. The domestic fishery proceeded with subsequent moderate removals of between 1,000-2,000 tons per year since 1976. Catches have been further reduced by management measures to about 700 tons since 1995.

Previous assessments were done in 1992 and 1995 and involved extensive analyses of diverse data types using an age structured model (the stock synthesis program). The new data presented in this assessment include updated catches, a revised length-at-age analyses, and the 1995 NMFS triennial-trawl survey estimate of biomass. Also particularly new to this assessment is an analysis of stock-recruitment relationship as an integrated part of the model. This provided estimates of the fishing mortality rate that achieves maximum yield to evaluate compared to the commonly used standard SPR rates (e.g., $F_{40\%}$). While analyses on stock-recruitment relationships typically require many assumptions, we feel that the integrated model addresses many of the problems (e.g., errors in the estimate of both stock size and recruitment values).

As with any fish stock assessment, there are a number of sources of uncertainty that complicate the scientific interpretation of the results. In this assessment we attempt to develop a model that encompasses greater realism in this uncertainty. For example, we allow for uncertainty in natural mortality, total catch (by weight) estimates, and in the survey catchability coefficients. For sensitivity analyses, other plausible alternatives suggest that the overall uncertainty may be greater than that predicted by a single model specification. Nonetheless, we propose that the reference case adequately envelopes the range of uncertainty.

The main issues that need addressing include careful consideration of stock-recruitment relationship, particularly as defined by assumptions of what constitutes a “stock”. Clearly a significant portion of the reproductive stock lies in Canadian waters yet these fish are not explicitly included in our assessment. This may be important also since we are at the southern extremity of the geographic range of POP. Maturity-at-age data need revising since we show that assumptions about maturity stage may impact harvest recommendations.

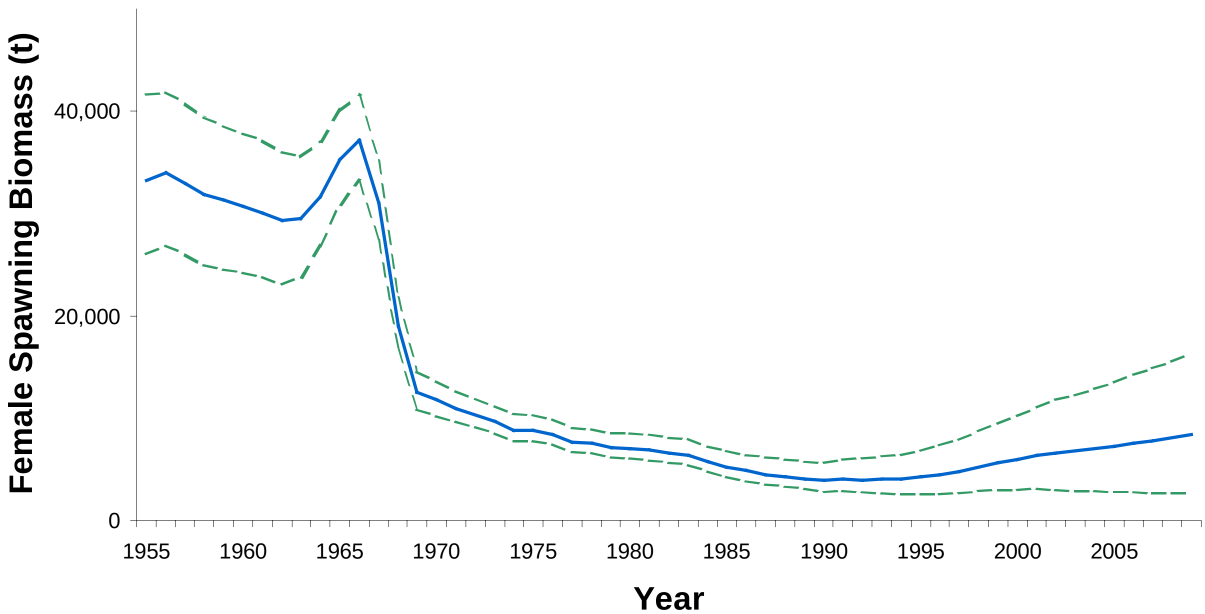
We introduced a procedure for estimating F_{msy} and associated yields directly within the larger model. This was included with the other SPR rates for contrast. Importantly, we evaluate our ability to estimate F_{msy} and provide associated levels of uncertainty. We found that the value for F_{msy} occurred at slightly higher values than the normal SPR values (e.g., $F_{35\%}$). However, the trade-off of lower fishing mortality rates represent only small reductions in overall sustainable yields.

Point estimates of female spawning biomass and total age 3+ biomass since 1978 are as follows:

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Female Spawning Biomass	7,522	7,157	7,073	6,920	6,690	6,497	5,872	5,382	5,033	4,721	4,517
Total Age 3+	21,867	20,648	19,497	18,271	17,617	17,397	16,544	15,733	15,259	14,941	15,048

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Female Spawning Biomass	4,339	4,147	4,259	4,232	4,276	4,286	4,491	4,732	4,986	5,371
Total Age 3+	14,833	14,572	14,918	14,849	15,304	15,523	15,883	16,419	17,006	17,629

Over the entire model time period, the reference-case model gave a distribution of spawning biomass estimates expressed in the following figure (with projections assuming F_{msy} harvest rate; with 95% confidence bands):



The recruitment pattern for POP is similar to many rockfish species. Recent decades have provided rather poor year-classes compared to the 1950s and 1960s. This has apparently caused declines in spawning levels.

The exploitation status of POP continues to be set to bycatch only. Since POP are at the southern limit of their geographical range, while the overall species condition has improved in other areas more central to their range (e.g., in the Canadian EEZ and in the Gulf of Alaska). Management actions of setting harvest guidelines to bycatch only (ABC=0) implemented over the past several years has not yet resulted in observable stock increases based on available data.

Forecasts for the next three years under an F_{msy} policy and for $F_{40\%}$ harvest rates are as follows:

Year	$F_{40\%}$	F_{msy}
1999	700	800
2000	735	834
2001	764	860

For the reference-case model specification we expressed the uncertainty in the form of a decision table (Table 16). The low-mod-high columns of this table represent different hypotheses about the current level of stock size being at low, moderate, or high levels. What seems clear from this is that even with zero fishing mortality, we expect the stock to reach of the target B_{msy} level. Examinations of the probability distributions about this target we conclude that there is a high degree of uncertainty about future stock conditions.

Our findings suggest that the current stock level remains low and is about 44% of the target (B_{msy}) stock size. Based on these results, we recommend harvests should remain at minimal levels until substantive stock increases are observed.

Following discussions presented at the STAR panel meeting, the following research recommendations have been identified:

- Attempt to collaborate on a stock-wide basis extending into the Canadian zone as appropriate. Operationally this system may be similar to that currently used for the whiting fishery.
- Collection of age structures should resume if possible in areas where POP are landed. Also, investigate the possibility of re-reading the old otoliths (previously aged using the surface method).
- The age at sexual maturity should be re-examined since there are concerns that visual-inspection may be biased.
- Since extensive logbook collections are available and issues remain about the impact of targeting behavior, we recommend adding questions about the characteristics of POP fishing in the NMFS Port Interview Program.
- Preliminary investigations of the Russian survey data were presented in this report. Continuing the work may improve future stock assessments since the analyses were shown to be sensitive to the historical (1956-1973) CPUE data. Also, analyses of changes in relative species composition may reveal important changes that occurred during this period when observations were limited.
- Since the results rely considerably on the NMFS triennial survey data, analyses of the effect of swept-area expansions onto untrawlable fishing grounds should be continued. Also, directed studies on the processes affecting the value of "q" for POP using NMFS's survey gear.
- Implement new observer data to obtain estimates of POP discard levels.

The source code, data files and final parameter files can be downloaded at http://www.refm.noaa.gov/wc
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In 1981 the Pacific Fishery Management Council (PFMC) adopted a 20-year plan to rebuild the depleted Pacific ocean perch (*Sebastes alutus*) resource in waters off the Washington and Oregon coast. This plan was based on the results of two studies. The first study employed a cohort analysis of 1966-76 catch and age composition data as a basis for examining various schedules of rebuilding (Gunderson 1979). This report was later updated with four additional years of catch and age information (Gunderson 1981). The second study provided an evaluation of alternative trip limits as a management tool for the Pacific ocean perch fishery (Tagart et al. 1980). Trip limits are now used by the Council as a means of curbing directed Pacific ocean perch fishing.

In this assessment, we have combined the Pacific ocean perch stocks from the INPFC Columbia region with the US-Vancouver area. Traditionally, distinction between these stocks was based on the size distribution and perceived differences in growth. Examination of size composition for these areas indicates, however, that good recruitment years coincided. Genetic studies of the stock structure suggest mixing of the breeding stock between the INPFC areas (Wishard et al. 1980 Seeb and Gunderson 1988.). Examination of the along-shore catch rate distribution of Pacific ocean perch during the surveys did not reveal substantial gaps which might indicate the need for separate management stocks. Parallel recruitment patterns, genetic similarities, and catch rate distribution suggest that the Pacific ocean perch along the west coast of the US may be from a single stock. If separate stocks do exist, a biological basis for splitting them has not been established. Local “pockets” of relatively isolated Pacific ocean perch probably do exist (D. Gunderson, pers. comm.) hence we recommend that management actions on a coast-wide stock should account for problems of effort concentration and to distribute the catch more evenly.

Prior to 1965, the Pacific ocean perch resource in the US-Vancouver and Columbia areas (Fig. 1) of the International North Pacific Fisheries Commission (INPFC) were harvested almost entirely by Canadian and United States vessels. Most of these vessels were of multi-purpose design used in other fisheries (e.g., salmon and herring) when not engaged in the groundfish fishery (Forrester et al. 1978). Generally under 200 gross tons and less than 33 meters (m) in length, these vessels had very little at-sea processing capabilities. Characteristics which, for the most part, restricted the distance the vessels could fish from home ports and limited the size of their landings. Landings from 1956 to 1964 averaged 2,018 and 1,980 metric tons (t) in the Vancouver and Columbia areas, respectively.

Catches increased dramatically after 1964 with the introduction of large distant-water fishing fleets from the Soviet Union and Japan. Both nations employed large factory stern trawlers as their primary method for harvesting Pacific ocean perch. These vessels generally operated independently by processing and freezing their own catch, and the use of support vessels (e.g., refrigerated transports, oil tankers, supply ships, etc.) permitted the large stern trawlers to operate at sea for extended periods of time. Peak removals by all nations combined amounted to 16,358 t from the Vancouver area in 1966 and 23,976 t from the Columbia area one year later in 1967.

Immediately following these peak years, production declined very rapidly. Apparently, these stocks were far too limited to sustain the large removals during the mid 1960s. By 1969, the Pacific ocean perch stocks were severely depleted throughout the Oregon-Vancouver Island region (Gunderson 1977). Harvests within the past seventeen years (1978-1994) have averaged 474 t and 833 t in the U.S-Vancouver and Columbia areas, respectively. Catches since 1979, however, have been restricted by the Pacific Fishery Management Council to promote rebuilding of the depleted stocks.

Removals and regulations

Prior to 1977, Pacific ocean perch stocks in the northeast Pacific were managed by the Canadian government in its waters and by the individual states in waters off the United States. With implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977, primary responsibility for management of groundfish stocks off Washington, Oregon, and California shifted from the states to the Pacific Fishery Management Council (PFMC). At that time, however, a fishery management plan (FMP) for the west coast groundfish stocks had not yet been approved. In the interim, the state agencies worked with the Council to address conservation issues. Specifically, in 1981 the Council adopted a management strategy to rebuild the depleted Pacific ocean perch stocks to levels which would produce maximum sustainable yields within 20 years. On the basis of a cohort analysis (Gunderson 1979) the Council set acceptable biological catch (ABC) levels at 600 t for the US portion of the INPFC Vancouver area and 950 t for the Columbia area. To implement this strategy, the states of Oregon and Washington established landing limits for Pacific ocean perch caught in their waters. Trip limits have remained in effect to this day (Table 1).

Past assessment methods

The condition of Pacific ocean perch stocks off British Columbia, Washington and Oregon have been assessed periodically since the intense pulse of exploitation in 1966-68. The mean exploitable biomass in the Vancouver area during 1966-1968 was estimated at about 34,000 t (Westrheim et al. 1972). Following the years of heavy fishing, catch-per-unit-of-effort (CPUE) for the Washington-based fleet in the Vancouver area dropped to 55% of the 1966-68 levels, indicating a decrease in biomass to 18,700 t during 1969-71 (Technical Subcommittee 1972). Catch rates declined further during 1972-74 which indicated a reduction in biomass by about 11% (Gunderson et al. 1977). The mean weighted CPUE rose slightly in the period from 1975-77 (Fraidenburg et al.1978), however, this may be due to improvements in gear efficiency (the use of “high rise” trawl nets).

Columbia area biomass estimates since 1966 have been calculated by dividing landings by estimated exploitation rates. The mean biomass estimates declined from 23,000 t during 1966-68 to 7,300 t during 1969-72 and 4,300 t during 1973-74 (Gunderson et al. 1977). An area-swept extrapolation from commercial CPUE data in the Columbia area resulted in a biomass estimate of between 8,000 and 9,600 t in 1977 (Fraidenburg et al. 1978). Since the commercial fishery operates mainly in areas of high abundance, these estimates are likely to be biased toward the high side.

Research surveys have been used to provide fishery independent assessments of the abundance, distribution, and biological characteristics of Pacific ocean perch. A coast-wide survey of the rockfish resource was conducted in 1977 (Gunderson and Sample 1980) with the objective of defining the distribution and measuring the abundance of the major species taken in bottom trawls. The 1977 coastwide survey has since been repeated every three years, yielding six fishery independent assessments of the resource in 1980, 1983, 1986, 1989, 1992 and 1995. The interannual variability of these survey estimates is substantial and given the large amount of sampling error within each year, depicting trends from the estimates alone is inappropriate unless a formal time-series approach is used (e.g., Pennington 1985). The values of the survey estimates and the associated errors are modeled with several other data types as presented below. This improves our abilility to assess population trends by taking into account the biology of the species and the fisheries involved in their harvest.

The relative imprecision of biomass estimates derived for Pacific ocean perch from the 1977 rockfish survey prompted requests from the fishing industry and resource managers for closer attention to the status of this resource. In response, the National Marine Fisheries Service (NMFS) coordinated a cooperative research survey of the Pacific ocean perch stocks off Washington and Oregon with the Washington Department of Fisheries and the Oregon Department of Fish and Wildlife in March-May

1979 (Wilkins and Golden 1983). This survey provided more precise biomass estimates indicating stock sizes similar to those calculated from the 1977 triennial survey. Another Pacific ocean perch survey was conducted in 1985 to determine what impact six years of restrictive catch regulations have had on the status of these stocks. Due to the directed effort of the 1979 and 1985 surveys to focus on Pacific ocean perch (and other rockfish species) these have been considered as estimates of absolute abundance whereas the triennial surveys have been used as relative abundance indices.

In the 1992 and 1995 assessment documents, the population dynamics of Pacific ocean perch in the US-Vancouver and Columbia areas combined were examined using a statistical age-structured model (Methot 1990). The current model implementation is based on the work of (Fournier and Archibald 1982 and more recently Methot 1997 and Tagart *et al.* 1997). As in past years, the concept of the estimation is to simulate the population through a process model, then evaluate the simulation according observations. The observation model includes the types of errors that occur due to sampling, biomass estimates, CPUE indices, and ageing error. The following presents the information used to set up and run the estimation procedure.

DATA

Fisheries

Catch history

The Pacific ocean perch fishery off the west coast the continental United States experienced extremely high catches during the late 1960's. Prior to 1965, this resource was harvested exclusively by Canadian and United States vessels in the Vancouver and Columbia areas. In 1965, however, foreign vessels (mainly trawlers from the Soviet Union and Japan) began intense harvesting operations for Pacific ocean perch in the Vancouver area, and one year later, entered the Columbia area. During the period from 1966 to 1975, the foreign fleets accounted for the bulk of the Pacific ocean perch removals (Fig. 2). The foreign fishery for Pacific ocean perch ended in 1977. Removals since 1979 have been restricted by the Pacific Fishery Management Council to promote the rebuilding of this resource. Estimated harvest by areas show that the Columbia area represented a large portion of catches through the 1980s and more recently the catch estimates are more evenly split between the US-Vancouver and Columbia areas (Fig. 3). The total catch estimates based on the PACFIN database indicates some slight differences with the catch estimates used in previous assessments (Fig 4). Catches by area and fleet are given in Table 2.

Size and age composition

Fishery age composition data were compiled by Gunderson (1981) for the Vancouver and Columbia INPFC areas. A similar pattern in year-class strength was evident between these areas suggesting that recruitment processes were the same. While the patterns of recruitment appear similar, the magnitudes of year-class strength varied between areas. To keep our model and presentation simple, and since the fisheries operating in both regions share many similarities, we combined the data from both areas (Table 3).

The age composition estimates from the fishery data were estimated by the otolith surface ageing technique. This method counts the number of annual bands apparent on the surface of the otolith. Recent advances in ageing methods have shown that this method is biased (Chilton and Beamish 1982). The bias under-reports the age of old Pacific ocean perch beyond the age of about 15 years old. Fish younger than 15 years age appear to be unbiased using the surface ageing method. For this reason we aggregate age 15 years and older to avoid biases.

Annual estimates of length composition from the commercial fishery were also available and used in the model as a surrogate for age. Length data were available from the Oregon Department of Fisheries and Wildlife (1983-91, 1994-1996) and from the Washington Department of Fisheries (1968-88, 1994-98).

CPUE Data

Catch per unit effort (CPUE) data from the domestic fishery (Gunderson 1978) were combined for the INPFC Vancouver and Columbia areas (Fig. 5). While these data reflect catch rates for the US fleet, the highest catch rates coincided with the largest removals by the foreign fleet. This suggests that, barring unaccounted changes in fishing efficiency during this period, the level of abundance during this time was high.

This year an effort was made to analyze recent fisheries logbook data. These data have been processed by NMFS Northwest Fisheries Science Center and exist as a large, coastwide database extending several years as reported by the different states. The source agencies and years of reporting for these data are: Washington 1985-1997; Oregon 1978-1996 and California 1978-1996.

The utility of POP CPUE indices derived from logbook data require careful considerations. For example, management measures have reduced the tendency for the commercial fleet to target or "top-off" a trip with POP. This will compromise the usefulness of logbook data for tracking abundance. That is, the activity of the fleet may reduce the potential harvests of POP. Actual harvests may be faithfully recorded in logbooks, but the fact that POP are being avoided by fishing masters' presents the potential for unaccounted-for biases in these data.

For these reasons, we present summaries of these data for comparison and have not included them in the model at this time. The trend of POP incidence in recorded tows has been fairly flat at about 10% for the period 1978-1997 with some indication of higher incidences in recent years (Fig. 6). A general linear model fit to these data with area, year, vessel, and depth as factors (J. Brodziak, NWFSC pers. comm.) suggest a substantial decline over this same period (Fig. 7). References (also supplied by Brodziak) on the methods of analyses of fisheries CPUE data include: Fox and Starr (1996), Gavaris (1980), Kimura (1981, 1988), Large (1992), Parsons *et al.* (1976), Robson (1966), Stefannson (1996), and Tyler *et al.* (1984)

Surveys

NMFS Cruises

The survey design used for the 1985 POP survey was similar to that used in 1979 (Wilkins and Golden 1983), but was standardized to correct inconsistencies that arose during the 1979 field work. The two most serious inconsistencies involved the use of three different trawls by four different vessels and variable depth coverage (165-475 m off Washington and 165-420 m off Oregon). The 1985 survey was designed to correct these inconsistencies and to compensate for the differences between the two surveys.

Sampling was done with the same style trawl net (Noreastern) in all areas. In the southern part of the Columbia area (Fig. 1), which had been sampled exclusively with the Mystic trawl in 1979, half of the stations were sampled with the Noreastern and half with the Mystic. The relative fishing power of the two nets was used to adjust Noreastern trawl catch rates in that area to the fishing efficiency of the Mystic trawl. In this way we were able to calculate abundance in the southern most subarea based on Mystic catch rates for comparison with 1979 results. No attempt was made to adjust fishing powers in the Columbia Middle area although a modified 400 eastern trawl was used there in 1979 and the Noreastern trawl was used in 1985. In calculating the 1985 Columbia South area abundance and size composition estimates for comparison with the 1979 results, hauls deeper than 420 m in the Columbia Middle and South subareas were excluded from the data to conform with the 1979 depth coverage.

Standardization of the survey design had no effect on the survey pattern in the Vancouver or Columbia North areas.

Length frequency distributions and age compositions from all the surveys are presented in the results section showing model fits (i.e., Figs. 16 & 17, respectively). Since 1985, the age compositions were determined using the break-and-burn method. This method is considered to provide accurate ages (Chilton and Beamish 1982). The available survey age composition data used in the model are presented in Table 4.

The biomass estimates and the standard errors used in the model runs treated the rockfish and triennial surveys both as **indices** of Pacific ocean perch abundance (Tables 5 and 6). This differs from previous assessments where the rockfish abundance series was treated as an absolute abundance index. The time series of these surveys combined are presented in Fig. 8.

Soviet surveys

Recently, the NMFS Alaska Fisheries Science Center developed a historical database of Soviet survey efforts that took place within the US EEZ during the period 1953-1978. These data represent a large body of work that has not previously been available for extensive analyses. We began some exploration of these data and the potential utility for the current assessment and present the preliminary findings here. The trawl locations ranged primarily from north of San Francisco well into the Canadian zone (Figs. 9). We examined these data for their potential as an alternative abundance index. The data exhibit a pattern very similar to that included in the CPUE index (presented above). There appears to be a severe drop in abundance coincident with the large amount of removals that occurred during the mid 1960s (Fig. 0). This figure also shows the relative areas of operations during this period and that the surveys were quite well spread out over the year. At this time we felt that more analyses of these were required before treating them as some type of abundance index. Our impression is that the assessment will change very little given these data. Once issues about species codings used by the Scientists aboard these vessels are resolved, we hope that some indication of any changes in relative species composition may be revealed. Also, there may be information that could improved the resolution of year-class strengths (say through the use of size composition data collected during these surveys).

Biology and life history

Natural mortality, longevity, and age at recruitment

Assessments of Pacific ocean perch have significantly changed in the past decade because of improved methods of age determination. Previously, Pacific ocean perch age determinations were done using scales and surface readings from otoliths. These gave estimates of mortality of about 0.15 and a longevity of about 30 years (Gunderson 1977). Based on the now accepted break and burn method of age determination using otoliths, Chilton and Beamish (1982) determined the maximum age of *S. alutus* to be 90 years. Using similar information, Archibald et al. (1981) concluded that natural mortality for Pacific ocean perch should be on the order of 0.05. Hoenig's (1983) relationship estimates that if Pacific ocean perch longevity is between 70 and 90 yr (Beamish 1979, Chilton and Beamish 1982), M would be 0.059 and 0.046, respectively. In previous assessments (Ianelli *et al.* 1992, 1995) we fixed M at 0.05. In the present analyses we broaden the definition of M and provide a "prior" distribution. Essentially, this acknowledges that we have a fair amount of uncertainty in the overall value of M while keeping its value within a reasonable range (McAllister and Ianelli 1996).

