

CHAPTER 11

PACIFIC OCEAN PERCH

by

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Executive Summary

The following changes were made to the Pacific Ocean Perch (POP) assessment relative to the November 2003 SAFE:

Changes in the Input Data

- (1) The 2003 harvest level has been revised and harvests through October 2, 2004 have been included in the assessment.
- (2) The survey biomass and length composition from the 2004 AI survey were included in the assessment.
- (3) The 2003 age composition from the Aleutian Islands (AI) fishery was included in the assessment.

Changes in the Assessment Results

- (1) A summary of the 2004 assessment recommended ABCs relative to the 2003 recommendations is as follows:

	Assessment Year	
	2004	2003
ABC	14,615 t	13,917 t
OFL	17,330 t	17,330 t

Responses to the Comments of the Statistical and Scientific Committee (SSC)

From the December, 2003, minutes: *“It is unknown if the loss of older age classes have measurable consequences to the stock productivity. The implications depend on whether older/larger age individuals contribute to stock productivity disproportionate to their biomass. Relevant questions include: (1) do older individuals have higher reproductive success?, (2) do they spawn in more favorable habitats?, (3) do they spawn at more favorable times of the year?, (4), do the progeny have a higher survival rate?, and (5) do fisheries cause genetic selection such that the heritable growth and mortality traits are lost when old fish no longer contribute to reproduction?. . .Owing to the lack of studies, it is difficult to quantify and incorporate such considerations into harvest specifications. The SSC is concerned that undesired outcomes could occur if exploitation rates are too high for the most productive individuals in the population. This is an area of needed research.”* An analysis that explicitly considers the effect of differential larval survival rates as a function of maternal age on the estimation of stock productivity is included as an Appendix, thus making an initial attempt to address item (4) above. The assessment authors agree that the other research questions are important areas for future research.

INTRODUCTION

Pacific ocean perch (*Sebastes alutus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Pacific ocean perch, and four other associated species of rockfish (northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*) were managed as a complex in the two distinct areas from 1979 to 1990. Known as the POP complex, these five species were managed as a single entity with a single TAC (total allowable catch). In 1991, the North Pacific Fishery Management Council separated POP from the other red rockfish in order to provide protection from possible overfishing. Of the five species in the former POP complex, *S. alutus* has historically been the most abundant rockfish in this region and has contributed most to the commercial rockfish catch.

Since 2001, POP in the Bering Sea-Aleutian Islands area have been assessed and managed as a single stock. The rationale for this change is based upon the paucity of data in the EBS upon which to base an age-structured assessment, and uncertainty that the EBS POP represent a discrete stock (Spencer and Ianelli 2001).

Information on Stock Structure

A variety of types of research can be used to infer stock structure of POP, including age and length compositions, growth patterns and other life-history information, and genetic studies. Spatial differences in age or length compositions can be used to infer differences in recruitment patterns that may correspond to population structure. In Queen Charlotte Sound, British Columbia, Gunderson (1972) found substantial differences in the mean lengths of POP in fishery hauls taken at similar depths which were related to differences in growth rates and concluded that Pacific ocean perch (POP) likely form aggregations with distinct biological characteristics. In a subsequent study, Gunderson (1977) found differences in size and age composition between Moresby Gully and two other gullies in Queen Charlotte Sound. Westheim (1970, 1973) recognized “British Columbia” and “Gulf of Alaska” POP stocks off the western coast of Canada based upon spatial differences in length frequencies, age frequencies, and growth patterns observed from a trawl survey. In a study that has influenced management off Alaska, Chikuni (1975) recognized distinct POP stocks in four areas – eastern Pacific (British Columbia), Gulf of Alaska, Aleutian Islands, and Bering Sea. However, Chikuni (1975) states that the eastern Bering Sea (EBS) stock likely receives larvae from both the Gulf of Alaska (GOA) and Aleutian Islands (AI) stock, and the AI stock likely receives larvae from the GOA stock.

Stock differentiation occurs from separation at key life-history stages, and another approach to evaluating stock structure involves examination of rockfish life-history stages directly. Because many rockfish species are not thought to exhibit large-scale movements as adults, movement to new areas and boundaries of discrete stocks may depend largely upon the pelagic larval and juvenile life-history stages.

In 2002, an analysis of archived *Sebastes* larvae was undertaken by Dr. Art Kendall; using data collected in 1990 off southeast Alaska (650 larvae) and the AFSC ichthyoplankton database (16,895 *Sebastes* larvae, collected on 58 cruises from 1972 to 1999). The southeast Alaska larvae all showed the same morph, and were too small to have characteristics that would allow species identification. A preliminary examination of the AFSC ichthyoplankton database indicates that most larvae were collected in the spring, the larvae were widespread in the areas sampled, and most are small (5-7 mm). The larvae were organized into three size classes for analysis: <7.9 mm, 8.0-13.9 mm, and >14.0 mm. A subset of the abundant small larvae was examined, as were all larvae in the medium and large groups. Species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Most of the small larvae examined belong to a single morph, which contains the species *S. alutus* (POP), *S. polyspinus*

(northern rockfish), and *S. ciliatus* (dusky rockfish). Some larvae belonged to a second morph which has been identified as *S. borealis* (shortraker rockfish) in the Bering Sea.