Sex ratio, maturation, and fecundity

Survey data indicated that sex ratios were different between INPFC areas (Ito et al. (1987). These differences were minor (within 5% of 1:1) so for the purpose of this study, we assumed a sex ratio of 1:1

by number. For the 1995 assessment, maturity at size were based on a total 400 female Pacific ocean perch visually examined during the 1986, 1989, and 1992 triennial surveys. Recently, the reliance of maturation studies using visual inspections has been questioned. Histological examinations have found that visual examinations can be biased. For this reason we selected to use age 10 as an estimate for when 50% of POP become sexually mature based on Heifetz *et al.* (1997; Fig. 10). As part of a sensitivity analyses, we ran the model with a younger age-at-sexual maturity for comparison.

Length-weight relationship

The length weight relationship for Pacific ocean perch was estimated using survey data collected from the west coast surveys from 1977 to 1989 (Fig. 11). Estimates from the 593 samples provided the following relationship:

$$W(L) = 9.82 \times 10^{-6} L^{3.1265}$$

where L = length in cm, W = weight in grams. The mean weights at age were computed from the length at age data and then used in the model.

Length at age

Previous age-length relationships were based on age data presented in Gunderson (1981). Using data collected from trawl surveys during 1977-1989 these relationships were estimated for Pacific ocean perch off the Oregon and Washington coast (Ianelli et al. 1992). This year, the survey age data from the 1992 was analyzed and used in establishing an updated length-at-age relationship (Fig. 12). The fitted von Bertalanffy growth model (combined sexes, 5,197 samples) was thus:

$$L_j = \theta_1 + \frac{(\theta_2 - \theta_1)(1 - k^{j-a_1})}{1 - k^{a_2 - a_1}}$$

where

θ_1 = average length of "young" age class

θ_2 = average length of "old" age class

a_1 = age of "young" age class (3 years)

a_2 = age of "old" age class (25 years)

k = growth rate

where L_j is the length (cm) at age j in years. The 1992 survey data on length at age were examined relative to the previous estimated relationship. The new data indicate that the size at age, particularly for the older fish, is slightly larger than estimates from previously collected data.

MODEL DESCRIPTION

For this assessment an forward projection age-structured model was developed similar to that of Methot (1990) and Tagart et al. (1997). The model equations, parameter descriptions and likelihood formulations are given in Tables 9 and 10.

As mentioned above, we selected a prior distribution for natural mortality instead of assuming a constant fixed value. Also, we allow selectivity to be a smooth function of age and to vary over time. We assume further that the catchability coefficient for NMFS area-swept biomass estimates may be different than 1.0. Here we provide a distribution about this value to acknowledge greater uncertainty in this value than has been done in the past. Finally, we re-parameterized the Beverton-Holt stock-recruitment model so that the critical shape parameter has an easier biological interpretation. We begin with:

$$R_i = \frac{S_{i-3} e^{\varepsilon_i}}{\alpha + \beta S_{i-3}}$$

where

- R_i is recruitment at age 3 in year *i*,
- S_i is the biomass of female spawners in year *i*,
- ε_i is the "recruitment anomaly" for year *i*,
- α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (*h*). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$

$$\beta = \frac{5h-1}{4hR_0}$$

where

- $\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawner biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawning biomass (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of 0.9 implies that 90% drop in the unfished spawning stock size will result in a 20% drop in the expected value of recruitment. Steepness of 0.9 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). Here we assume the expected value of steepness is 0.9 with a 10% coefficient of variation. The prior distribution was assumed to be lognormal within the range 0.2-1.0. Clearly, alternative values could be applied, particularly in the sense of taking the experience among other fish stocks (e.g., Lierman and Hilborn (1997)). Since we include a stock-recruitment curve as an integrated part of the assessment, assumptions about prior parameter values are critical, particularly if the data are non-informative. This feature also allows for computation of F_{msy} values and related quantities such as MSY, Bmsy etc. The method we develop for this is described in Addendum 1.

Analyses of model uncertainty was done three ways. First, for all parameters of interest, approximate variances were computed through the propogation-of-error techniques also known as the Delta method. This method provides an easily computed measure of relative uncertainty among different model parameters but requires assumptions about the shape of the likelihood surface that may be inappropriate. Namely, for the Delta method variance estimates (and those derived from inversion of the Hessian matrix) require that the likelihood surface is quadratic—a condition that holds when the parameters can be shown to be multivariate normally-distributed. To avoid these problems, we performed a Markov-

Chain Monte Carlo integration procedure to sample from the "true" posterior probability distribution. This accounts for possible curvature in the likelihood surface amongst parameters and integrates out uncertainty in all dimensions (as opposed to conditional upon, say, maximum likelihood estimates of other so-called "nuisance" parameters). These methods are described in Gilks *et al.* 1996 and in Gelman *et al.* (1996).

Issues of model convergence were assessed a number of ways. First, the Hessian matrix was inverted for all model runs to ensure that it was positive definite (an indication of a poorly converged or over-paramtrized model). Second, the estimation was always begun at starting values far from the final solution. Finally, the estimation was carried out in a number of phases. This averts problems where highly non-linear models (such as that used here) enter biologically unreasonable regions (e.g., stock sizes smaller than total catch or stock sizes several orders of magnitude too high).

We evaluated the effect of discards in past assessments. Briefly, Pikitch et al. (1987) reported that the estimated discard rate of Pacific ocean perch, based on observer data during 1985-1987, was largely a function of trip limit regulations. As trip limits were reduced, the discard rate increased. Furthermore, lower trip limits increased the proportion of unmarketable (small) fish that were discarded. The actual catch of Pacific ocean perch off the west coast is not accurately known, in part, due to the lack of information on fish not retained.

The fact that some Pacific ocean perch are being discarded warrants consideration since the current stock level appears to be low and the harvest rates potentially high, even though the species is caught only as bycatch in other fisheries. Previously, a 16% discard fraction was assumed for the recent fishery time period. For this assessment, the issue of discarded POP is addressed in the context of total removals in harvest projections.

Since the model's computer code was rewritten, it is critical to evaluate current results with that achieved in past models. We demonstrate this with direct comparisons to the 1995 results relative to our reference case (Model 1).

Sensitivity analyses and model selection were carried out in an attempt to address the concerns of reviewers and to evaluate consequences of model alternatives (Table 11). Breifly, these models include the reference case (Model 1), a model where catch during the peak three years was overestimated by a factor of two (Model 2); a run where selectivity in the survey was allowed to vary over time (Model 3) and a version of the model where the prior distributions about the survey catchability, natural mortality, and stock-recruitment steepness was increased (Model 4; Fig. 13). Model 5 ignores the fishery CPUE index completely. Model 6 represents a sensitivity run for alternate age-at-sexual maturity.

RESULTS

Time series of biomass, recruitment and fishing mortality or exploitation rate estimates are shown in Fig. 14. The fit to the stock-recruitment relationship indicates a fair amount of variability, especially during the early part of the time series when several strong year-class occurred. Above-median recruitment levels were generated throughout the the period 1956-1966 with relatively poor year-class strengths since the 1970 year-class. The residuals to the CPUE data indicate a pattern of low, followed by higher-than expected observations. The residuals for the survey data appear more regularly dispersed over time. Fishing mortality peaked during the mid 1960s and have stabilized between 0.05 and 0.10. The selectivity patterns estimated for the fishery are presented in Fig. 15. There is a moderate change in selectivity pattern over time. The fit of the model to the size and age composition data for both the fishery and surveys are presented in Figures 16 to 19.

The level of uncertainty about the 1998 stock size is expressed in Fig. 20. The 10^{th} and 90^{th} percentiles occurr at about 13,000 and 28,000 tons respectively. This represents a stock size that is very likely to be below the target B_{msy} level (Fig. 21). This figure shows that there is only about 10% chance that the current stock size is above the target level.

Table 12 lists all parameters in the stock assessment model used for the base run.

Comparison with previous assessment

This year's model gave very similar results to that used in the 1995 assessment, despite some major differences in the modeling approach (Fig. 22). The key differences were in the assumptions made about the survey catchability values. Previously, we assumed a constant survey catchability of 1.0 for the two rockfish surveys (conducted in 1979 and 1985) while the triennial surveys were used as a relative abundance index. This year we treat both surveys as relative abundance indices.

Uncertainty and sensitivity analyses

Results from the different models (described in Table 11) are given in Table 13. This table has three parts: the top section deals with stock status, the middle concerns the effect of different models on projection values, and the lower part gives the minus log-likelihood values due to the different data components and prior specifications.

The effect of reducing the peak catches (Model 2) during 1965-1967 by half seemed to affect the critical model results only slightly. The current stock size is slightly larger but the target stock size (B_{msy}) was very similar. Fixing fishery selectivity to be constant (Model 3) degraded the model fit (as expected) and also increased the estimated 1998 stock size. The current 1999 harvest level under F_{msy} for this model was slightly higher.

Broadening the prior distributions on M¸ q, and stock-recruitment steepness (Model 4) affected the model results in predictable ways. The value for stock-recruitment steepness dropped to 0.46 and the uncertainty on other quantities increased considerably. For example the (approximate) CV for the 1998 age 3+ biomass is 27% for Model 1 while for Model 4 the CV is 45%.

The effect of ignoring the CPUE data (Model 5) lowers the current stock size and provides a more pessimistic outlook regarding the current stock status. However, the MSY level is similar to most of the other models. The effect of using a younger age-at-50% maturity (Model 6) further increased 1998 1998 stock size predictably affected the level of SPR harvest rates. That is, the 1999 harvest levels under $F_{40\%}$ is more than 31% higher in Model 6 than for the reference (Model 1) case (700 tons versus 922 tons). This is due to the reliance of the SPR rates on age-at-maturation. A similar increase in the SPR rates was found in Model 4 (broader priors on critical parameters). This was due to the higher natural mortality rate (0.055) compared to the other models (0.043-0.048).

Estimates of the number at age for Model 1 are presented in Table 14.

Harvest projections

Reference harvest levels

To evaluate the properties of the yield computations we plotted the yield curve relative to values obtained under different spawners-per-recruit (SPR) harvest rates (e.g., $F_{35\%}$). This suggests that for westcoast POP, the F_{msy} value is closest to the $F_{35\%}$ level (Fig. 23). The actual estimate of uncertainty in the F_{msy} value suggests that the 10^{th} and 90^{th} percentiles are approximately between 0.05 and 0.09 (Fig 24). Since measures of uncertainty are available under the methods developed above, we evaluated the uncertainty in these harvest rates and stock size to project the level of 1999 harvests. These indicate a relatively broad overlap between these values (Fig. 25).

Harvest rates, and associated yields over the next 3 years are presented in the middle part of Table 13. These show some effect of different harvest levels and future stock sizes but only represent the "point estimates" of these outcomes. In our analyses, we performed an Markov-chain Monte Carlo integration scheme to encapsulate the uncertainty in the multivariate parameter space. In the decision analysis application that we present here, there are some important distinctions to be made between considering "point estimates" compared to the expected outcomes when a full MCMC integration is performed (e.g., Table 15). These differences can be due to several causes, the easiest can be illustrated through a simple univariate case as follows. Consider the distribution of annual income among US citizens. Clearly, this is skewed with a "mode" or "maximum" in the range of middle-class people. That is, there are the greatest number of people making wages within that range. The expected value or "mean" of this distribution of all people will be typically higher than this "mode" due to the few people that make extremely large sums of money. The point here is that the "mode" of the distribution is analogous to the "point estimates" we produce in stock assessments while the expected value is a more accurate reflection of the mean. Adding multivariate dimensions to a distribution (which is the case for our model) each of which may also exhibit some type of "skewness" increases the chances that the point estimates expected values will be different. While many of these concepts are not new, their use in Westcoast groundfish management has been limited. We feel that our analyses should be viewed as a small step towards incorporating the scientific data formally within the management framework. More work is needed to evaluate and further develop the implications of these guidelines for fisheries management. However, given the current model structure, we our approach is appropriate for developing harvest recommendations.

An analyses projecting forward for 11 years (to 2009) showing alternative current stock sizes and outcomes under different harvest policies is presented in Table 16. This shows that under most policies, the expected value indicates that the target (B_{msy}) will be attained by the year 2009. I.e., the expected value of the ratio of female spawning biomass in 2009 over B_{msy} is close to 1 (note that these ratios are expressed as percents: $F_{35\%}$ = 98%; $F_{40\%}$ = 104%; F_{msy} = 99%). This is tempered somewhat by displays of the uncertainty in future stock sizes (Figs. 26 and 27). If our harvest proceeds at these levels and the true "state of nature" is a low stock size (rather than the expected value) then the ratio of the 2009 stock size over B_{msy} would only be 63% under F_{msy} harvest levels. This pessimistic view of the stock condition would still result in an expected increase in stock size from the 1998 level of about 54% by the year 2009 (see middle panel of Table 16).

RECOMMENDATIONS

In this assessment we investigated several alternative model specifications for the different data types. Our findings suggest that the current stock level remains at low levels and is about 30% of the target stock size. Based on these results, we recommend harvests should remain at minimal levels until substantive stock increases are observed.

ACKNOWLEDGMENTS

Dr. Jon Brodziak conducted analyses for the recent logbook CPUE data and kindly provided these results and data for this assessment. Mark Wilkins provided the information on the NMFS triennial survey data. Bob Lauth gave the summaries from the NMFS slope surveys. Mark Saelens and Mark Freeman provided the commercial fisheries data from Oregon. Martha Rickey compiled and provided data from the state of Washington.

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RESPONSES TO EXTERNAL REVIEW

What follows are the comments from an external anonymous reviewer. Our comments in response are provided in italics.

April 16, 1998

Review of West Coast POP Assessment by Ianelli, Ito, and Wilkins

The text is generally well written and, in particular, is simple enough that it should be intelligible to a lay audience. The authors should be commended for including the alternative model specifications in the 1995 report. This represents a substantial improvement over the 1992 report. Some specific comments/criticisms are below:

1. There is no mention anywhere in the report of what past ABC's have been. These would be helpful to the reader. Maybe they could be included in Addendum Table A1. Some discussion about catches in recent years would also be useful. How long have the catches been entirely from bycatch? What are the target fisheries the POP bycatch is coming from? Why were catches allowed to be so high that they resulted in the high F's listed in Table 5 of the 1995 report? In recent years, have catches been higher than recommended ABC's, and if so, why?

The section (table) indicates that POP have been on a bycatch only status since 1979..

2. A minor point - the Wishard et al (1980) reference on stock structure of POP is out of date. A more recent and comprehensive reference is:

Seeb, L. W., and D. R. Gunderson. 1988. Genetic variation and population structure of Pacific ocean perch (*Sebastes alutus*). Can. J. Fish. Aquat. Sci. 45:78-88.

Included in current SAFE.

3. It's unclear to me why the authors have chosen in the model to differentiate between the 1979 and 1985 rockfish surveys and the triennial surveys. In the model, the rockfish surveys are used for absolute abundance estimates, and the triennial surveys as an index of relative abundance. The reason for this given in the reports is that the rockfish surveys were more precise (1992 report) or more focused on rockfish (1995 report). However, Figure 17 in the 1995 report shows the confidence intervals of the rockfish surveys are very similar to the adjoining triennial surveys. Thus, they do not appear to be any more precise. In Tables 2 and 3 (1995 report), the CV's of the triennial surveys are higher than those of the rockfish surveys, but this is comparing apples with oranges - the CV's for the triennial surveys are for each INPFC area, and the CV's for the rockfish surveys are for the areas combined. One would expect the CV's to be more precise for the combined areas. It may be more appropriate to treat all the surveys in a consistent fashion, i.e., either all as absolute estimates or all as abundance indices.

Included in current SAFE.

4. As a follow up to comment 3, I also noted from Figure 17 that the biomass estimates from the rockfish surveys happen to be two of the three highest biomass estimates in the whole time series. Using these two estimates as absolute abundances to tune the model (as the authors have done) results in higher yields than would be the case if all 8 biomass estimates were used for the tuning. Given the very depressed condition of the stock, choosing these high biomass estimates for the tuning strikes me as being somewhat risky, especially because I am not sure that these two surveys are that much better than the triennial surveys.

Since in this assessment both surveys are treated the same way, we hope to alleviate some of the problems associated with treating the surveys differently.

5. The authors use a new maturity relationship in the 1995 report, but state that the new relationship is "very similar to that assumed in the previous assessment based on Chikuni's (1975) results". However, when I compared the new relationship as shown in Figure 3 of the 1995 report versus Chikuni's relationship in Figure 2 of the 1992 report, I found them to be quite different. Age at 50% maturity in the new relationship is about 5.5 years, whereas it is approximately 7 years according to Chikuni. This difference is large enough that it could have a substantial impact on results from the model used in 1995. It would be helpful if Chikuni's curve were shown in Figure 3 along with the new relationship so readers could more easily compare them. (Minor aside: a maturity relationship from Gunderson is shown in Figure 3. There is no mention of this in the text. Why was it included?) Also, I checked age

at 50% maturity presently being used in the Gulf of Alaska POP assessment, and it turned out to be 10 years. Why is there such a big discrepancy between Alaska and the West Coast as to POP maturity?

> *Based on the recent results from the Gulf of Alaska, we have revised our age at 50% maturity to 10 years old. We also ran a model (Model 6) using age 7 as the age at 50% maturity for comparison.*

6. The von Bertalanffy parameters should be re-estimated using just break-and-burn data. Presently in the assessment, age data from 1977-89 are used to determine the age-length relationship. The authors don't give any information as to the aging methods used, but I would presume that samples collected in 1977 and perhaps some later were not aged with break-and-burn, as this technique did not become widely accepted until the early 1980's. The authors probably did some sort of correction to adjust these older age results to the newer break-and-burn methods, but I think it would be better to only use the break-and-burn data. There appear to be enough total age samples that the older samples could easily be dropped from the analysis without losing any precision. Also, are the authors sure all the age samples from the triennial surveys were random, and not length stratified?

> *Done. The age samples from the triennial survey were length stratified but examined for possible bias.*

7. Why is the selectivity curve for the foreign fishery asymptotic, whereas during the same years, it is dome shaped for the domestic fishery? (Compare Figures 10 and 21 in 1995 report.) Why is the right side of the dome shape so steep for older fish? This doesn't seem intuitive to me. What are the selectivity patterns of the surveys? I suggest a selectivity curve for the surveys be included in the report.

> *The approach to modeling selectivity was changed substantially and the current assessment alleviates this problem in my opinion.*

8. Although I am not an aging expert, I am a little skeptical that otolith surface readings and break-and-burn for POP would yield the same ages up to age 15, as the report claims Tagart's study showed. As Tagart's study is in a rather obscure publication, it would be useful if a figure showing the relationship between surface and break-and-burn ages were included in the POP assessment report.

> *In recognition of this problem, we chose to leave out the ages known to be biased. This avoids some model fitting problems with biased ages for the older groups which typically hold little information on relative year-class strengths. Also, the derivation of these data (from Gunderson 1978) are not well understood and could be re-analyzed.*

9. How were the length compositions for the domestic fishery derived, and how valid are these? I suspect the authors must think there are problems with these data because the data were assigned a weighting of only 0.1 in the model. Would better length data from recent catches be helpful, and could these data be collected?

> *The domestic length composition data from the earlier (1992, 1995) models were given less weight due to contradiction with the survey biomass time series and other data. This inconsistency may have been resolved for the current assessment since the length-age relationship was re-evaluated.*

10. The length frequencies for the 1979 and 1985 rockfish surveys appear very different from those of the triennial surveys (Figure 15 in 1995 report). It almost looks like the rockfish surveys were sampling a different population than were the triennial surveys. The rockfish surveys show a restricted length distribution of mostly large fish, whereas the triennials show a broader distribution including more small fish. Is there any explanation for this? Did the rockfish surveys fail to sample areas inhabited by small fish?

> *Generally, both surveys should sample the small-fish habitat about equally. However, both surveys sample the population age-compositions relatively poorly (since a small, highly non-random sample is taken). We believe that the differences commented on are due to sampling errors.*

11. The authors mention that the weighting factors in the model (Table 4 in the 1995 report) were determined "subjectively". Could some "subjective" reasons be given to explain why one factor was weighted much more than another? I realize some of these may be difficult to verbalize. However, if a rationale for the weighting scheme were provided, it would improve the reader's understanding of how the model works and lend greater support to the conclusions deduced from the model.

> *A weighting scheme was abandoned in the current analyses (although assumptions about sample-size and index measurement errors were made). We chose to treat these types of analyses as more discrete "all or*

nothing" effects rather than different emphasis factors. In other words, we attempted to de-emphasize the use of emphasis factors to simplify the presentation.

12. The text states that the initial slope parameter *A* of the Beverton-Holt stock-recruitment relationship was fixed (p. B-21 of 1995 assessment). This value is important for determining the harvest recommendation when the stock is at low abundance, which is the current stock status. What was the value chosen and how was it chosen? Are the harvest recommendations sensitive to the value of *A*?

In past assessments, this factor was not important in setting harvest rate guidelines. This comment does apply in the current assessment since the (analogous) value for the A parameter plays an critical role in harvest recommendations under any MSY-type policy. We feel that the current analyses are an improvement since the stock-recruitment data are integral to the model and the estimates (instead of arbitrary fixed values) and can be evaluated given the available data. Note however that our results about the level of "prior" information on this stock-recruitment parameter is critical as demonstrated in Model 4 relative to the other models.

13. Model alternative 4 was the one the authors ended up selecting as their preferred option. In the text, they state that the major difference between alternative 4 and the baseline (1992) model is that alternative 4 places a higher weighting on the stock-recruitment relationship. However, they fail to provide a rationale for the increased emphasis on stock recruitment. Because their selection of alternative 4 is critical for determining recommended ABC, I think they need to discuss their reasoning for changing the weighting of stock recruitment in 1995.

Ok. See response to 12.

14. In reference to Fig. 18 of the 1995 report (retention function used for discarded fish), the authors show that 50% of age 5 fish are retained. Based on the age-length relationship presented in the report, age 5 fish would translate to about 27 cm in length. A 27 cm POP is a pretty small fish, and, at least in my opinion, I doubt many fishermen would retain fish of this size. I suggest the authors may want to re-examine their retention function to see if it is actually valid.

In the present assessment, we have downplayed the effect of discards on POP as primarily a sensitivity issues. Given all indications about the stock condition, conclusions about the impact of discards affect the larger problems of recent recruitment failure very little.

15. The beginning of the results section (3.1 in the 1995 report) states that all 5 model alternatives show the same overall trend. While this is true in a general sense (i.e., all showed high abundance in the early 1960's, then a sharp decline, followed by a protracted period of very low abundance), the biomass trends and estimates in the 1990's are different between the alternatives. For example, alternatives 2 and 4 show an increasing trend in the 1990's, whereas the baseline and alternative 1 do not; the 1995 estimated biomass for alternative 2 is nearly twice that of the baseline or alternative 1. Part of the problem is that the large y axis scale of Figure 19 causes the more recent trends to be obscured. A blow-up of the more recent years would be helpful.

OK.

16. I suggest that the authors be more explicit in their recommendation of ABC. After reading the 1995 report, I was initially unsure what they were recommending. In section 3.3, several alternative values were presented, but it was unclear to me which value the authors preferred. I finally deduced from the bold text in Table 7 that $F_{35\%}$, or 591 mt, must be their recommendation. It's almost as if the authors were trying to hide or obscure what they were recommending!

Due to the background of trying to provide scientific information about the biological condition of the stock, there is little demand for recommendations of harvest rates since the management had been in a "rebuilding" mode for this species since 1979?

17. I'm a little concerned the $F_{35\%}$ recommendation for ABC may not be conservative enough. For comparison, I checked the Gulf of Alaska SAFE report on slope rockfish. I see the authors there have used more conservative levels of $F_{44\%}$ and $F_{40\%}$ in recent years for their POP ABC recommendations, despite the fact that the Alaska stocks appear to be in better shape than the West Coast and are thought to be increasing in abundance. The estimates of F given in Table 5 in the West Coast 1995 report (if valid) show the stocks there have been continually hammered throughout the 1980's and 1990's, even though abundance has been very depressed during this time period. In

addition, I'm especially troubled by the lack of information on discards of POP on the West Coast. The authors assume a 16% discard rate for the 1995 report, but this is based on relatively old information from reports written in 1987 and 1990. Discard rates often change with time, as fisheries and markets change, and the discard rate could be very different today. What if a lot more POP are being caught and discarded than we think? All these factors argue on the side of conservatism, maybe more conservative than $F_{35\%}$.

The present analyses takes a long step towards an individual assessment of the relavence of an "F35%" harvest rate as an appropriate proxy for MSY. In fact, we present MSY values based on analyses of the current available data. The fact that this Fmsy rate is more conservative than even the F40% rate (even without considering discards) suggests that lower than F35% rate is probably more appropriate.

18. I found the 20 year projections in the 1992 report to be useful and was sorry to see them dropped from the 1995 report. A long term perspective for POP is needed.

We present a longer term perspective two ways, after 10 years and a long-term target levels (e.g., Bmsy).

19. After reading the report, I went back to re-read the abstract at the beginning, and I was surprised to see the statement that the stock is presently "stable to slightly increasing". The use of the term "slightly increasing" seemed to put a positive slant to things that did not appear warranted based on my reading of the text. Some of the alternative versions of the model showed an increase; others did not (see comment 15). The abstract is important because it is all that many people, such as council members or fishermen, may read and remember. I think the salient point to communicate in the abstract is that the stock is extremely depressed and does not appear to be rebuilding to any significant extent. This, combined with the fact that fishing mortality has been excessively high for years, is a strong justification for setting ABC's as low as possible.

OK.

TABLES

Table 1. Pacific Fishery Management Council groundfish management/regulatory actions regarding Pacific ocean perch (POP) since Fishery Management Plan implementation in 1982.

Date	Regulatory Action
November 10, 1983	Recommended closure of Columbia area to POP fishing until the end of the year as 950 t OY for this species has been reached; retain 5,000 pound trip limit or 10 percent of total trip weight on landings of POP in the Vancouver area.
January 1, 1984	Continuation of 5,000 pound trip limit or 10 percent of total trip weight on POP as specified in FMP. Fishery closes when area OY's are reached (see action effective November 10, 1983 above).
August 1, 1984	Recommended immediate reduction in trip limit for POP in the Vancouver and Columbia areas to 20 percent by weight of all fish on board, not to exceed 5,000 pounds per vessel per trip. When OY is reached in either area, landings of POP will be prohibited in that area (Oregon and Washington implemented POP recommendation in mid-July).
August 16, 1984 (Automatic closure)	Commercial fishing for POP in the Columbia area closed for remainder of the year. (See items regarding this species effective January 1 and August 1, 1984 above.)
January 10, 1985	Recommended Vancouver and Columbia areas POP trip limit of 20 percent by weight of all fish on board (no 5,000 pound limit as specified in last half of 1984).
April 28, 1985	Recommended the Vancouver and Columbia areas POP trip limit be reduced to 5,000 pounds or 20 percent by weight of all fish on board, whichever is less. Landings of POP less than 1,000 pounds will be unrestricted. The fishery for this species will close when the OY in each area is reached.
June 10, 1985	Recommended landings of POP up to 1,000 pounds per trip will be unrestricted regardless of the percentage of these fish on board.
January 1, 1986	Recommended the POP limit in the area north of Cape Blanco (42 degrees, 50 minutes N) should be 20 percent (by weight) of all fish on board or 10,000 pounds whichever is less; landings of POP should be unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 600 t; Columbia area OY = 950 t.
December 1, 1986	OY quota for POP reached in the Vancouver area; fishery closed until January 1, 1987.
January 1, 1987	Recommended the coastwide POP limit should be 20 percent of all legal fish on board or 5,000 pounds whichever is less (in round weight); landings of POP unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 500 t; Columbia area OY = 800 t.
January 1, 1988	Recommended the coastwide POP trip limit should be 20 percent (by weight) of all fish on board or 5,000 pounds, whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 500 t; Columbia area OY = 800 t.
January 1, 1989	Established the coastwide POP trip limit at 20 percent (by weight) of all fish on board or 5,000 pounds whichever is less; landings of POP unrestricted if less than 1,000 pounds regardless of percentage on board (Vancouver area OY = 500 t; Columbia area OY = 800 t).
July 26, 1989	Reduced the coastwide trip limit for POP to 2,000 pounds or 20 percent of all fish on board, whichever is less, with no trip frequency restriction. Increased the Columbia area POP OY from 800 to 1,040 t.
December 13, 1989	Closed the POP fishery in the Columbia area because 1,040 t OY reached.
January 1, 1990	Established the coastwide POP trip limit at 20 percent (by weight) of all fish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board. (Vancouver area OY = 500 t; Columbia area OY = 1,040 t).
January 1, 1991	Established the coastwide POP trip limit at 20 percent (by weight) of all fish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,000 t).
January 1, 1992	Established the coastwide POP trip limit at 20 percent (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,550 mt).
January 1, 1993	Continued the coastwide POP trip limit at 20 percent (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,550 mt).
January 1, 1994	Adopted the following management measure for the limited entry fishery in 1994: POP: Trip limit of 3,000 pounds or 20 percent of all fish on board, whichever is less, in landings of POP above 1,000 pounds.
	Adopted the following management measure for open access gear except trawls in 1994: Rockfish: Limit of 10,000 pounds per vessel per trip, not to exceed 40,000 pounds cumulative per month, and the limits for any rockfish species or complex in the limited entry longline or pot fishery must not be exceeded.
May 1, 1994	Changed trip limit for rockfish taken with setnet gear off California. The 10,000 pound trip limit for rockfish caught with setnets, which applied to each trip, was removed. The 40,000 pound cumulative limit that applies per calendar month remains in effect.
January 1, 1995	Established cumulative trip limits of 6,000 pounds per month.
January 1, 1996	Established cumulative trip limits of 10,000 pounds every two months.
July 1, 1996	Reduced cumulative 2-month trip limit to 8,000 poinds.
January 1, 1997	Established cumulative trip limits of 10,000 pounds every two months.

Table 2. Pacific ocean perch catches in the US Vanvouver and Columbia areas and by fleet.

Year	US-Vancouver	Columbia	Foreign	Total Domestic (all areas)
1956	813	1,306	-	2,119
1957	866	1,454	-	2,320
1958	506	1,002	-	1,508
1959	726	1,134	-	1,860
1960	1,181	1,065	-	2,246
1961	1,864	2,060	-	3,924
1962	2,893	2,610	-	5,503
1963	2,900	3,549	-	6,449
1964	1,874	3,643	-	5,517
1965	2,660	5,375	375	7,660
1966	12,269	11,270	20,500	3,039
1967	10,112	23,976	33,204	885
1968	7,813	11,562	18,783	592
1969	2,558	2,496	4,361	692
1970	3,242	2,842	4,435	1,649
1971	2,920	2,869	4,792	997
1972	1,954	2,619	3,995	578
1973	2,867	634	3,148	353
1974	1,105	305	1,060	326
1975	708	1,116	1,201	623
1976	1,048	1,500	1,146	1,366
1977	709	478	7	1,180
1978	916	1,098	0	2,014
1979	615	1,239	0	1,854
1980	376	1,491	0	1,867
1981	248	1,099	0	1,359
1982	191	624	0	980
1983	286	1,409	0	1,797
1984	551	968	0	1,585
1985	440	786	0	1,329
1986	542	696	0	1,273
1987	366	546	0	1,075
1988	442	631	0	1,152
1989	473	894	0	1,405
1990	401	551	0	968
1991	504	704	0	1,224
1992	470	392	0	908
1993	453	613	0	1,093
1994	336	512	0	858
1995	284	405	0	701
1996	237	387	0	640
1997	326	275	0	616

Table 3. Domestic fishery catch at age for Vancouver and Columbia areas combined (from Gunderson, 1981). Otolith surface ageing method was used for these years. Note that the ages 15 and older were ommitted to avoid potential problems with these biased ageing methods.

Age	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	0	0	0	0	6	0	0	2	0	0	0	0	0	0	0
4	0	0	19	0	0	0	4	9	0	0	0	4	2	0	0
5	12	44	29	18	22	0	31	29	6	87	200	7	23	8	4
6	24	61	559	7	233	12	65	44	14	88	1,353	91	48	17	23
7	82	543	1,206	64	319	117	142	70	15	105	425	529	95	34	53
8	294	872	1,648	109	711	291	277	110	28	67	289	144	333	87	159
9	353	1,580	1,191	97	1,459	956	540	311	94	101	201	118	183	257	345
10	801	2,780	1,667	230	1,081	1,640	990	709	241	218	316	98	195	191	351
11	1,401	4,989	2,484	578	907	1,083	1,511	1,170	402	321	420	155	208	166	214
12	2,731	8,115	4,142	1,267	904	798	620	1,326	505	373	403	157	279	195	189
13	1,648	6,322	3,845	1,369	937	686	402	564	370	390	297	141	264	178	197
14	1,201	5,496	3,130	1,103	807	652	420	279	142	351	248	122	296	170	200
15	1,425	4,523	2,703	1,060	818	667	426	242	106	97	133	83	215	164	176
16	1,342	3,595	2,051	586	700	572	402	218	79	77	62	71	170	146	166
17	812	2,501	1,317	215	390	538	377	233	66	86	61	42	106	124	146
18	589	1,326	938	184	269	252	271	187	65	70	60	37	68	99	107
19	259	992	651	71	148	220	137	146	41	54	45	36	33	73	60
20	118	379	520	7	74	149	90	105	37	32	49	27	30	44	69
21	35	115	248	0	27	75	58	72	34	23	15	12	17	32	39
22	12	141	146	4	0	21	31	25	25	12	25	2	11	21	23
23	12	44	34	0	0	0	6	10	14	8	15	5	3	18	16
24	0	27	0	0	0	0	0	0	5	3	16	1	0	2	20
25	0	0	0	0	0	0	0	0	0	0	0	0	0	4	12

Table 4. Survey age compositions for the combined US Vancouver and Columbia areas. Note that the age 1 and 2 values for the population were not used in the model, neither were the data from 1977-1980 since the sample size was quite low and they were aged using surface methods.

Age	1977	1979	1980	1985	1989
1	0	0	0	0	46,138
2	18,214	2,556	0	21,200	254,816
3	84,582	13,231	0	122,477	89,226
4	119,793	228,325	295,155	332,342	3,176,682
5	125,448	667,058	702,456	731,141	1,219,343
6	460,779	652,383	591,543	1,017,246	656,796
7	2,631,845	870,267	350,490	418,657	833,499
8	745,320	2,341,122	514,736	290,206	2,353,474
9	474,994	3,722,415	576,100	294,572	928,618
10	383,316	1,663,880	268,615	603,853	748,928
11	455,394	1,148,334	253,944	523,611	573,984
12	900,039	1,169,177	371,575	301,193	416,323
13	888,055	1,004,988	403,092	405,146	353,090
14	1,251,141	1,080,766	224,522	553,271	219,216
15	1,013,324	933,723	365,190	554,201	24,770
16	1,036,159	914,997	240,000	290,312	129,282
17	551,481	738,255	192,922	210,758	20,177
18	939,938	592,137	220,671	284,327	9,974
19	976,370	418,312	0	189,918	36,992
20	768,559	320,882	0	265,433	20,936
21	406,035	171,105	64,715	263,709	49,188
22	139,400	108,387	0	213,783	23,570
23	98,700	58,304	0	217,418	119,073
24	7,982	17,428	0	200,765	132,707
25	54,337	15,899	0	3,163,096	2,195,421

Table 5. Biomass index from triennial groundfish surveys by area, 1977 - 1989.

Area/ Year	Depth (m)	Biomass Estimates	Sampling CV
US Vancouver			
1977	91-366	7,589	64.8%
1980	55-366	3,128	53.7%
1983	55-366	3,786	37.6%
1986	55-366	1,214	38.3%
1989	55-366	7,719	55.3%
1992	55-366	5,358	65.4%
1995	55-500	3,555	63.0%
Columbia			
1977	91-366	6,656	22.5%
1980	55-366	3,340	81.4%
1983	55-366	2,947	43.4%
1986	55-366	1,583	69.8%
1989	55-366	1,536	53.9%
1992	55-366	2,243	45.7%
1995	55-500	761	28.0%

Table 6. Survey estimates from directed Pacific ocean perch surveys for US Vancouver and Columbia areas combined, 1979 and 1985.

Year	Biomass	Cv
1979	14,245	29.6%
1985	10,696	20.1%

Table 7. Soviet Union scientific survey operations by year and month. Upper left panel shows the number of tows where POP were found, middle left shows the number of all tows. Other panels as labeled.

POP Tows

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1963							5						5
1964													0
1965			58	63	66	36	17	41	39	4			324
1966						28		22	55	1	1		107
1967		7	33	16	6	23	44	1	15	8	34	21	208
1968	25	38			11	21	46	28				17	186
1969	8	10	3	3	16	18	50	17	2	18			145
1970			2	3	17	8	2	17	19	29			97
1971							8	26	19	26	54		133
1972	2	1			2								5
1973			5		4	6					11	23	49
1974			4						3	9	76	42	134
1975	2	9							1	18	2		32
1976	5				37		39	63	29	33	14		220
1977						4		8	5				17
1978						1	1			1			3
Total	42	65	105	85	159	145	212	223	187	147	192	103	1665

Proportion POP Tows

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1963							36%						
1964													
1965			81%	84%	71%	95%	81%	89%	75%	27%			
1966		0%	0%	0%	0%	25%	0%	42%	60%	8%	50%		
1967		70%	52%	31%	12%	28%	45%	4%	27%	57%	48%	18%	
1968	37%	31%	0%		20%	29%	32%	29%				39%	
1969	40%	13%	8%	30%	25%	19%	36%	25%	3%	38%			
1970	0%		11%	7%	43%	57%	7%	25%	22%	38%	0%		
1971							28%	48%	40%	39%	71%		
1972	8%	25%	0%	0%	29%		0%	0%	0%	0%	0%		
1973			23%	0%	6%	7%	0%	0%	0%		52%	43%	
1974	0%	0%	4%					0%	5%	21%	70%	72%	
1975	5%	28%	0%	0%	0%	0%			17%	33%	6%		
1976	25%			0%	18%	0%	41%	56%	64%	42%	48%		
1977						25%	0%	6%	5%				
1978						7%	2%	0%	0%	3%			

All Tows

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1963							14						14
1964													
1965			72	75	93	38	21	46	52	15			412
1966		55	87	63	11	114	63	53	91	12	2		551
1967		10	64	52	49	81	97	28	55	14	71	114	635
1968	67	121	6		56	72	146	98				44	610
1969	20	76	38	10	64	97	140	69	75	48			637
1970	4		18	46	40	14	29	67	86	77	27		408
1971							29	54	48	66	76		273
1972	24	4	9	2	7		12	78	38	75	40		289
1973			22	22	65	81	46	41	40		21	53	391
1974	23	9	93					1	65	43	109	58	401
1975	41	32	78	64	101	82			6	55	31		490
1976	20			37	203	160	95	113	45	78	29		780
1977						16	62	137	103				318
1978						15	53	14	2	37			121
Total	199	307	487	371	689	770	807	799	706	520	406	269	6330

Average Depth of tows (meters)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1963													
1964													
1965			306	270	321	235	244	NA	475	NA			299
1966		367	270	270	315	304	296	318	550	NA	NA		313
1967		232	232	247	150	179	202	169	140	316	236	340	210
1968	320	373	NA		161	251	239	203				318	253
1969	232	209	238	264	217	228	187	151	250	198			209
1970	299		170	213	174	181	135	231	248	223	530		213
1971							NA	130	NA	25	360		172
1972	455	NA	NA	NA	NA		NA	234	NA	NA	NA		322
1973			305	53	107	174	194	184	222		192	304	190
1974	355	254	183					180	161	262	295	301	244
1975	306	370	241	203	200	140			139	221	181		217
1976	334			206	206	148	251	NA	198	319	172		227
1977						138	106	163	225				146
1978						123	135	118	60	194			152
Total	308	302	233	214	191	188	196	184	201	235	255	315	223

Average Latitude

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1963							49						49
1964													
1965			49	49	46	49	48	49	45	43			48
1966		43	44	44	45	47	44	44	46	44	44		45
1967		47	47	42	45	44	47	38	48	47	47	39	44
1968	42	44	40		46	46	46	45				47	45
1969	51	47	39	52	45	42	45	46	40	46			44
1970	33		38	42	48	52	45	43	43	45	37		43
1971							45	47	47	46	46		46
1972	38	40	37	33	41		38	44	48	46	45		44
1973			43	34	37	44	45	47	40		47	41	42
1974	34	35	38					46	48	41	44	43	42
1975	40	43	38	38	39	42			48	45	39		40
1976	42			39	43	41	41	45	46	44	46		43
1977						44	42	44	44				44
1978						42	45	44	41	45			44
Total	41.1	44.2	42.1	42.5	43.4	43.9	44.8	44.8	44.9	44.8	44.5	41.5	43.9

Average CPUE

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1963							40						40
1964													
1965			695	271	284	623	111	543	340	153			425
1966						198		148	104	0	32		136
1967		10	86	100	1	8	42	0	2	137	226	13	76
1968	112	112			0	0	0	5				11	38
1969	23	0	0	0	3	10	19	4	15	71			19
1970					21	46	0	83	0	60			42
1971							48	70	91	14	79		64
1972	99				9								54
1973			22		4	10					242	13	69
1974			0						65	54	5	0	7
1975	0	2							3	36			23
1976	81				4		2	1	33	26	140		20
1977						2		12	0				6
1978							3			0			1
Total	88	66	424	229	115	205	25	131	117	48	90	7	122

Table 8. List of data and time periods covered for the current assessment.

Data source	**Years**
Fishery Biased Age Composition	1966-1980
Fishery Size Composition	1968-89, 1994-1998
Fishery CPUE	1956-73
Triennial Survey Biomass	77, 80, 83, 86, 89, 92, 95
Triennial Survey Age Composition.	86, 89, 92
Triennial Survey Size Composition.	77, 80, 83, 86, 89, 92, 95
Rockfish Survey Biomass	1979, 1985
Rockfish Survey Size Composition	1979, 1985

Table 9. Equations describing catch-at-age model used for this assessment.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1956, …., 98}	1956 … 98 = 43 years	
Age index: j = {3, 4, 5, …, 24, 25^+}	3 … 25^+ = 23 age groups	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Prior distribution = lognormal(0.05, 0.1^2)
Size-age error, j = 3, …, 25^+ : the probability of size of true age j fish as in length bin j', i.e.,	$A_{jj'}$ $\sum_{j'=1}^{25} A_{jj'} = 1.0$	$\hat{P}_{ij'} = E\left[P_{ij'}\right] = \sum_{j=1}^{25} P_{ij} \ A_{j\,j'}$
Sample size for proportion at sex k and age j in year i	T_i	Scales multinomial assumption about estimates of proportio
Survey catchability coefficients	Q^s, Q^R	Prior distribution = lognormal(1.0 , 0.2^2)
Data Description	**Symbol/Constraints**	**Expected Values Based on Catch At Age Model**
Survey abundance index by year i = 1977, 80, 83, 86, 89, 92, 95	Y_i^s	$\hat{Y}_i^s = Q_i^s \sum_{j=3}^{25^+} s_j^s W_{ij} N_{ij} e^{-Z_{ij}}$
Rockfish survey index by year i = 1979 and 1985	Y_i^R	$\hat{Y}_i^R = Q_i^R \sum_{j=3}^{25^+} s_j^f W_{ij} N_{ij}$
Historical CPUE index by year i = 1956, 57, …, 73	Y_i^f	$\hat{Y}_i^f = Q_i^f \sum_{j=3}^{25^+} s_j^f W_{ij} N_{ij} \ c$
Catch biomass by Year, i = 1956,…,98	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Proportion at age or length bin j, in year i	P_{ij}, $\sum_{j=1}^{25} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{l=1}^{25} N_{il} s_{il}^f}$
Initial numbers at age	$j = 3$	$N_{k,1956,3} = e^{\mu_R + \rho_{1956}}$
	$3 < j < 25$	$N_{1956,j} = e^{\mu_R} \prod_{l=3}^{j} e^{-M}$
	$j = 25^+$	$N_{1956,25} = N_{1956,24}\left(1 - e^{-M}\right)^{-1}$
Subsequent years…	$j = 3$	$N_{i,3} = \frac{S_{i-3} e^{\rho_i}}{\alpha + \beta S_{i-3}}$
(i > *1956*)	$3 < j < 25$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 25^+$	$N_{i,25^+} = N_{i-1,24} \, e^{-Z_{i-1,24}} + N_{i-1,25} \, e^{-Z_{i-1,25}}$

Table 9. (continued)

Parameter Description	**Estimated Parameter, Constraints**	**Derived Parameters, Use in Catch at Age Model**
Index catchability		
Mean effect	μ^s, μ^f, μ^R	$Q_i^s = e^{\mu^s}$, $Q_i^R = e^{\mu^R}$, $Q_i^f = e^{\mu^f}$
Age effect	η_j^s, $\sum_{j=3}^{25^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
annual effect of fishing in year *i*	ϕ_i, $\sum_{i=1956}^{1998} \phi_i = 0$	
age effect of fishing (regularized form)	η_j^f, $\sum_{j=3}^{25^+} \eta_j = 0$	$s_j^f = e^{\eta_j^f}$, $j \le$ maxage $s_j^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment	μ_R	
Beverton-Holt form		
Year effect, *i* = 1956, …, 98	ρ_i, $\sum_{i=1956}^{1998} \rho_i = 0$	$R_i = e^{\mu_R + \rho_i}$

Table 9. (continued)

Likelihood Component	Specification	Description / notes
Abundance indices	$L_1 = \lambda_1^s \sum_i \ln\left(Y_i^s / \hat{Y}_i^s\right)^2$	Triennial Survey
	$L_2 = \lambda_1^f \sum_i \ln\left(Y_i^f / \hat{Y}_i^f\right)^2$	CPUE index
	$L_3 = \lambda_1^R \sum_i \ln\left(Y_i^R / \hat{Y}_i^R\right)^2$	Rockfish Survey index
Smoother for selectivities	$L_4 = \sum_l \lambda_2^l \sum_{j=3}^{25^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2 +$ $\lambda_3^l \sum_{j=3}^{25^+} \mathrm{I}\left(\eta_j^l < \eta_{j-1}^l\right)\left(e^{\eta_j^l} - e^{\eta_{j-1}^l}\right)^2$	Smoothness Degree of declining selectivity with age Note: *l={s, R, or f}* for survey and fishery selectivity
Recruitment regularity	$L_5 = \lambda_4 \sum_{i=1956}^{1998} \rho_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_6 = \lambda_5 \sum_{i=1956}^{1998} \ln\left(C_i / \hat{C}_i\right)^2$	
Proportion at age likelihood	$L_7 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \log\left(\hat{P}_{ij}^l \cdot P_{ij}^l\right)$	*l={s, f}* for survey and fishery age composition observations
Fishing mortality regularity	$L_8 = \lambda_6 \sum_{i=1956}^{1998} \phi_i^2$	(relaxed in final phases of estimation)
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{9} L_i$	

Table 10. List of lambda's, their influence on model fitting, and standard deviations.