Rockfish identification can be aided by studies that combine genetic and morphometric techniques and information has been developed to identify individual species based on allozymes (Seeb and Kendall 1991) and mitochondrial DNA (Gharrett et al. 2001, Rocha-Olivares 1998). The Ocean Carrying Capacity (OCC) field program, conducted by the Auke Bay laboratory, uses surface trawls to collect juvenile salmon and incidentally collects juvenile rockfish. These juvenile rockfish are large enough (approximately 25 mm and larger) to allow extraction of a tissue sample for genetic analysis without impeding morphometric studies. In 2002, species identifications were made for an initial sample of 55 juveniles with both morphometric and genetic techniques. The two techniques showed initial agreement on 39 of the 55 specimens, and the genetic results motivated re-evaluation of some of the morphological species identifications. Forty of the specimens were identified as POP, and showed considerably more morphological variation for this species than previously documented. Given the success of this initial examination of the OCC data with these techniques, a more comprehensive study is planned for the near future.

Because stocks are, by definition, reproductively isolated population units, it is expected that different stocks would show differences in genetic material due to random drift or natural selection. Thus, analysis of genetic material from north Pacific rockfish is currently an active area of research.

Seeb and Gunderson (1988) used protein electrophoresis to infer genetic differences based upon differences in allozymes from POP collected from Washington to the Aleutian Islands. Discrete genetic stock groups were not observed, but instead gradual genetic variation occurred that was consistent with an isolation by distance model. The study included several samples in Queen Charlotte Sound where Gunderson (1972, 1977) found differences in size compositions and growth characteristics. Seeb and Gunderson (1988) concluded that the gene flow with Queen Charlotte Sound is sufficient to prevent genetic differentiation, but adult migrations were insufficient to prevent localized differences in length and age compositions. However, recent studies of POP using microsatellite DNA indicate population structure at small spatial scales, consistent with the work of Gunderson (1972, 1977), and suggest that adult POP do not migrate far from their natal grounds and larvae are entrained by currents in localized retention areas (Withler et al. 2001).

Interpretations of stock structure are influenced by the particular genetic analysis conducted, as illustrated by the differing conclusions produced from the POP allozyme work of Seeb and Gunderson (1988) and the microsatellite work of Withler et al. (2001); note that these two components of the genome diverge on very different time scales and that, in this case, microsatellites are much more sensitive. Protein electrophoresis examines DNA variation only indirectly via allozyme frequencies, and does not recognize situations where differences in DNA may result in identical allozymes (Park and Moran 1994). In addition, many microsatellite loci may be selectively neutral or near-neutral, whereas allozymes are central metabolic pathway enzymes and do not have quite the latitude to produce viable mutations. The mutation rate of microsatellite alleles can be orders of magnitude higher than allozyme locus mutation rates. Most current studies on rockfish genetic population structure involve direct examination of either mitochondrial DNA (mtDNA) or microsatellite DNA.

A recent analysis by Dr. Anthony Gharrett of the Juneau Center of Fisheries and Ocean Sciences examined the mtDNA for POP samples collected in the GOA and BSAI, and conducted a preliminary analysis of POP microsatellite variation in these regions. The POP mtDNA analysis was performed on 124 fish collected from six regions ranging from southeast Alaska to the Bering Sea slope and central Aleutian Islands. No population structure was observed, as most fish (102) were characterized by a common haplotype. However, the preliminary work with 10 microsatellite loci from the six regions resulted in 7 loci with significant heterogeneity in the distribution of allele frequencies. Additionally, the sample in each region was distinct from those in adjacent regions, suggesting population structure on a relatively fine spatial scale consistent with the results on Gunderson (1972, 1977) and Withler et al. (2001). Ongoing genetic research with POP is focusing on increasing the sample sizes and collection

sites for the microsatellite analysis in order to further refine our perception of stock structure.

FISHERY

Pacific ocean perch were highly sought by Japanese and Soviet fisheries and supported a major trawl fishery throughout the 1960s. Catches in the eastern Bering Sea peaked at 47,000 (metric tons, t) in 1961; the peak catch in the Aleutian Islands region occurred in 1965 at 109,100 t. Apparently, these stocks were not productive enough to support such large removals. Catches continued to decline throughout the 1960s and 1970s, reaching their lowest levels in the mid 1980s. With the gradual phase-out of the foreign fishery in the 200-mile U.S. Exclusive Economic Zone (EEZ), a small joint-venture fishery developed but was soon replaced by a domestic fishery by 1990. In 1990 the domestic fishery recorded the highest Pacific ocean perch removals since 1977. The history of *S. alutus* landings since implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) is shown in Table 11.1.