Lambda	Description	Log-scale standard deviation (unless otherwise noted)
λ_1^s	Variance term for triennial survey	(annual, sampling error)
λ_1^R	Variance term for rockfish index	(annual, sampling error)
λ_1^f	Variance term for historical CPUE data	0.25
λ_2^f	Variance term for fishery selectivity stability	0.16
λ_2^s	Variance term for survey selectivity stability	0.71
λ_3^f	Variance term for degree of declining fishery selectivity	0.07
λ_3^s	Variance term for degree of declining survey selectivity	0.07
λ_4	Variance term for recruitment regularity	2.24
λ_5	Variance term for matching catch biomass	0.07
λ_6	Variance term for annual fluctuations in fishing mortality	2.24

Table 11. Description of alternative models evaluated for sensitivity analyses.

Model	**Description**
1	Reference case
2	Top 3 harvest years catch reduced by 50%
3	Constant fishery selectivity
4	Broader Prior on q, M and stock-recruitment steepness (dashed line, Fig. 13)
5	Ignore CPUE Data
6	Age at 50% maturity set to 7 years

Table 12. List of parameters in the POP stock assessment for Model 1. Shaded labels represent derived parameters.

Name	Value	Stdev
log_Rzero	1.64	0.12
log_q_cpue	-12.51	0.07
log_q_surv	-0.84	0.14
log_q_surv2	-0.37	0.20
natmort	0.05	0.00
steepness	0.68	0.06
log_avg_F	-2.57	0.36
Rec_Dev Year 35	-0.05	0.50
Rec_Dev Year 36	-0.05	0.50
Rec_Dev Year 37	-0.05	0.50
Rec_Dev Year 38	-0.06	0.50
Rec_Dev Year 39	-0.06	0.49
Rec_Dev Year 40	-0.06	0.49
Rec_Dev Year 41	-0.07	0.49
Rec_Dev Year 42	-0.08	0.49
Rec_Dev Year 43	-0.09	0.49
Rec_Dev Year 44	-0.10	0.48
Rec_Dev Year 45	-0.11	0.48
Rec_Dev Year 46	-0.12	0.48
Rec_Dev Year 47	-0.13	0.48
Rec_Dev Year 48	-0.14	0.48
Rec_Dev Year 49	-0.14	0.48
Rec_Dev Year 50	-0.13	0.48
Rec_Dev Year 51	-0.11	0.48
Rec_Dev Year 52	-0.08	0.49
Rec_Dev Year 53	-0.03	0.50
Rec_Dev Year 54	0.03	0.52
Rec_Dev Year 55	0.10	0.53
Rec_Dev Year 56	1.17	0.34
Rec_Dev Year 57	1.71	0.25
Rec_Dev Year 58	1.56	0.22
Rec_Dev Year 59	1.50	0.20
Rec_Dev Year 60	1.06	0.20
Rec_Dev Year 61	0.66	0.21
Rec_Dev Year 62	0.39	0.21
Rec_Dev Year 63	0.50	0.19
Rec_Dev Year 64	0.92	0.15
Rec_Dev Year 65	0.64	0.15
Rec_Dev Year 66	0.09	0.17
Rec_Dev Year 67	-0.30	0.18
Rec_Dev Year 68	-0.57	0.19
Rec_Dev Year 69	-0.69	0.18
Rec_Dev Year 70	-0.78	0.18
Rec_Dev Year 71	-0.63	0.18
Rec_Dev Year 72	-0.35	0.17
Rec_Dev Year 73	0.42	0.14
Rec_Dev Year 74	-0.39	0.19
Rec_Dev Year 75	-0.83	0.24
Rec_Dev Year 76	-0.93	0.28
Rec_Dev Year 77	-0.76	0.28
Rec_Dev Year 78	-0.68	0.29
F40	0.05	0.01
F35	0.06	0.01
F30	0.08	0.02
endbiom	17629	4816
q_surv	0.43	0.06
q_surv2	0.69	0.14
q_cpue	0.00	0.00
begbiom	95111	7071
Depletion	0.13	0.04
MSY	1632	181
Fmsy	0.05	0.01
Rmsy	0.92	0.40
Bmsy	12336	1720
Bcur_Bmsy	0.44	0.15

Name	Value	Stdev
Rec_Dev 79	-0.67	0.29
Rec_Dev 80	-0.71	0.29
Rec_Dev 81	-0.70	0.29
Rec_Dev 82	-0.43	0.26
Rec_Dev 83	-0.34	0.25
Rec_Dev 84	0.10	0.22
Rec_Dev 85	-0.58	0.30
Rec_Dev 86	-0.35	0.30
Rec_Dev 87	-0.19	0.29
Rec_Dev 88	0.22	0.25
Rec_Dev 89	-0.57	0.33
Rec_Dev 90	0.08	0.31
Rec_Dev 91	0.33	0.30
Rec_Dev 92	-0.15	0.39
Rec_Dev 93	0.33	0.47
Rec_Dev 94	0.11	0.48
Rec_Dev 95	-0.16	0.46
Rec_Dev 96	-0.03	0.50
Rec_Dev 97	-0.01	0.50
Rec_Dev 98	0.00	0.51
Fdevs Year 56	-1.23	0.37
Fdevs Year 57	-1.11	0.37
Fdevs Year 58	-1.51	0.37
Fdevs Year 59	-1.29	0.37
Fdevs Year 60	-1.09	0.37
Fdevs Year 61	-0.57	0.37
Fdevs Year 62	-0.24	0.37
Fdevs Year 63	-0.10	0.37
Fdevs Year 64	-0.31	0.37
Fdevs Year 65	0.00	0.37
Fdevs Year 66	1.08	0.37
Fdevs Year 67	1.71	0.36
Fdevs Year 68	1.57	0.36
Fdevs Year 69	0.55	0.37
Fdevs Year 70	0.83	0.36
Fdevs Year 71	0.82	0.36
Fdevs Year 72	0.68	0.36
Fdevs Year 73	0.50	0.36
Fdevs Year 74	-0.37	0.36
Fdevs Year 75	-0.05	0.36
Fdevs Year 76	0.34	0.36
Fdevs Year 77	-0.37	0.36
Fdevs Year 78	0.20	0.36
Fdevs Year 79	0.18	0.36
Fdevs Year 80	0.25	0.36
Fdevs Year 81	-0.03	0.36
Fdevs Year 82	-0.35	0.36
Fdevs Year 83	0.33	0.36
Fdevs Year 84	0.29	0.36
Fdevs Year 85	0.20	0.36
Fdevs Year 86	0.20	0.36
Fdevs Year 87	0.08	0.36
Fdevs Year 88	0.19	0.36
Fdevs Year 89	0.41	0.37
Fdevs Year 90	0.06	0.37
Fdevs Year 91	0.28	0.38
Fdevs Year 92	-0.04	0.38
Fdevs Year 93	0.13	0.39
Fdevs Year 94	-0.13	0.39
Fdevs Year 95	-0.38	0.40
Fdevs Year 96	-0.53	0.41
Fdevs Year 97	-0.63	0.41
Fdevs Year 98	-0.56	0.41

Name	Value	Stdev
sel_devs_fish Year 61 age 3	-0.02	0.32
sel_devs_fish Year 61 age 4	0.00	0.26
sel_devs_fish Year 61 age 5	0.02	0.26
sel_devs_fish Year 61 age 6	0.02	0.25
sel_devs_fish Year 61 age 7	0.00	0.25
sel_devs_fish Year 61 age 8	-0.02	0.25
sel_devs_fish Year 61 age 9	-0.04	0.25
sel_devs_fish Year 61 age 10	-0.05	0.25
sel_devs_fish Year 61 age 11	-0.03	0.25
sel_devs_fish Year 61 age 12	0.01	0.24
sel_devs_fish Year 61 age 13	0.02	0.21
sel_devs_fish Year 61 age 14	0.00	0.19
sel_devs_fish Year 61 age 15	-0.01	0.19
sel_devs_fish Year 61 age 16	-0.02	0.18
sel_devs_fish Year 61 age 17	-0.03	0.18
sel_devs_fish Year 61 age 18	-0.02	0.18
sel_devs_fish Year 61 age 19	-0.01	0.19
sel_devs_fish Year 61 age 20	0.01	0.19
sel_devs_fish Year 61 age 21	0.05	0.19
sel_devs_fish Year 61 age 22 +	0.11	0.21
sel_devs_fish Year 66 age 3	-0.04	0.32
sel_devs_fish Year 66 age 4	0.00	0.25
sel_devs_fish Year 66 age 5	0.04	0.25
sel_devs_fish Year 66 age 6	0.06	0.24
sel_devs_fish Year 66 age 7	0.04	0.24
sel_devs_fish Year 66 age 8	0.04	0.24
sel_devs_fish Year 66 age 9	0.03	0.23
sel_devs_fish Year 66 age 10	-0.06	0.23
sel_devs_fish Year 66 age 11	-0.09	0.23
sel_devs_fish Year 66 age 12	0.08	0.22
sel_devs_fish Year 66 age 13	0.14	0.20
sel_devs_fish Year 66 age 14	0.05	0.19
sel_devs_fish Year 66 age 15	-0.02	0.18
sel_devs_fish Year 66 age 16	-0.05	0.18
sel_devs_fish Year 66 age 17	-0.06	0.18
sel_devs_fish Year 66 age 18	-0.06	0.18
sel_devs_fish Year 66 age 19	-0.05	0.18
sel_devs_fish Year 66 age 20	-0.04	0.18
sel_devs_fish Year 66 age 21	-0.02	0.19
sel_devs_fish Year 66 age 22 +	0.01	0.22
sel_devs_fish Year 71 age 3	-0.07	0.32
sel_devs_fish Year 71 age 4	0.04	0.25
sel_devs_fish Year 71 age 5	0.20	0.24
sel_devs_fish Year 71 age 6	0.31	0.22
sel_devs_fish Year 71 age 7	0.29	0.21
sel_devs_fish Year 71 age 8	0.18	0.21
sel_devs_fish Year 71 age 9	0.21	0.20
sel_devs_fish Year 71 age 10	0.33	0.19
sel_devs_fish Year 71 age 11	0.27	0.18
sel_devs_fish Year 71 age 12	-0.12	0.17
sel_devs_fish Year 71 age 13	-0.31	0.18
sel_devs_fish Year 71 age 14	-0.23	0.18
sel_devs_fish Year 71 age 15	-0.17	0.18
sel_devs_fish Year 71 age 16	-0.14	0.18
sel_devs_fish Year 71 age 17	-0.12	0.18
sel_devs_fish Year 71 age 18	-0.11	0.18
sel_devs_fish Year 71 age 19	-0.11	0.18
sel_devs_fish Year 71 age 20	-0.12	0.18
sel_devs_fish Year 71 age 21	-0.14	0.18
sel_devs_fish Year 71 age 22 +	-0.18	0.21
rec_dev 1999	0	0.286
rec_dev 2000	0	0.286
rec_dev 2001	0	0.286
rec_dev 2002	0	0.286
rec_dev 2003	0	0.286
rec_dev 2004	0	0.286

Name	Value	Std. Dev.
sel_devs_fish Year 76 age 3	-0.04	0.31
sel_devs_fish Year 76 age 4	0.00	0.25
sel_devs_fish Year 76 age 5	0.12	0.23
sel_devs_fish Year 76 age 6	0.38	0.22
sel_devs_fish Year 76 age 7	0.34	0.21
sel_devs_fish Year 76 age 8	0.11	0.20
sel_devs_fish Year 76 age 9	-0.13	0.19
sel_devs_fish Year 76 age 10	-0.38	0.18
sel_devs_fish Year 76 age 11	-0.38	0.18
sel_devs_fish Year 76 age 12	-0.25	0.19
sel_devs_fish Year 76 age 13	-0.15	0.18
sel_devs_fish Year 76 age 14	-0.01	0.18
sel_devs_fish Year 76 age 15	0.03	0.18
sel_devs_fish Year 76 age 16	0.05	0.18
sel_devs_fish Year 76 age 17	0.06	0.17
sel_devs_fish Year 76 age 18	0.07	0.17
sel_devs_fish Year 76 age 19	0.06	0.18
sel_devs_fish Year 76 age 20	0.05	0.18
sel_devs_fish Year 76 age 21	0.04	0.18
sel_devs_fish Year 76 age 22 +	0.03	0.20
sel_devs_fish Year 81 age 3	0.03	0.31
sel_devs_fish Year 81 age 4	-0.06	0.25
sel_devs_fish Year 81 age 5	-0.25	0.24
sel_devs_fish Year 81 age 6	-0.53	0.22
sel_devs_fish Year 81 age 7	-0.48	0.22
sel_devs_fish Year 81 age 8	-0.23	0.22
sel_devs_fish Year 81 age 9	-0.07	0.21
sel_devs_fish Year 81 age 10	0.07	0.21
sel_devs_fish Year 81 age 11	0.09	0.21
sel_devs_fish Year 81 age 12	0.13	0.21
sel_devs_fish Year 81 age 13	0.21	0.20
sel_devs_fish Year 81 age 14	0.14	0.19
sel_devs_fish Year 81 age 15	0.12	0.18
sel_devs_fish Year 81 age 16	0.11	0.18
sel_devs_fish Year 81 age 17	0.11	0.18
sel_devs_fish Year 81 age 18	0.11	0.18
sel_devs_fish Year 81 age 19	0.12	0.18
sel_devs_fish Year 81 age 20	0.12	0.18
sel_devs_fish Year 81 age 21	0.12	0.18
sel_devs_fish Year 81 age 22 +	0.13	0.21
sel_devs_fish Year 86 age 3	0.03	0.32
sel_devs_fish Year 86 age 4	-0.07	0.25
sel_devs_fish Year 86 age 5	-0.19	0.24
sel_devs_fish Year 86 age 6	-0.28	0.23
sel_devs_fish Year 86 age 7	-0.27	0.23
sel_devs_fish Year 86 age 8	-0.18	0.23
sel_devs_fish Year 86 age 9	-0.07	0.23
sel_devs_fish Year 86 age 10	0.06	0.23
sel_devs_fish Year 86 age 11	0.15	0.23
sel_devs_fish Year 86 age 12	0.15	0.22
sel_devs_fish Year 86 age 13	0.09	0.20
sel_devs_fish Year 86 age 14	0.06	0.19
sel_devs_fish Year 86 age 15	0.06	0.18
sel_devs_fish Year 86 age 16	0.06	0.18
sel_devs_fish Year 86 age 17	0.06	0.18
sel_devs_fish Year 86 age 18	0.06	0.18
sel_devs_fish Year 86 age 19	0.06	0.18
sel_devs_fish Year 86 age 20	0.06	0.18
sel_devs_fish Year 86 age 21	0.07	0.18
sel_devs_fish Year 86 age 22 +	0.09	0.20
rec_dev 2005	0	0.286
rec_dev 2006	0	0.286
rec_dev 2007	0	0.286
rec_dev 2008	0	0.286
rec_dev 2009	0	0.286

Name	Value	Std. Dev.
sel_devs_fish Year 91 age 3	0.01	0.32
sel_devs_fish Year 91 age 4	-0.04	0.25
sel_devs_fish Year 91 age 5	-0.08	0.25
sel_devs_fish Year 91 age 6	-0.08	0.24
sel_devs_fish Year 91 age 7	-0.04	0.24
sel_devs_fish Year 91 age 8	0.02	0.24
sel_devs_fish Year 91 age 9	0.04	0.23
sel_devs_fish Year 91 age 10	0.02	0.24
sel_devs_fish Year 91 age 11	-0.01	0.24
sel_devs_fish Year 91 age 12	-0.03	0.23
sel_devs_fish Year 91 age 13	-0.03	0.20
sel_devs_fish Year 91 age 14	-0.02	0.19
sel_devs_fish Year 91 age 15	-0.01	0.18
sel_devs_fish Year 91 age 16	-0.01	0.18
sel_devs_fish Year 91 age 17	0.00	0.18
sel_devs_fish Year 91 age 18	0.01	0.18
sel_devs_fish Year 91 age 19	0.03	0.18
sel_devs_fish Year 91 age 20	0.04	0.18
sel_devs_fish Year 91 age 21	0.07	0.19
sel_devs_fish Year 91 age 22 +	0.10	0.22
sel_devs_fish Year 96 age 3	0.00	0.32
sel_devs_fish Year 96 age 4	-0.02	0.26
sel_devs_fish Year 96 age 5	-0.03	0.25
sel_devs_fish Year 96 age 6	-0.02	0.25
sel_devs_fish Year 96 age 7	0.03	0.25
sel_devs_fish Year 96 age 8	0.07	0.24
sel_devs_fish Year 96 age 9	0.05	0.24
sel_devs_fish Year 96 age 10	0.01	0.24
sel_devs_fish Year 96 age 11	-0.04	0.24
sel_devs_fish Year 96 age 12	-0.05	0.24
sel_devs_fish Year 96 age 13	-0.03	0.24
sel_devs_fish Year 96 age 14	0.00	0.24
sel_devs_fish Year 96 age 15	0.01	0.24
sel_devs_fish Year 96 age 16	0.01	0.24
sel_devs_fish Year 96 age 17	-0.01	0.24
sel_devs_fish Year 96 age 18	-0.01	0.24
sel_devs_fish Year 96 age 19	-0.01	0.24
sel_devs_fish Year 96 age 20	0.00	0.24
sel_devs_fish Year 96 age 21	0.01	0.24
sel_devs_fish Year 96 age 22 +	0.02	0.28
surv_sel_coffs age 3	-0.59	0.32
surv_sel_coffs age 4	-0.28	0.26
surv_sel_coffs age 5	-0.08	0.25
surv_sel_coffs age 6	0.00	0.24
surv_sel_coffs age 7	0.03	0.24
surv_sel_coffs age 8	0.10	0.24
surv_sel_coffs age 9	0.21	0.24
surv_sel_coffs age 10	0.33	0.24
fish_sel_coffs age 3	-4.80	0.72
fish_sel_coffs age 4	-3.93	0.53
fish_sel_coffs age 5	-3.10	0.46
fish_sel_coffs age 6	-2.33	0.43
fish_sel_coffs age 7	-1.64	0.41
fish_sel_coffs age 8	-1.03	0.40
fish_sel_coffs age 9	-0.49	0.39
fish_sel_coffs age 10	-0.02	0.37
fish_sel_coffs age 11	0.35	0.35
fish_sel_coffs age 12	0.56	0.31
fish_sel_coffs age 13	0.60	0.28
fish_sel_coffs age 14	0.57	0.27
fish_sel_coffs age 15	0.53	0.27
fish_sel_coffs age 16	0.48	0.26
fish_sel_coffs age 17	0.42	0.27
fish_sel_coffs age 18	0.35	0.27
fish_sel_coffs age 19	0.28	0.27
fish_sel_coffs age 20	0.20	0.28
fish_sel_coffs age 21	0.11	0.29
fish_sel_coffs age 22 +	0.02	0.30

Table 13. Summary of stock condition (in biomass), projections, and relative fits among different models. Note: coefficients of variation (CV's) are in parentheses. "Spawners" refers to female spawning biomass.

Stock Condition	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
1998 Total age 3+ biomass (tons)	17,629	19,177	18,957	16,234	14,352	19,802
	(27%)	(28%)	(28%)	(45%)	(28%)	(25%)
1998 Spawners	5,371	5,887	5,920	5,302	4,437	8,077
B_{msy}	12,336	12,455	12,636	17,387	15,852	13,175
	(14%)	(14%)	(14%)	(13%)	(11%)	(13%)
1998 Spawners / 1956 Spawners	13%	14%	14%	12%	9%	19%
	(30%)	(30%)	(31%)	(46%)	(31%)	(27%)
1998 Spawners / B_{msy}	44%	47%	47%	30%	28%	61%
	(35%)	(35%)	(36%)	(51%)	(35%)	(32%)
MSY	1,632	1,677	1,660	1,328	1,711	1,714
	(11%)	(11%)	(11%)	(18%)	(10%)	(11%)
F 1998 / F_{msy}	0.923	0.824	0.837	1.584	1.370	0.689
	(43%)	(43%)	(43%)	(66%)	(42%)	(43%)
Natural Mortality	0.047	0.048	0.048	0.055	0.043	0.047
	(8%)	(8%)	(8%)	(12%)	(8%)	(8%)
Stock-recruitment steepness	0.68	0.68	0.67	0.46	0.63	0.69
	(9%)	(9%)	(9%)	(15%)	(8%)	(10%)
Triennial Survey q	0.430	0.405	0.398	0.346	0.468	0.418
	(14%)	(15%)	(15%)	(22%)	(13%)	(14%)
Rockfish Survey q	0.693	0.667	0.653	0.618	0.763	0.676
	(20%)	(20%)	(21%)	(25%)	(19%)	(20%)
SPR F=0	8.06	7.94	7.97	6.54	9.19	8.74
Projections (based on point estimates)						
2009 Spawners @ F = 0	11,391	12,287	12,113	8,956	9,430	15,492
2009 Spawners @ F_{msy}	7,242	7,739	7,691	6,729	6,444	9,896
2009 Spawners @ $F_{30\%}$	6,427	6,894	6,817	4,653	5,493	8,705
2009 Spawners @ $F_{40\%}$	7,656	8,220	8,107	5,653	6,493	10,496
1999 Harvest @ F_{msy}	800	894	873	459	540	1,071
2000 Harvest @ F_{msy}	834	927	901	477	571	1,107
2001 Harvest @ F_{msy}	860	953	923	490	596	1,135
1999 Harvest @ $F_{40\%}$	700	775	771	742	529	922
2000 Harvest @ $F_{40\%}$	735	811	801	754	560	963
2001 Harvest @ $F_{40\%}$	764	840	825	758	585	996
Fit to data (R.M.S.E.)						
Triennial Survey	0.437	0.436	0.435	0.425	0.432	0.442
Rockfish Survey	0.060	0.070	0.071	0.065	0.058	0.066
CPUE	0.205	0.208	0.209	0.210	0.387	0.201
Recruitment	0.316	0.322	0.308	0.242	0.205	0.334
Catch	0.026	0.013	0.028	0.023	0.014	0.028
Fit to age/size compositions (effective sample size) [1]						
Survey Age	38	39	50	38	35	39
Fishery Age	220	220	220	218	213	219
Survey Size	62	62	78	59	67	62
Fishery Size	287	290	294	304	289	284
Priors (posterior variance / prior variance)						
M	0.04	0.04	0.04	0.03	0.03	0.04
Steepness	0.63	0.63	0.63	0.36	0.53	0.67
Q triennial	0.50	0.49	0.49	0.38	0.52	0.49

[1] Note that is is based on computations presented in McAllister and Ianelli (1997) relating the goodness of fit to the "effective sample size." E.g., larger values indicate better fits to the data.

Table 14**.** Numbers at age (millions of fish) for the US west coast population of Pacific ocean perch, 1956-1998.

	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1956	16.5	5.4	4.8	4.3	3.9	3.6	3.4	3.2	3.1	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.2	2.1	2.0	1.9	1.8	39.3
1957	28.4	15.7	5.2	4.6	4.1	3.7	3.4	3.2	3.0	2.8	2.7	2.6	2.5	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.8	38.3
1958	24.6	27.1	15.0	4.9	4.4	3.9	3.5	3.2	3.0	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.9	1.8	1.7	37.3
1959	23.0	23.4	25.9	14.3	4.7	4.2	3.7	3.3	3.0	2.8	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.9	1.8	1.8	1.7	36.6
1960	14.7	21.9	22.3	24.6	13.6	4.4	3.9	3.5	3.1	2.8	2.5	2.3	2.2	2.1	2.0	2.0	1.9	1.9	1.8	1.7	1.7	1.6	35.7
1961	9.8	14.0	20.9	21.3	23.4	12.9	4.2	3.7	3.3	2.9	2.6	2.3	2.1	2.0	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.6	34.7
1962	7.5	9.4	13.4	19.9	20.2	22.2	12.1	3.9	3.4	2.9	2.5	2.3	2.0	1.9	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.5	33.0
1963	8.4	7.1	8.9	12.7	18.9	19.0	20.7	11.2	3.5	3.0	2.5	2.2	1.9	1.8	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.4	30.7
1964	12.6	8.0	6.8	8.5	12.0	17.8	17.7	19.0	10.0	3.1	2.5	2.1	1.8	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.3	1.2	28.3
1965	9.5	12.0	7.6	6.4	8.1	11.4	16.6	16.4	17.2	8.8	2.6	2.2	1.8	1.6	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	26.5
1966	5.5	9.1	11.5	7.2	6.1	7.6	10.6	15.2	14.6	14.8	7.4	2.2	1.8	1.5	1.4	1.2	1.1	1.1	1.0	1.0	1.0	1.0	24.2
1967	3.7	5.2	8.6	10.8	6.7	5.6	6.7	8.8	11.9	10.5	9.2	4.4	1.4	1.2	1.1	1.0	0.9	0.8	0.8	0.8	0.8	0.8	18.7
1968	2.9	3.5	4.9	8.1	9.9	5.9	4.6	5.0	5.8	6.8	4.5	3.7	2.0	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	11.6
1969	2.5	2.7	3.4	4.6	7.4	8.8	4.9	3.5	3.4	3.5	3.2	2.0	1.8	1.0	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	7.6
1970	2.3	2.4	2.6	3.2	4.3	6.9	8.0	4.4	3.0	2.8	2.6	2.3	1.5	1.4	0.8	0.3	0.3	0.3	0.3	0.3	0.3	0.2	6.5
1971	2.4	2.2	2.3	2.5	3.0	4.0	6.2	6.8	3.6	2.3	1.9	1.7	1.6	1.1	1.0	0.6	0.2	0.2	0.2	0.2	0.2	0.2	5.3
1972	2.9	2.3	2.1	2.2	2.3	2.7	3.5	5.1	5.2	2.5	1.6	1.4	1.3	1.2	0.8	0.8	0.5	0.2	0.2	0.2	0.2	0.2	4.4
1973	6.0	2.7	2.2	2.0	2.0	2.1	2.4	3.0	4.0	3.8	1.8	1.2	1.0	1.0	0.9	0.6	0.6	0.4	0.1	0.1	0.1	0.1	3.7
1974	2.6	5.7	2.6	2.1	1.8	1.9	1.9	2.1	2.4	3.1	2.9	1.4	0.9	0.8	0.8	0.7	0.5	0.5	0.3	0.1	0.1	0.1	3.2
1975	1.6	2.5	5.5	2.5	2.0	1.7	1.7	1.7	1.8	2.1	2.7	2.5	1.2	0.8	0.7	0.7	0.7	0.5	0.4	0.3	0.1	0.1	3.0
1976	1.4	1.6	2.4	5.2	2.3	1.8	1.6	1.6	1.5	1.5	1.7	2.2	2.1	1.1	0.7	0.6	0.6	0.6	0.4	0.4	0.2	0.1	2.8
1977	1.7	1.4	1.5	2.2	4.8	2.1	1.6	1.4	1.3	1.2	1.3	1.4	1.8	1.7	0.9	0.6	0.5	0.5	0.5	0.3	0.3	0.2	2.4
1978	1.8	1.6	1.3	1.4	2.1	4.5	2.0	1.5	1.3	1.2	1.1	1.1	1.2	1.6	1.5	0.8	0.5	0.5	0.4	0.4	0.3	0.3	2.4
1979	1.8	1.7	1.5	1.2	1.3	1.9	4.1	1.7	1.3	1.1	1.0	0.9	0.9	1.0	1.3	1.3	0.6	0.4	0.4	0.4	0.4	0.3	2.3
1980	1.7	1.7	1.6	1.4	1.2	1.2	1.8	3.6	1.5	1.1	0.9	0.8	0.7	0.7	0.8	1.1	1.1	0.5	0.4	0.3	0.3	0.3	2.2
1981	1.7	1.6	1.6	1.5	1.3	1.1	1.1	1.6	3.2	1.3	0.9	0.7	0.7	0.6	0.6	0.7	0.9	0.9	0.4	0.3	0.3	0.3	2.2
1982	2.1	1.6	1.5	1.5	1.5	1.2	1.0	1.0	1.4	2.8	1.1	0.8	0.6	0.6	0.5	0.5	0.6	0.8	0.8	0.4	0.3	0.2	2.2
1983	2.3	2.0	1.5	1.4	1.5	1.4	1.2	0.9	0.9	1.2	2.4	1.0	0.7	0.5	0.5	0.5	0.5	0.5	0.7	0.7	0.4	0.2	2.2
1984	3.6	2.2	1.9	1.4	1.3	1.4	1.3	1.0	0.8	0.8	1.0	1.9	0.8	0.5	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.3	2.0
1985	1.8	3.4	2.1	1.8	1.3	1.3	1.2	1.1	0.9	0.7	0.6	0.8	1.6	0.6	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.5	2.0
1986	2.2	1.7	3.2	2.0	1.7	1.3	1.2	1.1	1.0	0.8	0.5	0.5	0.7	1.3	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.4	2.1
1987	2.5	2.1	1.6	3.1	1.9	1.6	1.2	1.0	1.0	0.8	0.6	0.4	0.4	0.5	1.0	0.4	0.3	0.3	0.2	0.2	0.2	0.3	2.2
1988	3.6	2.3	2.0	1.5	2.9	1.8	1.5	1.1	0.9	0.8	0.7	0.5	0.4	0.3	0.5	0.9	0.4	0.3	0.2	0.2	0.2	0.2	2.1
1989	1.5	3.4	2.2	1.9	1.5	2.7	1.6	1.4	0.9	0.8	0.7	0.6	0.4	0.3	0.3	0.4	0.7	0.3	0.2	0.2	0.2	0.2	2.0
1990	2.9	1.5	3.2	2.1	1.8	1.4	2.5	1.5	1.2	0.8	0.6	0.5	0.4	0.3	0.2	0.2	0.3	0.6	0.2	0.2	0.2	0.1	1.8
1991	3.6	2.7	1.4	3.1	2.0	1.7	1.3	2.3	1.3	1.0	0.6	0.5	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.2	0.2	0.1	1.7
1992	2.2	3.4	2.6	1.3	2.9	1.9	1.6	1.1	2.0	1.1	0.8	0.5	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.4	0.2	0.1	1.5
1993	3.4	2.1	3.3	2.5	1.3	2.7	1.8	1.4	1.0	1.7	0.9	0.7	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.2	0.4	0.2	1.5
1994	2.8	3.3	2.0	3.1	2.3	1.2	2.5	1.6	1.3	0.9	1.4	0.8	0.6	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.2	0.3	1.4
1995	2.1	2.7	3.1	1.9	3.0	2.2	1.1	2.3	1.4	1.1	0.7	1.2	0.7	0.5	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	1.5
1996	2.4	2.0	2.5	3.0	1.8	2.8	2.1	1.0	2.1	1.3	1.0	0.7	1.1	0.6	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	1.5
1997	2.5	2.3	1.9	2.4	2.8	1.7	2.6	1.9	0.9	1.9	1.1	0.9	0.6	1.0	0.5	0.4	0.2	0.2	0.2	0.2	0.1	0.1	1.4
1998	2.6	2.4	2.2	1.9	2.3	2.7	1.6	2.5	1.8	0.9	1.7	1.0	0.8	0.5	0.9	0.5	0.3	0.2	0.2	0.2	0.1	0.1	1.4

Table 15. Comparison of point estimates versus the expected values based on the MCMC integration.

	Expected Value MCMC	**Point estimate**
Spawning biomass in 1998	5,543	5,371
B_{msy}	9,184	12,336
2009 Spawners @ F=0	13,140	11,391
2009 Spawners @ F_{msy}	9,112	7,242
2009 Spawners @ $F_{30\%}$	8,329	6,427
2009 Spawners @ $F_{40\%}$	9,511	7,656

Table 16. Decision table showing outcomes of alternative harvest rate applications (rows) by different 1998 stock size hypotheses (columns). The labels low, mod, and high represent the lower, middle, and upper third quantile of the 1998 stock size. For these columns, the values shown represent the expected outcome within that quantile.

	1998 Stock Size			
	Low	Mod	High	Expected Value
	3,970	**5,384**	**7,275**	**5,543**

Policy	1999 Harvest (tons)
F=0	0
Fmsy	794
F40	695
F35	834
F30	1,007

Policy	2009 Stock Size			
	Low	Mod	High	Expected Value
F=0	10,160	12,966	16,295	13,140
Fmsy	6,097	8,940	12,299	9,112
F40	6,500	9,338	12,694	9,511
F35	5,942	8,786	12,146	8,958
F30	5,307	8,158	11,523	8,329

Policy	Ratio 2009 / 1998 Stock Size			
	Low	Mod	High	Expected Value
F=0	256%	241%	224%	237%
Fmsy	154%	166%	169%	164%
F40	164%	173%	174%	172%
F35	150%	163%	167%	162%
F30	134%	152%	158%	150%

Policy	Ratio 2009 / Bmsy			
	Low	Mod	High	Expected Value
F=0	105%	142%	186%	143%
Fmsy	63%	98%	140%	99%
F40	67%	102%	145%	104%
F35	62%	96%	138%	98%
F30	55%	89%	131%	91%

FIGURES

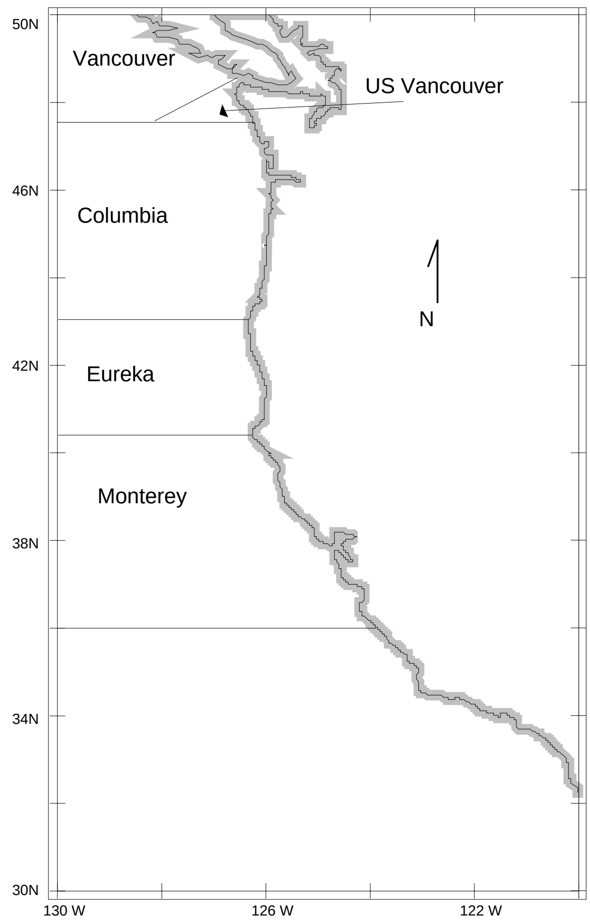

Figure 1. Map showing the INPFC areas. Currently, POP in the US Vancouver and Columbia areas are managed as a unit. Catches south of these areas are minor and are included with "other rockfish".

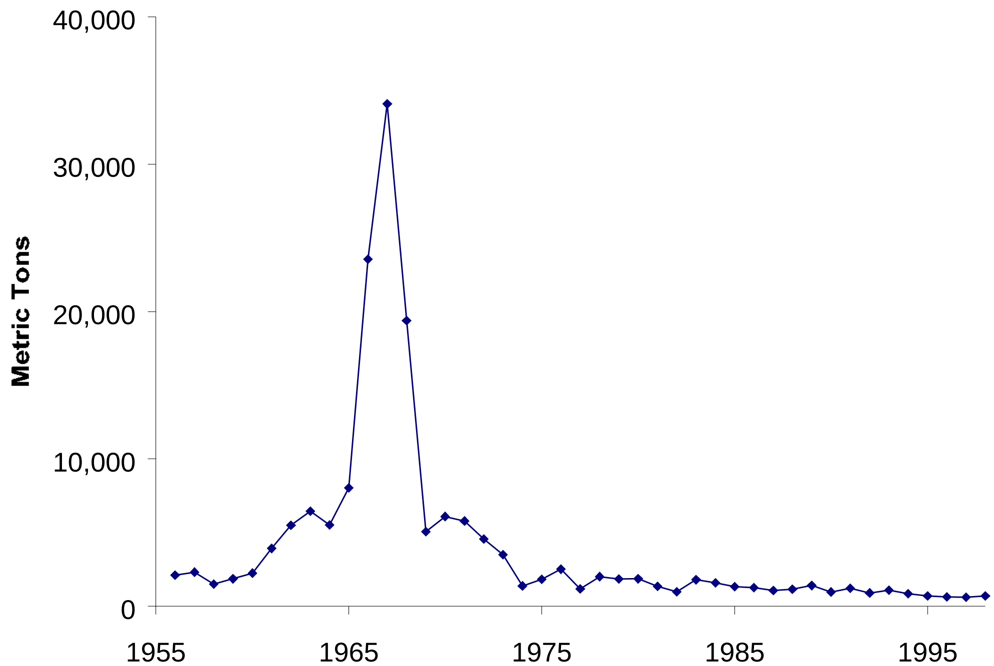

Figure 2. Pacific ocean perch catch including domestic and foreign fleets.

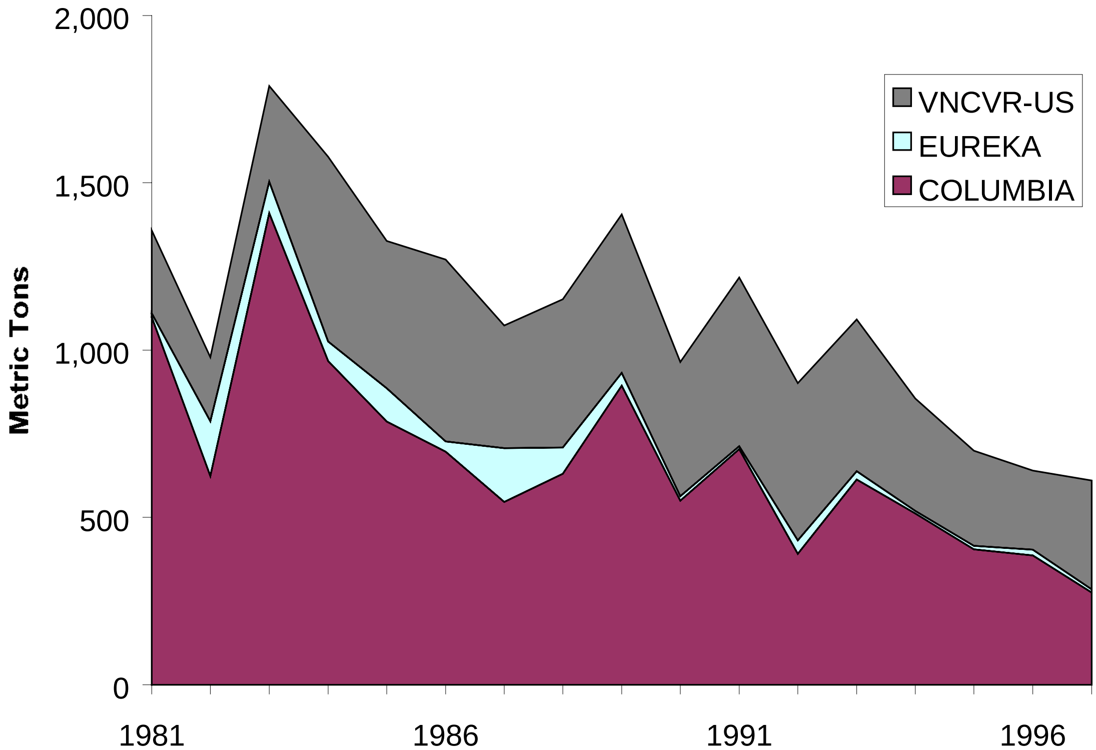

Figure 3. Pacific ocean perch catch including domestic and foreign fleets.

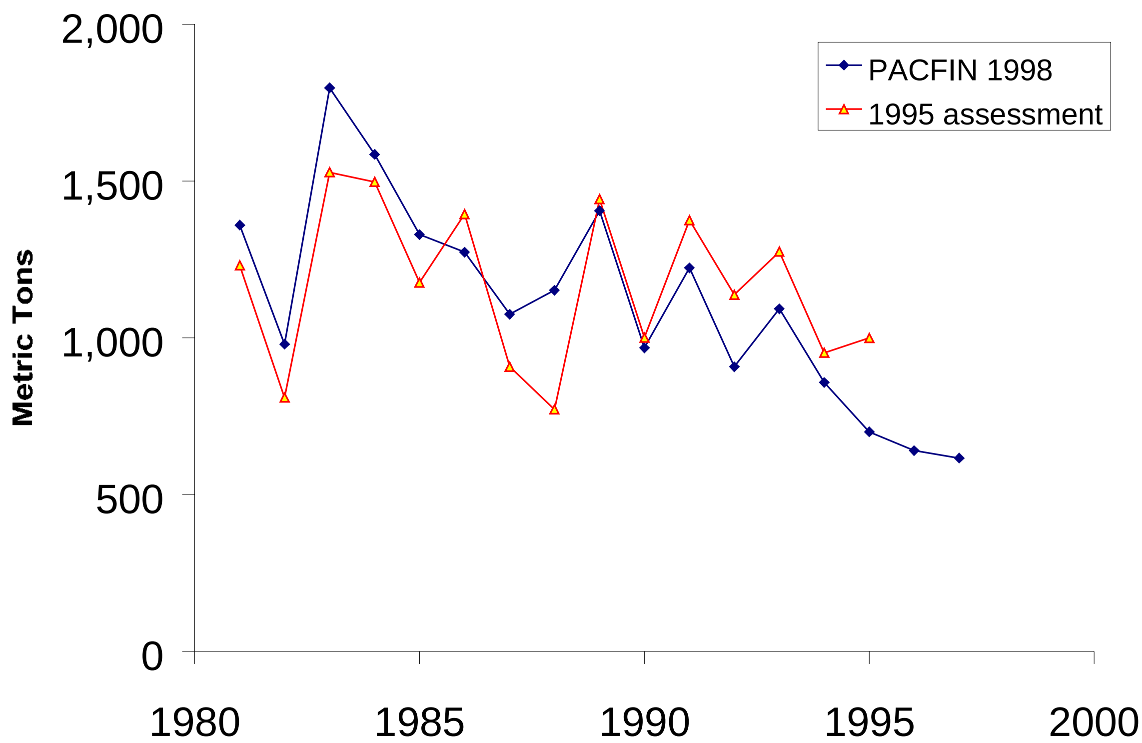

Figure 4. POP Catch estimates from the 1995 assessment compared with updated PACFIN estimates used in the current assessment.

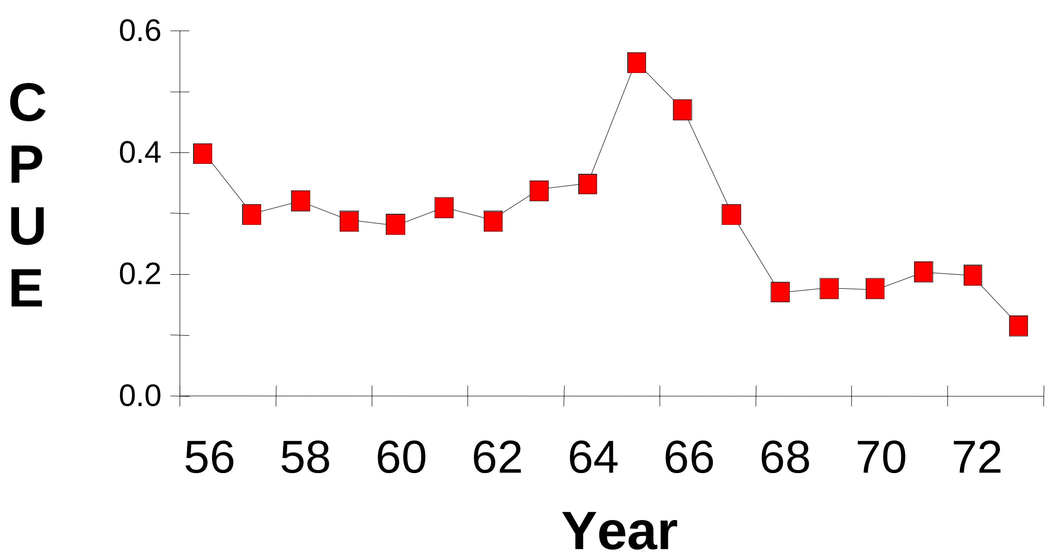

Figure 5. Pacific ocean perch catch per unit of effort data for the combined domestic fishery off INPFC area US- Vancouver and Columbia.

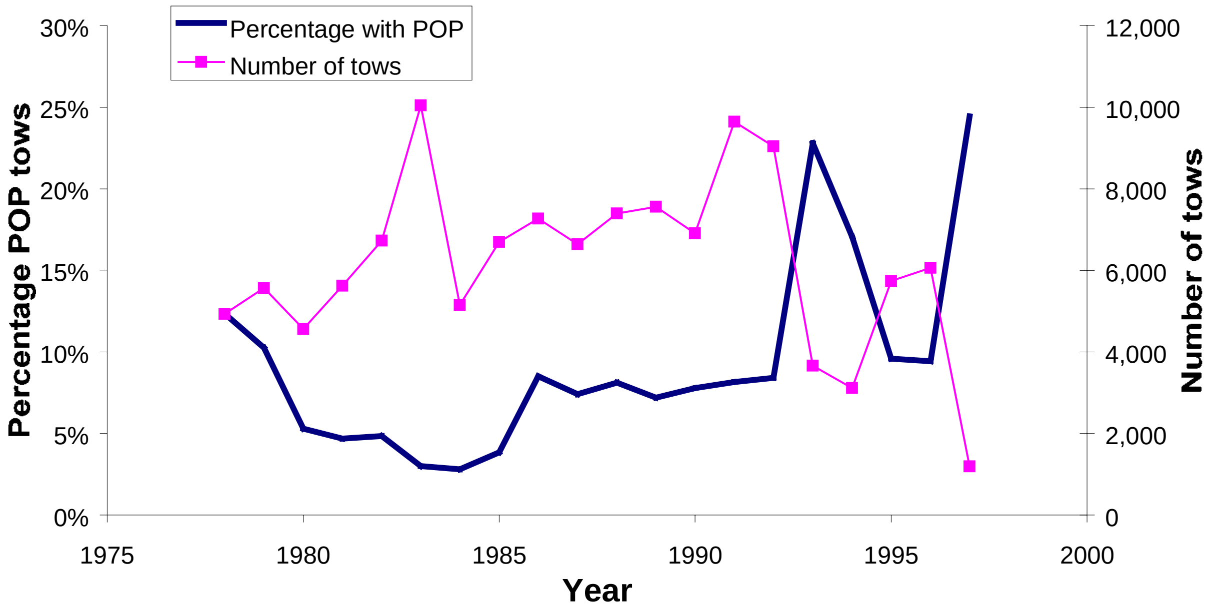

Figure 6. Proportion of POP recorded in logbook tows between 100-400 fathoms.

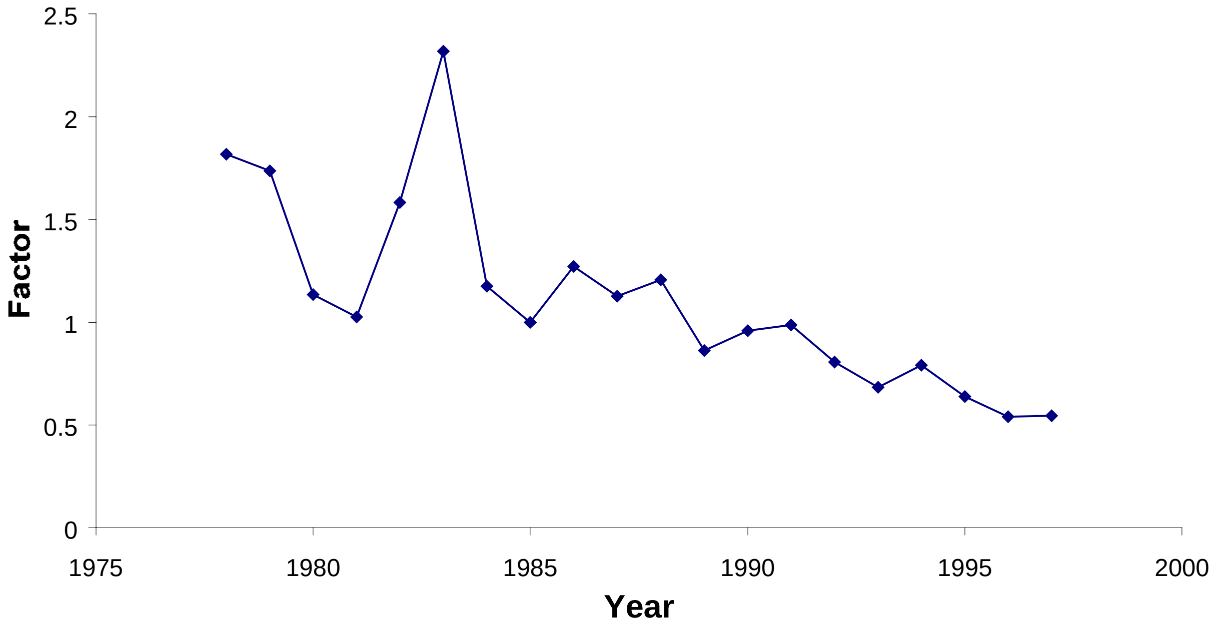

Figure 7. Year-effect factor for GLM analyses of POP catches from logbook data.

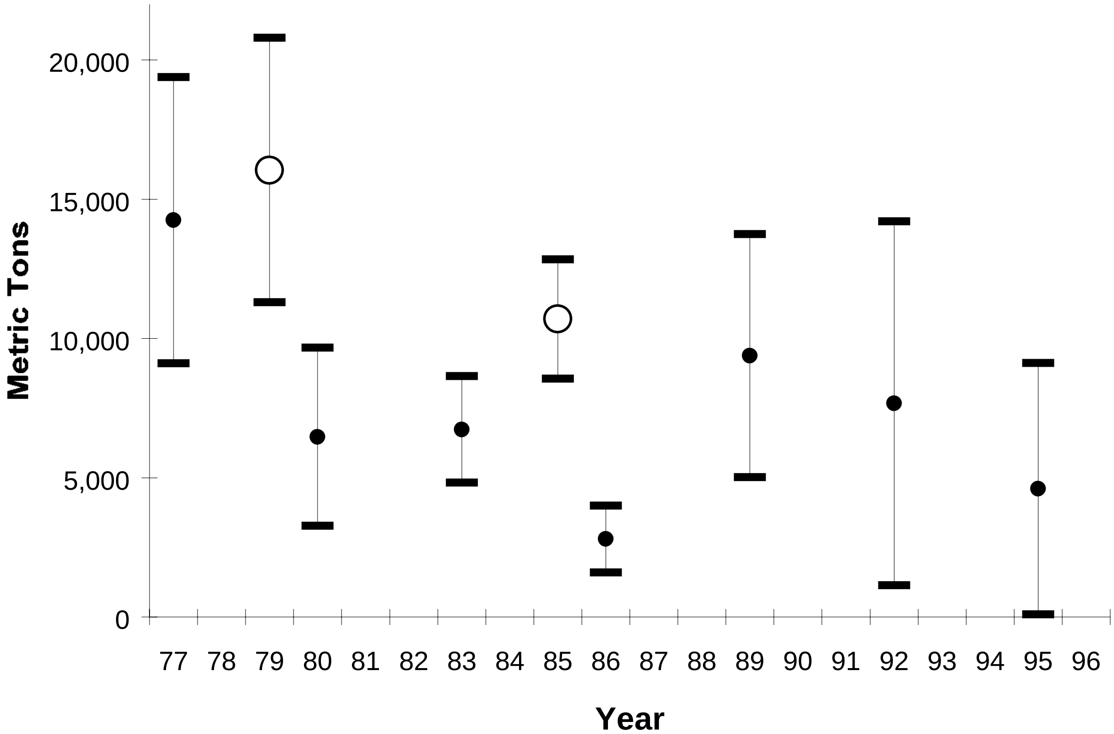

Figure 8. Survey biomass estimates and 95% confidence bounds for Pacific ocean perch. Open circles represent rockfish survey values and dark circles represent triennial survey biomass estimates.

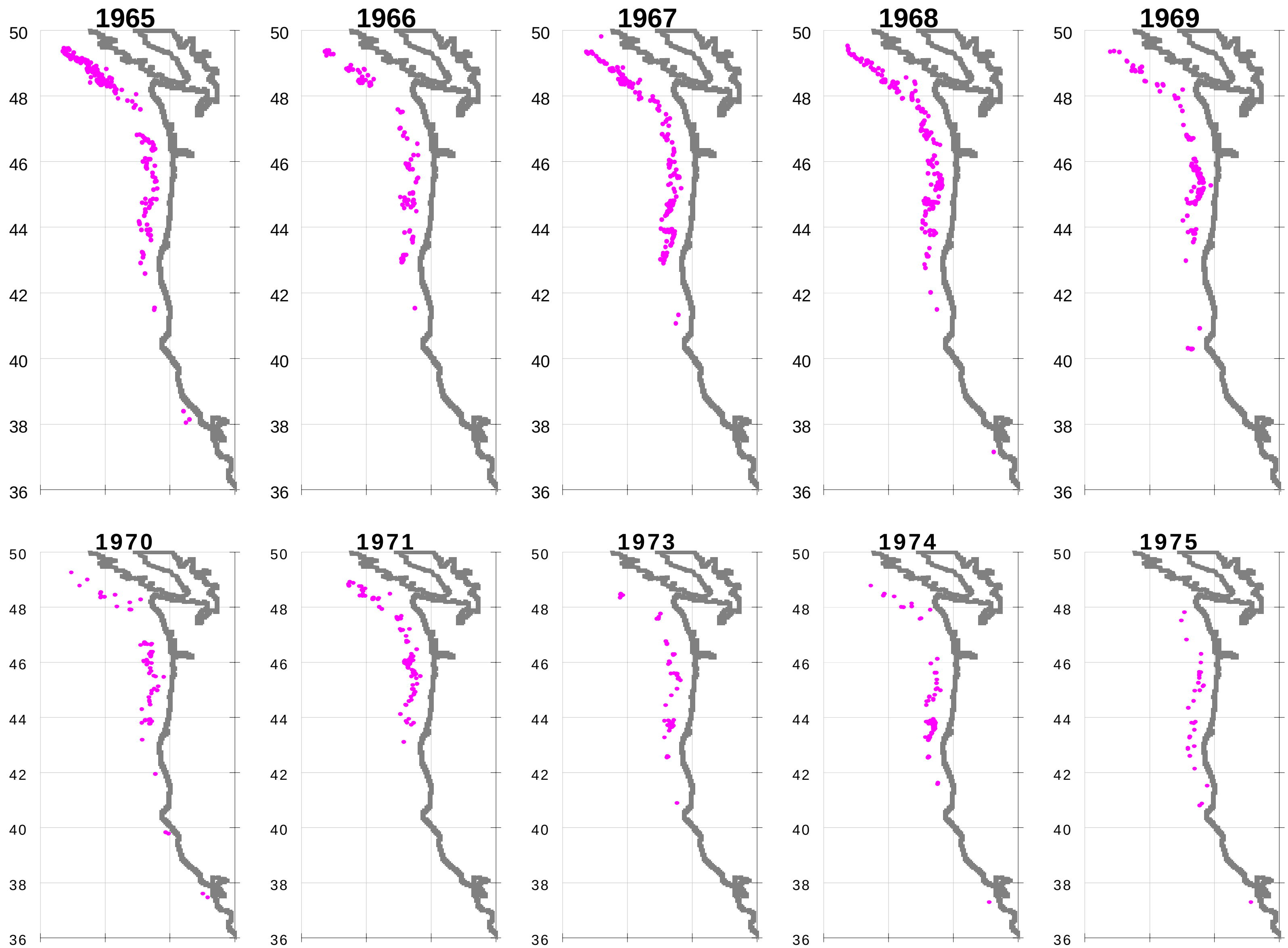

Figure 9. Locations of Soviet survey operations by year, 1965-1971, 1973-1975.

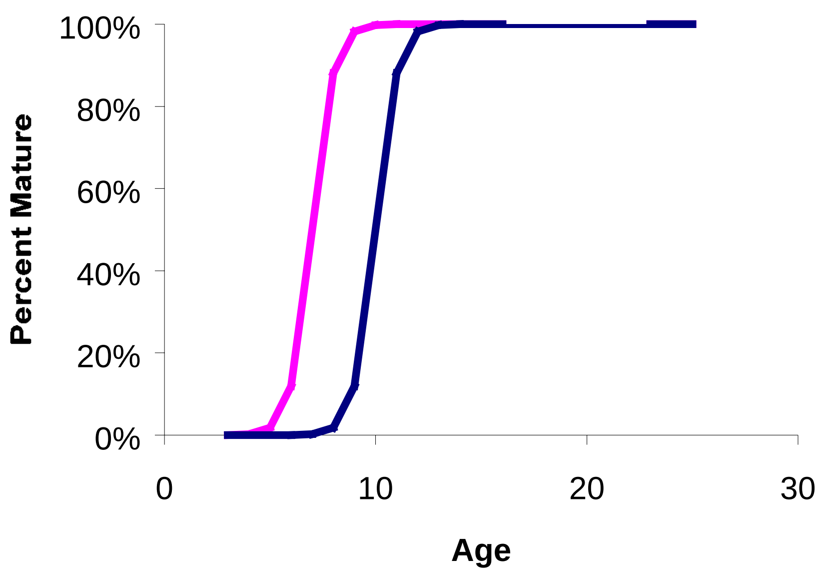

Figure 10. Estimated relationship between age and percent mature for POP in the Columbia and US-Vancouver areas. The left-most line was used in Model 6, whereas the other was used for all other model configurations.

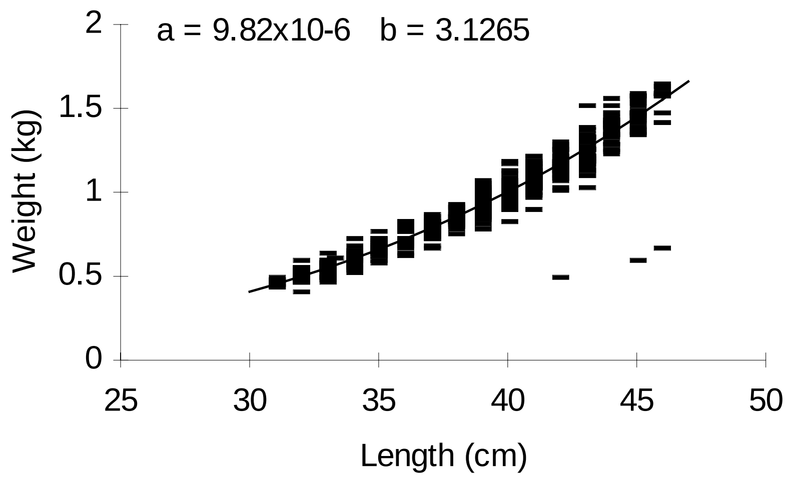

Figure 11. Estimated length versus weight relationship used for Pacific ocean perch in this study. The three obvious outliers were not included in the estimation.

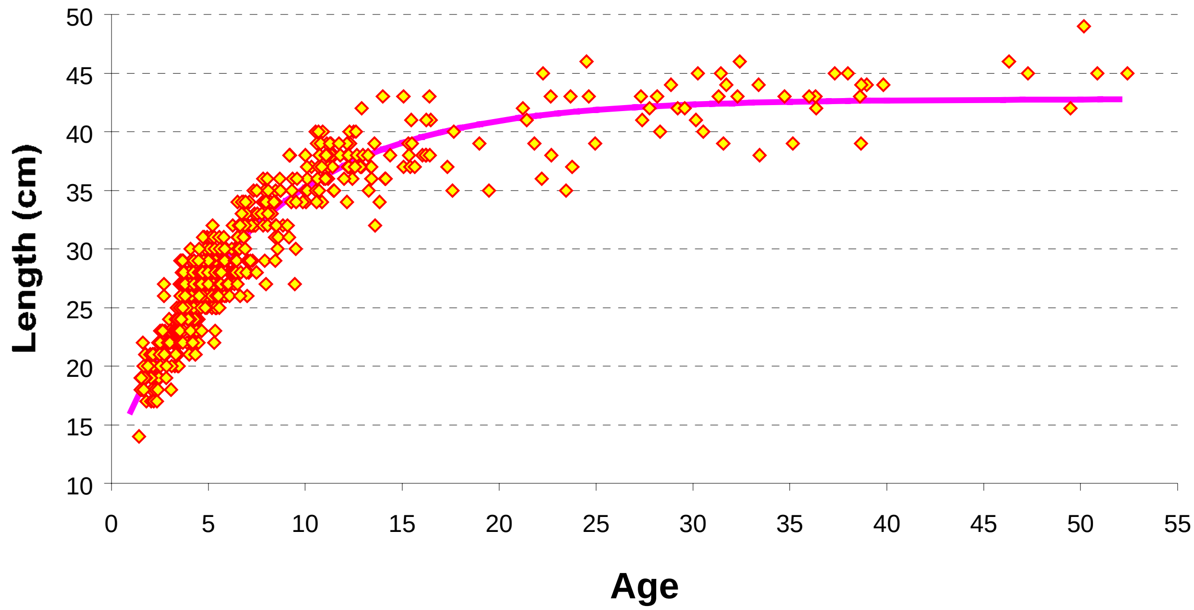

Figure 12. Length at age relationship for Pacific ocean perch off the Washington and Oregon coast based on the 1992 break-and-burn age samples. Points were randomized slightly to reveal density.

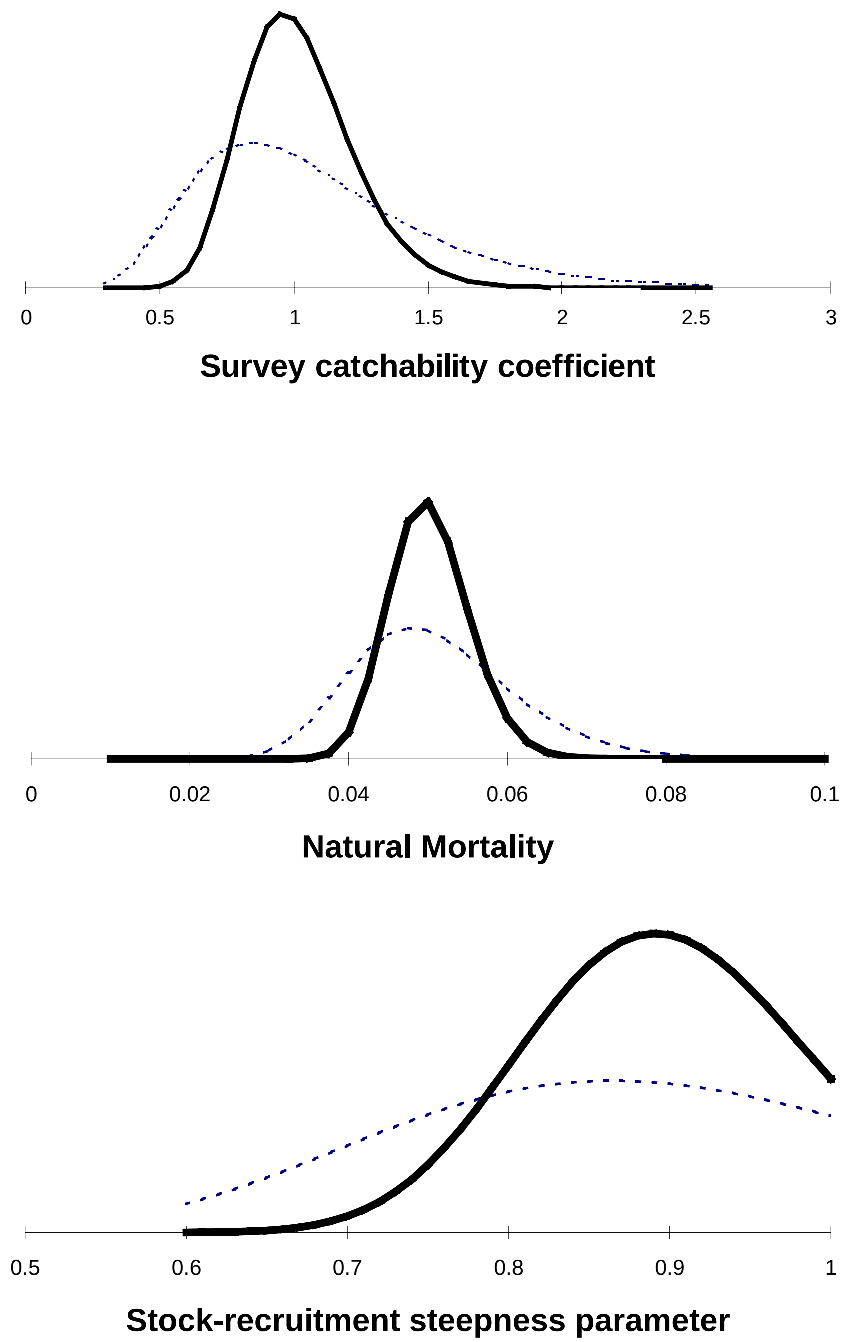

Figure 13. Plot showing the prior distributions assumed for survey catchability, M, and stock-recruitment steepness for POP. Model 4 variant is shown in dashed lines.

Model 1

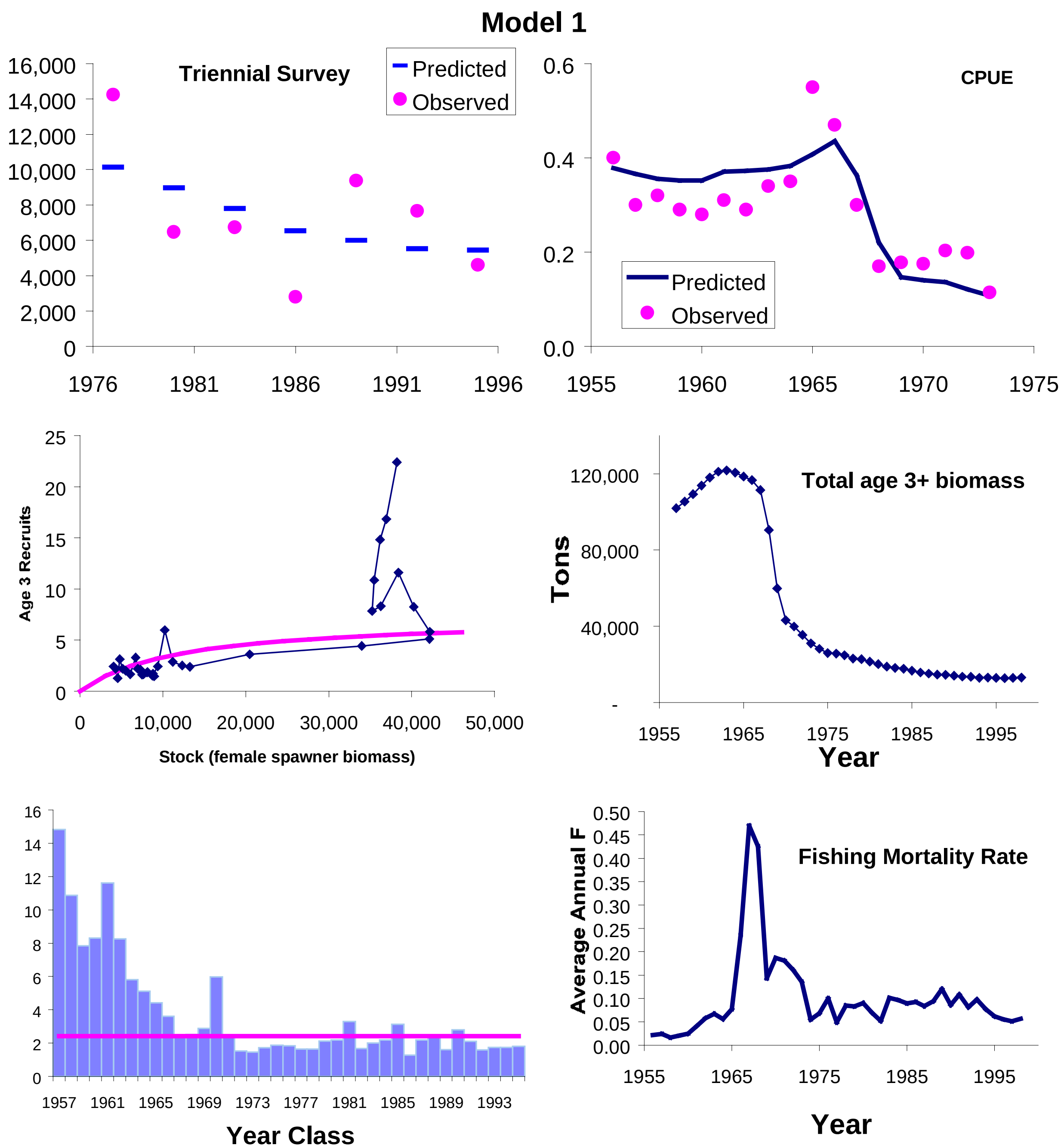

Figure 14. Summary of Model 1 results for Pacific ocean perch.

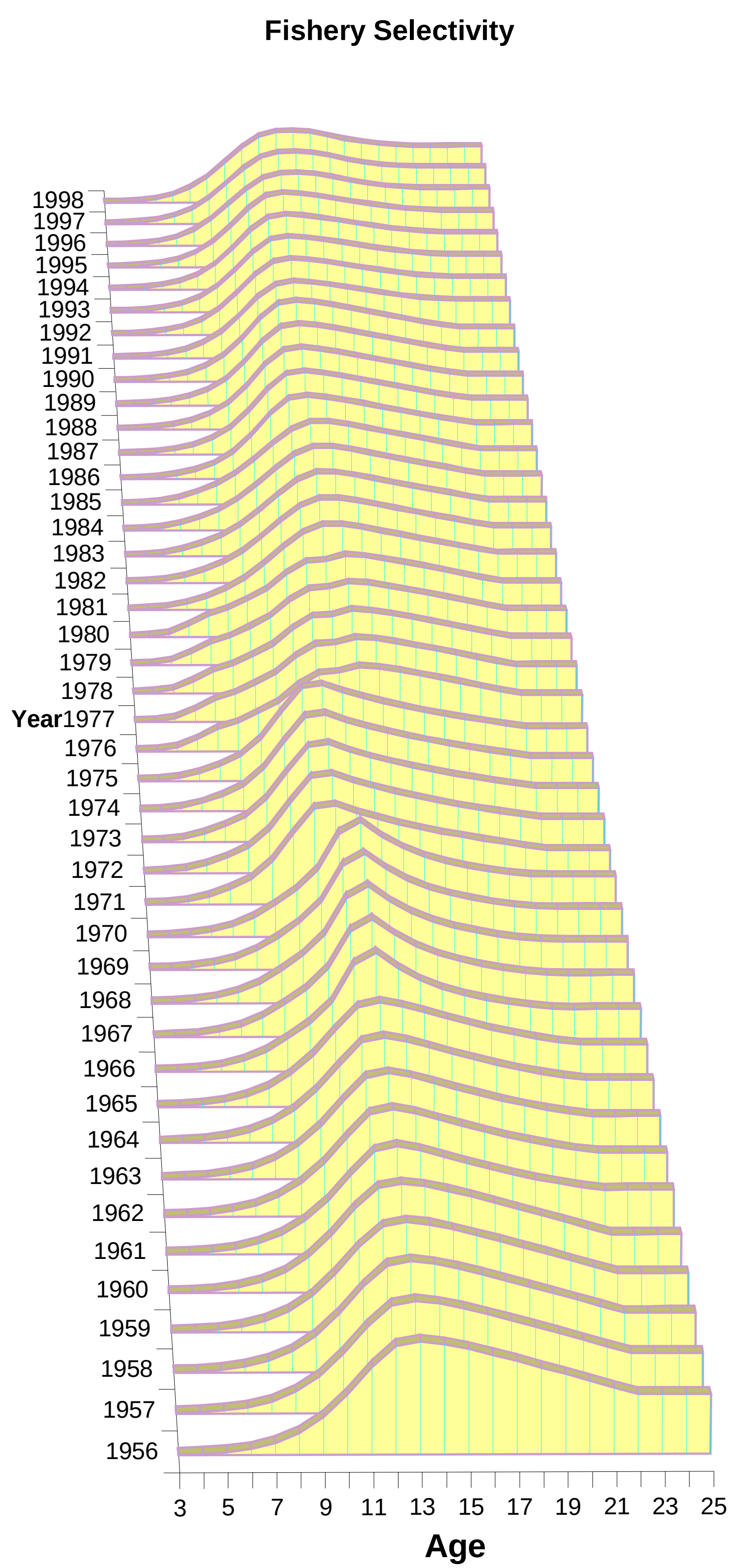

Figure 15. Fishery selectivity estimates for Pacific ocean perch, 1956-1998.

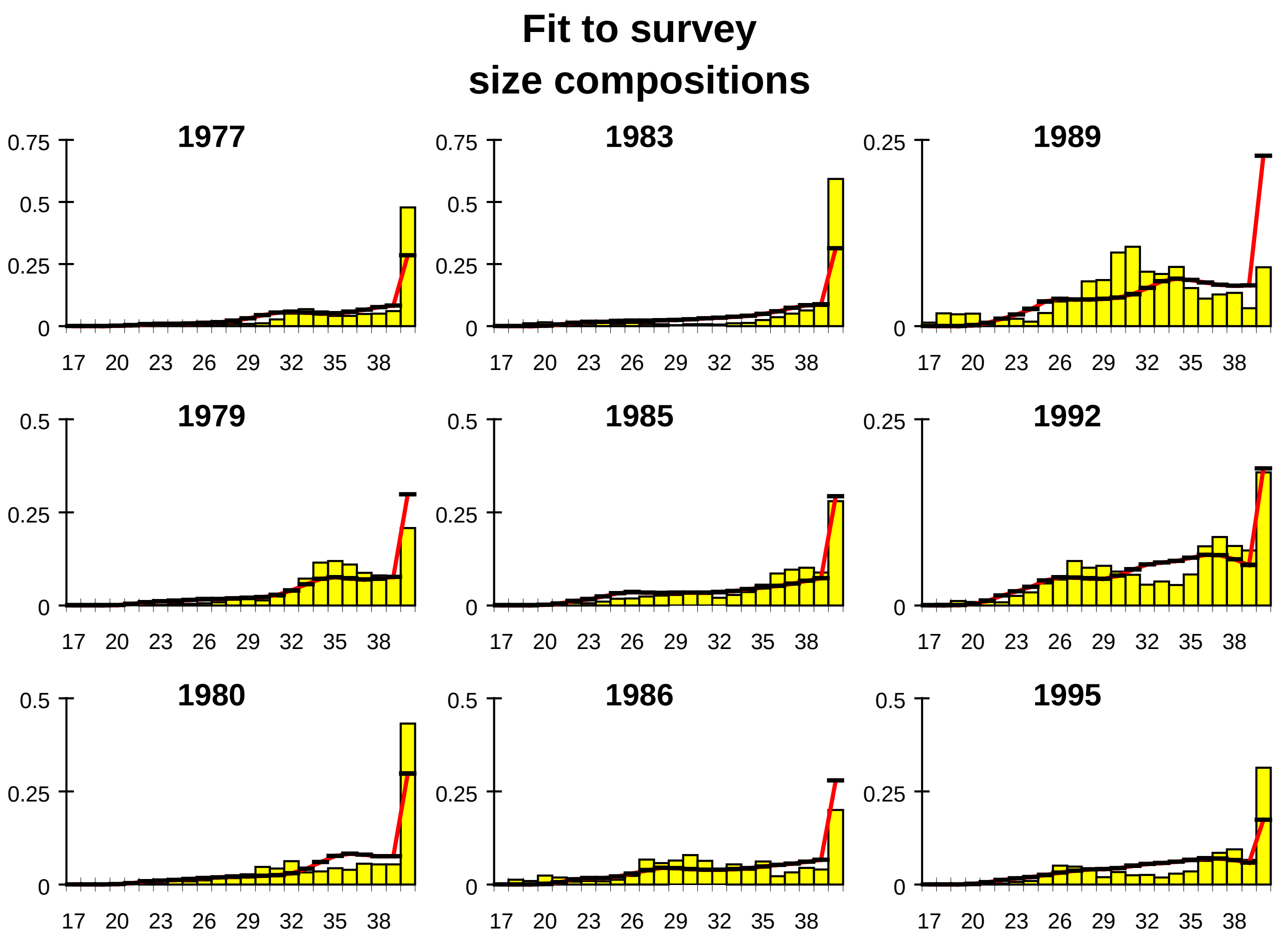

Figure 16. Predicted POP proportions-at-size (lines) relative to observed values (bars) for triennial survey data (Model 1).

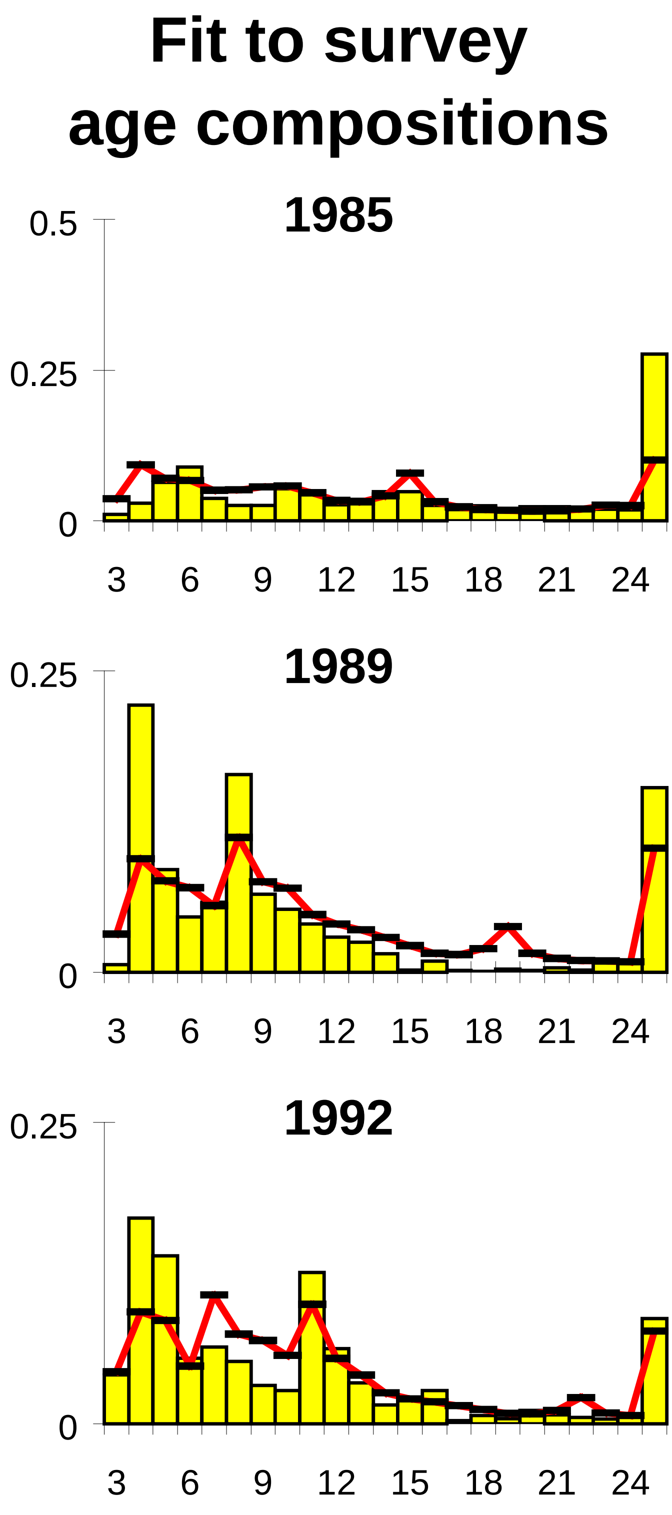

Figure 17. Predicted POP proportions-at-age (lines) relative to obeserved values (bars) for triennial survey data (Model 1).

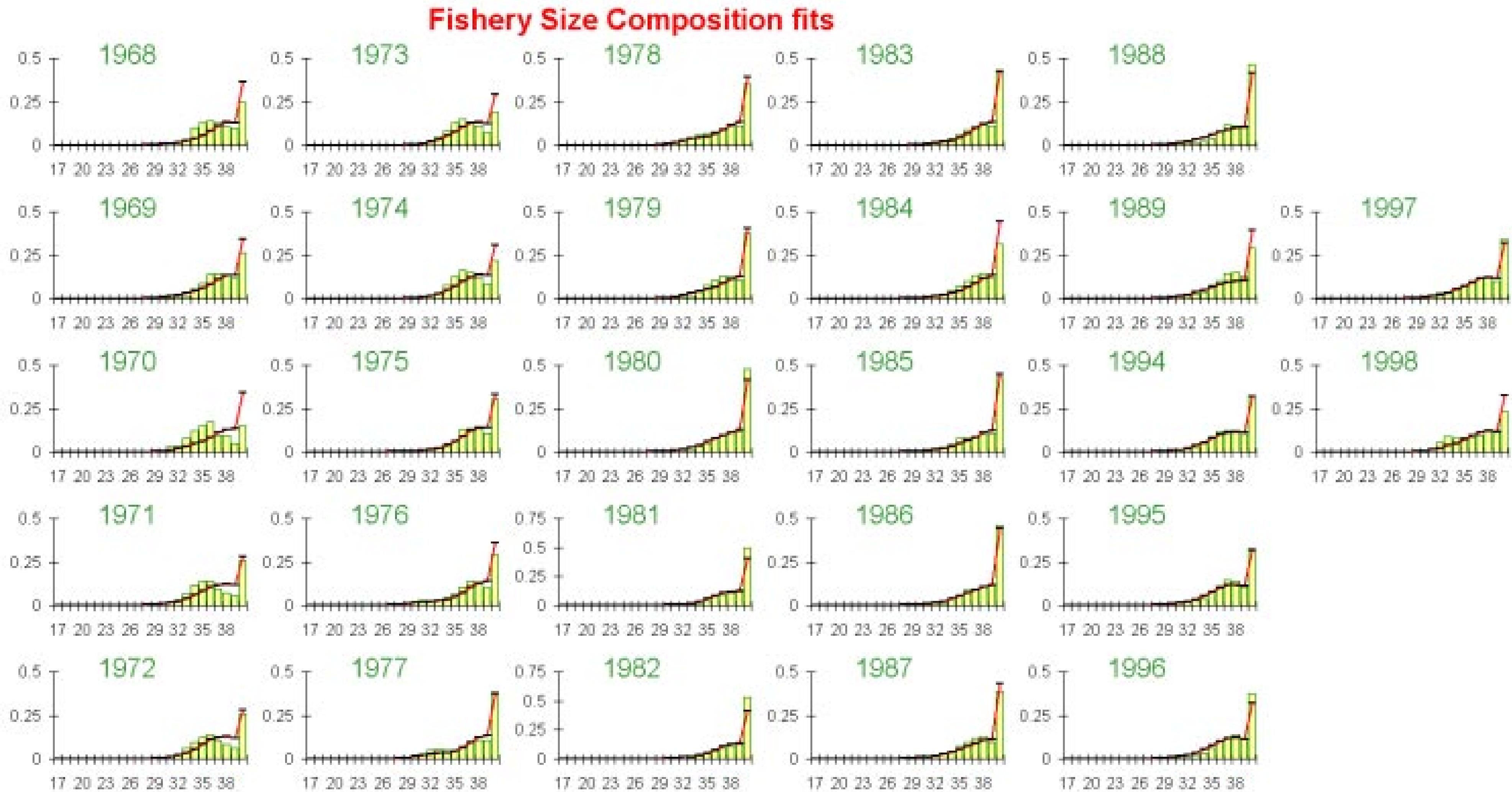

Figure 18. Predicted POP proportions-at-length (lines) relative to obeserved values (bars) for aggregate fisheries data (Model 1).

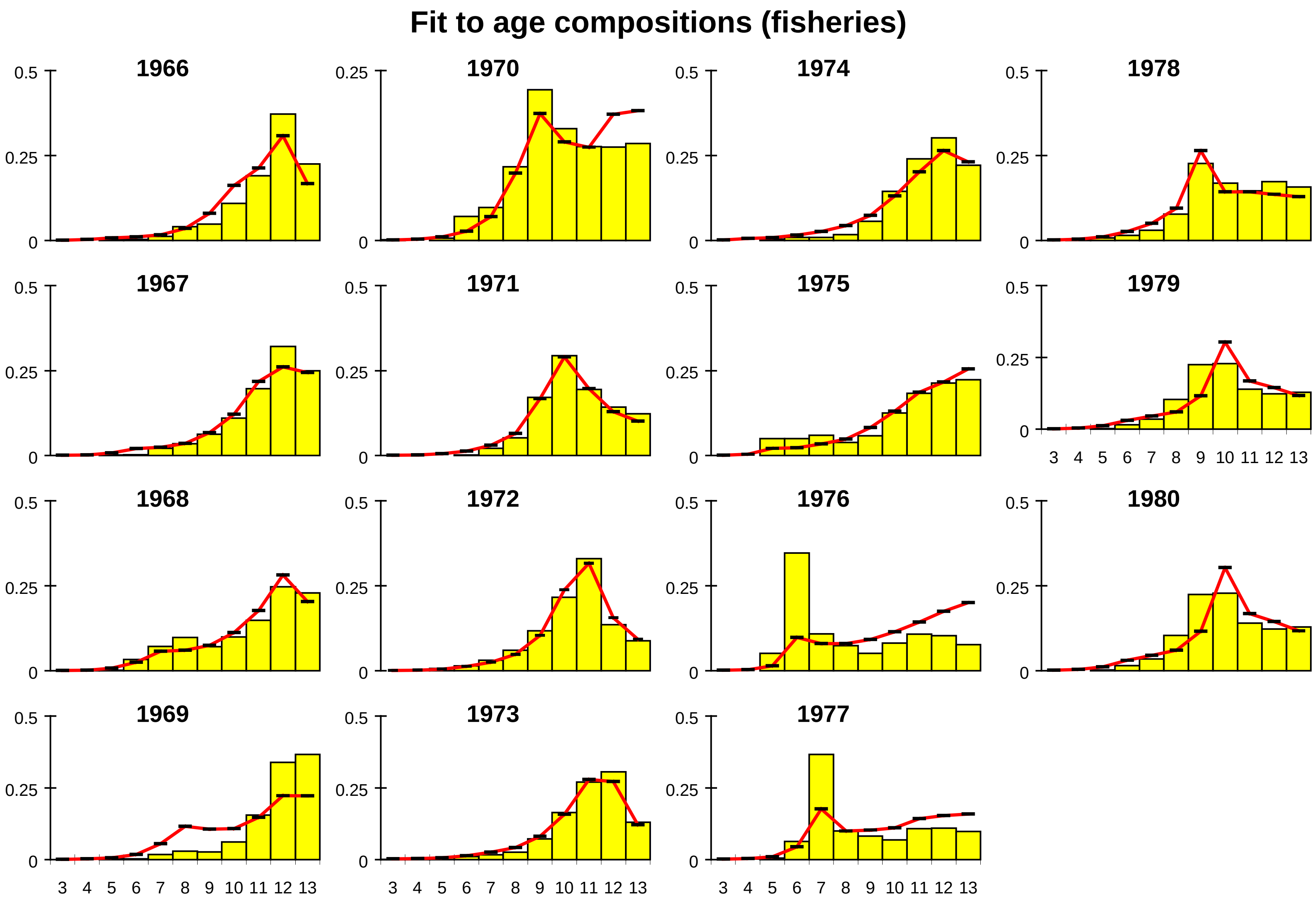

Figure 19. Predicted POP proportions-at-length (lines) relative to obeserved values (bars) for aggregate fisheries data (Model 1).

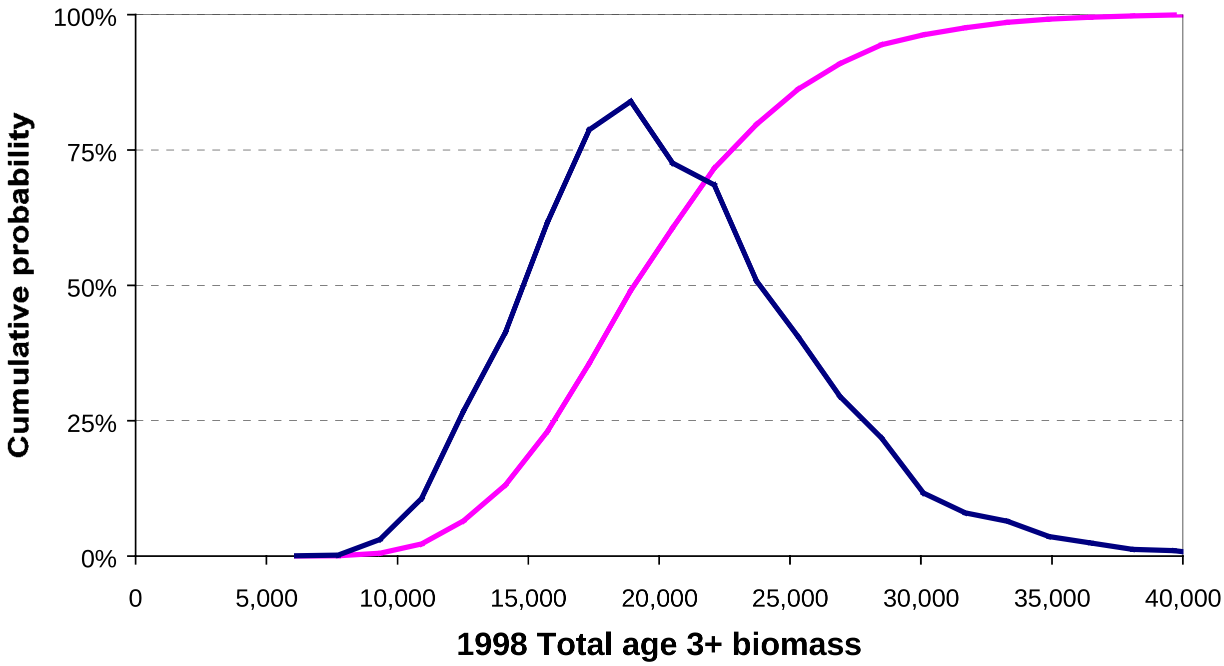

Figure 20. Estimated 1998 POP stock size probability distribution for Model 1. MCMC integration was used to obtain this marginal distribution (Gilks *et al.* 1996).

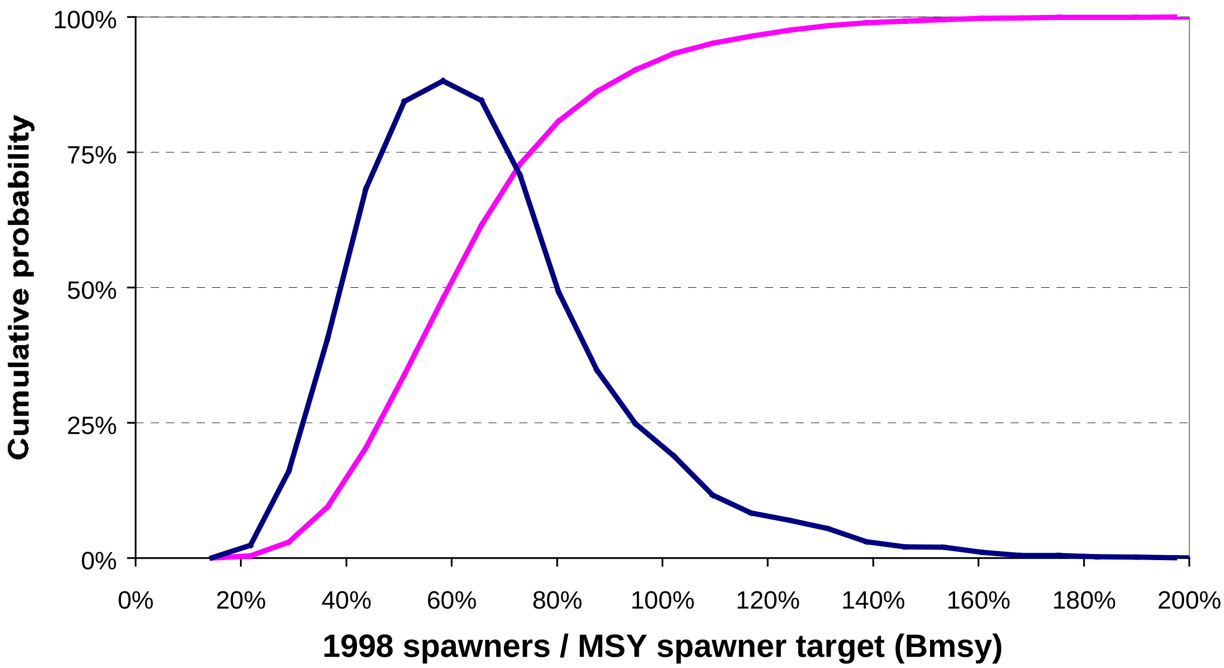

Figure 21. Estimated probability distribution for Model 1 current POP spawning biomass over the MSY target spawning biomass level. MCMC integration was used to obtain this marginal distribution (Gilks *et al.* 1996).

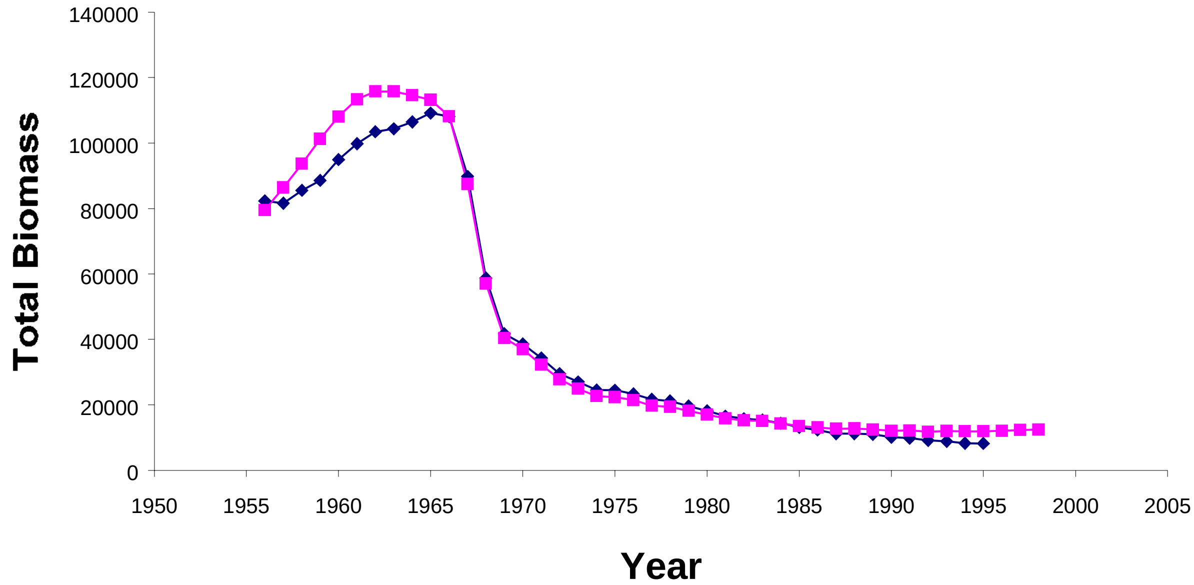

Figure 22. Total POP biomass trajectory comparing Model 1 results with the 1995 (stock-synthesis) analyses.

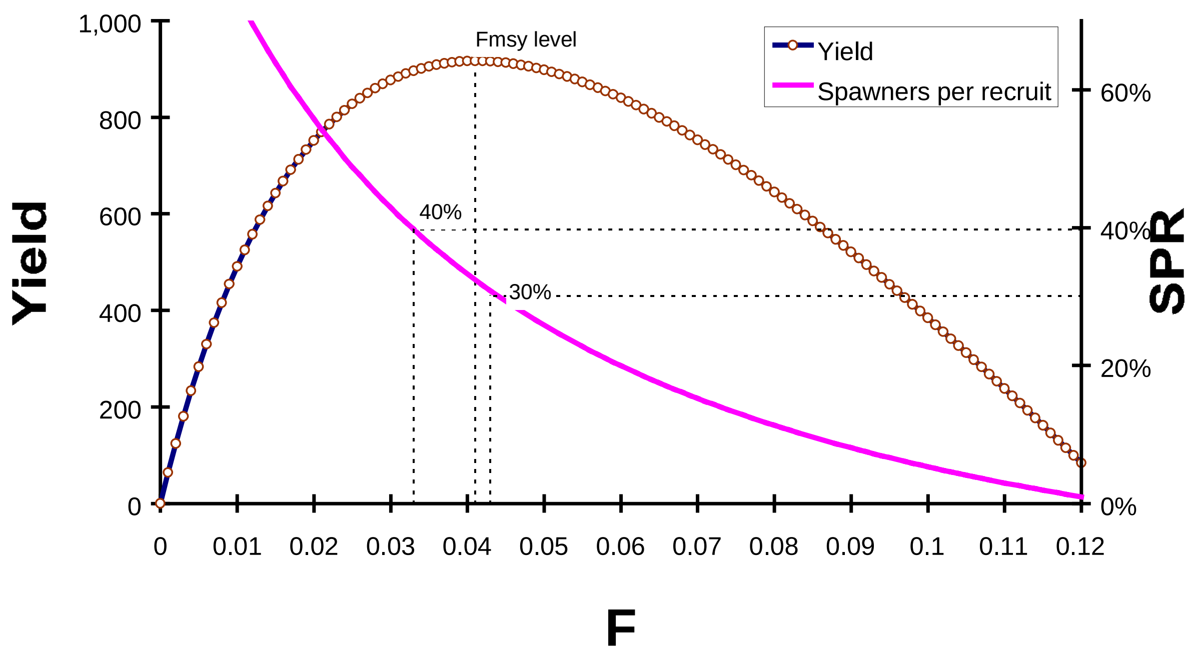

Figure 23. Plot showing POP yield curve relative to SPR (spawners-per-recruit) for different levels of fishing mortality.

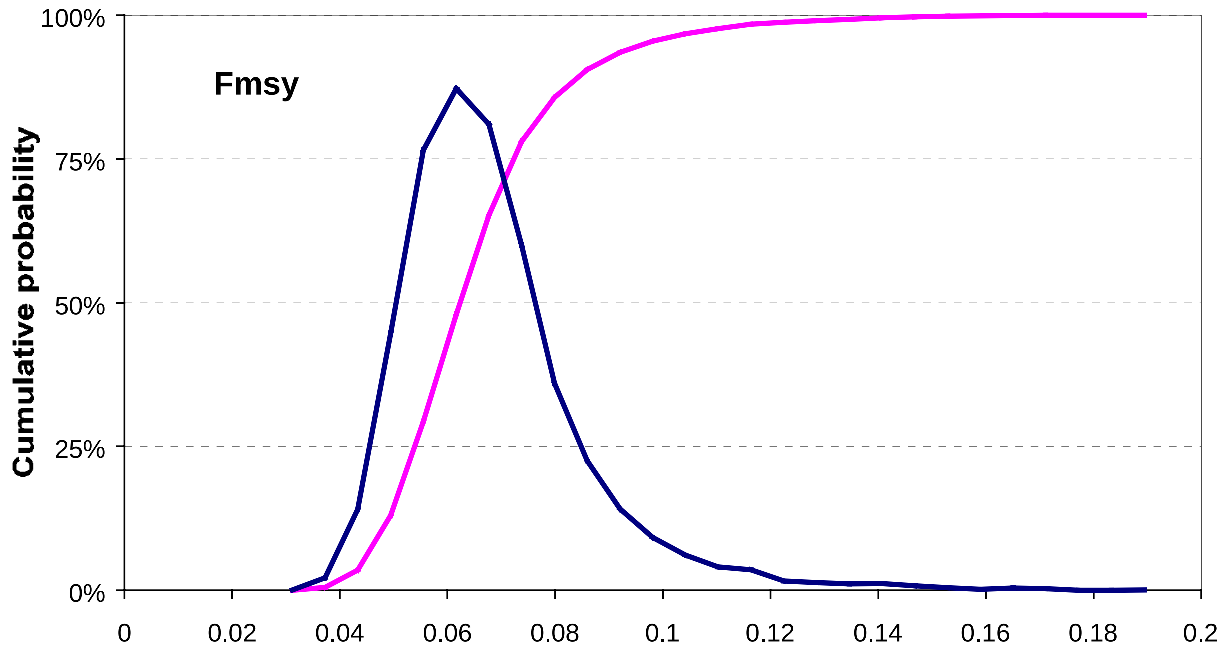

Figure 24. Estimated probability distribution for Model 1 F_{msy} level based on the MCMC integration for POP.

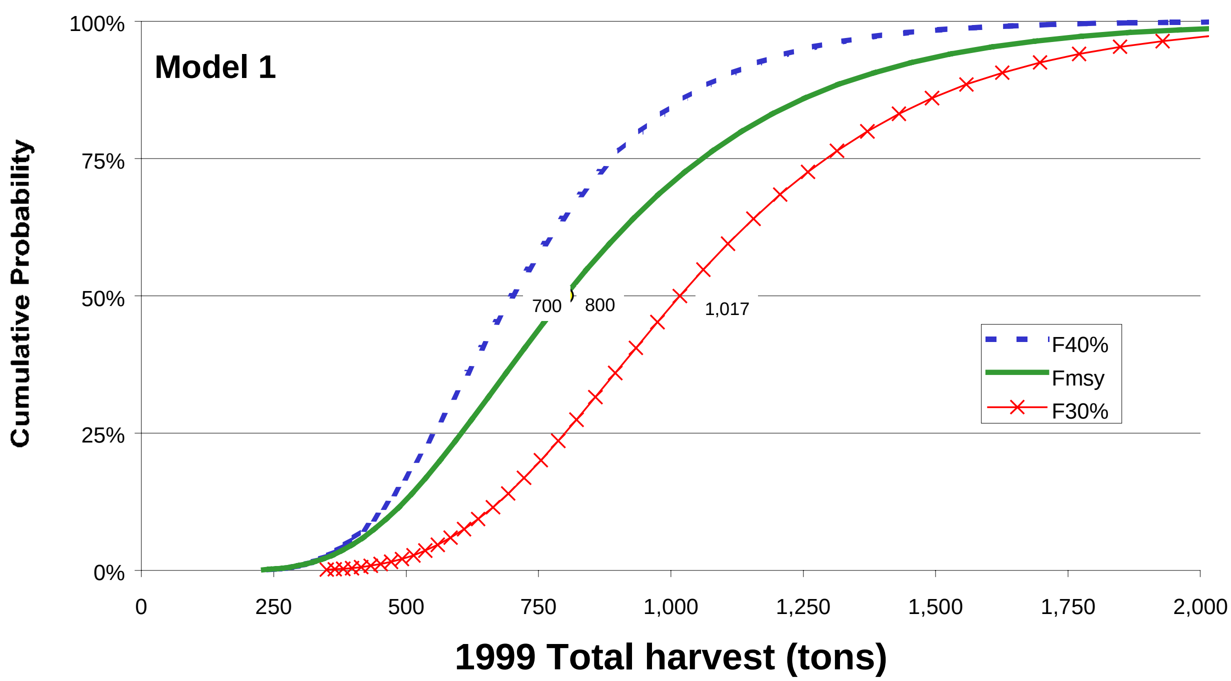

Figure 25. Cumulative probability distribution of 1999 POP yield under different harvest rates, Model 1.

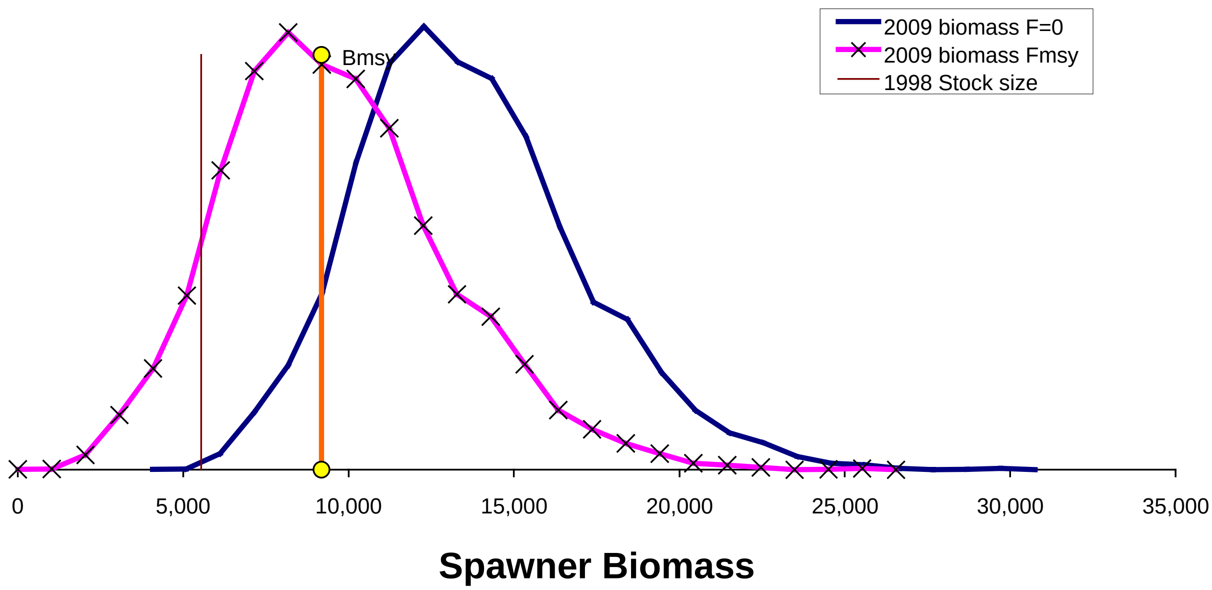

Figure 26. Probability distributions of projected POP female spawning biomass in the year 2009 under F_{msy} harvest compared to F=0 harvests. Vertical lines are reference points.

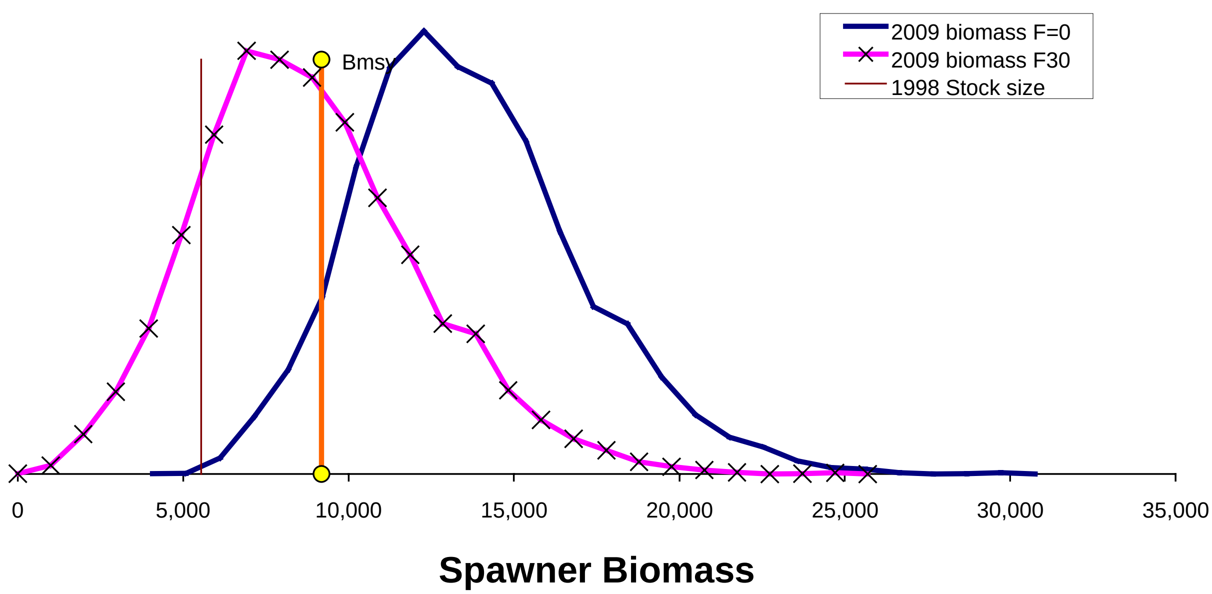

Figure 27. Probability distributions of projected POP female spawning biomass in the year 2009 under $F_{30\%}$ harvest compared to F=0 harvests. Vertical lines are reference points.

ADDENDUM I

Solving for F_{msy} in an integrated model context

Recruitment in year *i* is given by

$$R_i = \frac{S_{i-3} e^{\varepsilon_i}}{\alpha + \beta S_{i-3}}$$

where

R_i	is recruitment at age 3 in year *i*,
S_i	is the biomass of female spawners in year *i*,
ε_i	is the "recruitment anomaly" for year *i*,
α, β	are stock-recruitment function parameters.

Since ϕ (see below) is the expected female spawning biomass produced by a single recruit, then at equilibrium we have

$R_{eq} = \dfrac{R_{eq}\phi}{\alpha + \beta R_{eq}\phi}$. Solving for R_{eq} gives

$$R_{eq} = \frac{(\phi - \alpha)}{\beta\phi}$$

with

$$\phi = 0.5 \sum_{j=3}^{25+} W_j N_j s_j f_j$$

$$N_j = 1 \qquad j = 3$$

$$N_j = N_{j-1} s_{j-1} \qquad 3 \le j \le 25$$

Note that the survival rate, s_j, and proportion mature, f_j, are age specific. Equilibrium yield (*Y*) is computed for a given exploitation rate (*F*), giving $Y = F \cdot \overline{B}$ where $\overline{B}$ is the average equilibrium exploitable biomass. Solving for the MSY simply involves determining the exploitation rate where yield is maximized. Analytical methods are commonly used to find this value by taking the first derivative with respect to *F*, setting the result equal to zero, and solving for *F*. Unfortunately, such analytical methods are not readily available for common forms of stock-recruitment functions used in fisheries with non-trivial age-specific selectivities. Here we implement a numerical method which solves for MSY and can be applied to a broad family of models. The method implements the Newton-Raphson technique for finding the root of an equation (here, the first derivative of yield). The steps are outlined as:

1) pick a trial *F* and evaluate the equilibrium yield, *f*(*F*);
2) compute the first and second derivatives of yield wrt *F*;

3) update original trial F from 1) by subtracting the ratio $\frac{f'(F)}{f''(F)}$

4) repeat steps 1) – 3) a fixed number of times so that the final adjustment in step 3) is very small. Note, convergence is usually implemented through the use of some sort of tolerance level. However, in our case we wish maintain differentiability, therefore we use a fixed number of iterations.

In practice, finite difference approximations for the derivatives given above appear to work satisfactorily which further improves one's ability to implement this type of algorithm. That is, let

$f'(F) = \frac{f(F+d) - f(F-d)}{2d}$ and $f''(F) = \frac{f(F+d) - 2f(F) + f(F-d)}{d^2}$ where d is some small value, say $1\text{x}10^{-7}$.