Estimates of retained and discarded Pacific ocean perch from the fishery have been available since 1990 (Table 11.2). The eastern Bering Sea region generally shows a higher discard rate than in the Aleutian Islands region. For the period from 1990 to 2003, the Pacific ocean perch discard rate in the eastern Bering Sea averaged 33%, and the 2003 discard rate was 52%. In contrast, the discard rate from 1990 to 2003 in the Aleutian Islands averaged 15%, with a 2003 discard rate of 16%. The removals from trawl and hydroacoustic surveys are shown in Table 11.3.

There has been little change in the distribution of observed Aleutian Islands POP catch with respect to fishing depth and management area (based on observer records) between the broad periods covering the foreign and joint venture fisheries (years 1977-1988) and the domestic fishery (years 1990-2003). The fishing depth accounting for the largest proportion of catch in each fishery was 200-299 m, with 49% and 65% of the observed foreign/joint venture and domestic catch, respectively (Table 11.4). Management area 541 contributes the largest share of the observed catch in each fishery; with 46% and 40% in the foreign/joint venture and domestic fisheries, respectively (Table 11.5). In contrast, area 543 contributes the largest share of the catch in the 2003 fishery due to the spatial allocation of harvest quotas. Although the catch by management area between the two time periods was similar, variations occurred within each of these periods. For example, area 543 contributed a large share of the catch in the late 1970s foreign fishery, as well as the domestic fishery from the mid-1990s to the present. In the late 1980s to the early 1990s, area 541 contributed a large share of the catch, and prompted management changes to spatially allocate POP harvest. Note that the extent to which the patterns of observed catch can be used as a proxy for patterns in total catch is dependent upon the degree to which the observer sampling represents the true fishery. In particular, the proportions of total POP caught that were actually sampled by observers were very low in the foreign fishery, due to low sampling ratio prior to 1984 (Megrey and Wespestad 1990).

DATA

Fishery Data

Catch per unit effort (CPUE) data from Japanese trawl fisheries indicate that Pacific ocean perch stock abundance has declined to very low levels in the Aleutian Islands region (Ito 1986). By 1977, CPUE values had dropped by more than 90-95% from those of the early 1960s. Japanese CPUE data after 1977, however, is probably not a good index of stock abundance because most of the fishing effort has been directed to species other than Pacific ocean perch. Standardizing and partitioning total

groundfish effort into effort directed solely toward Pacific ocean perch is extremely difficult. Increased quota restrictions, effort shifts to different target species, and rapid improvements in fishing technology undoubtedly affect our estimates of effective fishing effort. Consequently, we included CPUE data primarily to evaluate its consistency with other sources of information. We used nominal CPUE data for class 8 trawlers in the eastern Bering Sea and Aleutian Islands regions from 1968-1979. During this time period these vessels were known to target on Pacific ocean perch (Ito 1982).

Length measurements and otoliths read from the EBS and AI management areas were combined to create fishery age/size composition matrices (Table 11.6). Years which were not selected for age or length composition were rejected due to low samples sizes of fish measured (<300; years 1973-1976, 1985-1986), and/or otoliths read (<150; years 1984, 1987, 1989). In 1982, the method for aging otoliths at the Alaska Fisheries Science Center changed from surface reading to the break and burn method (Betty Goetz, Alaska Fisheries Science Center, pers. comm.), as the latter method is considered more accurate for older fish (Tagart 1984). The time at which the otoliths collected from 1977 to 1982 were read is not known for many vessels and cruises. However, the information available suggests that otoliths from 1977 to 1980 were read prior to 1981, whereas otoliths from 1981 and 1982 were read after 1982.

Survey Data

The Aleutian Islands survey biomass estimates were used as an index of abundance for the BSAI POP stock. Note that there is wide variability among survey estimates from the portion of the southern Bering Sea portion of the survey (from 165° W to 170° W), as the post-1991 coefficients of variation (CVs) range from 0.41 to 0.64 (Table 11.7). The biomass estimates in this region increased from 1,501 t in 1991 to 18,217 t in 1994, and have ranged between 12,099 t and 18,870 t between 1997 and 2002 before increasing to 74,208 t in 2004. The estimated biomass of Pacific ocean perch in the Aleutian Islands management area region (170° W to 170° E) appears to be less variable, with CVs ranging from 0.16 to 0.24. For the entire survey area, there has been a steady increase from 1980 to 1997, followed by declines to the 2000 and 2002 estimates and an increase in 2004. The 1991 trawl survey produced a biomass estimate of 351,093 t, more than three times the 1980 point estimate. The 1994 and 1997 trawl surveys produced biomass estimates of 383,618 and 625,272 t. Since 1997, the trawl survey estimates declined from 511,706 t in 2000 and 468,588 t in 2002 before increasing to 578,999 t in 2004. Age composition data exists for each survey except the 2004 survey. The length measurements and otoliths read from the Aleutian Islands surveys are shown in Table 11.8.

Historically, the Aleutian Island surveys have indicated higher abundances in the western and central Aleutian Islands, and this pattern was repeated in the 2004 survey (Figure 11.1). In particular, areas near Amchitka and Kiska Islands, Tahoma Bank-Buldir Island, and Attu Island and Stalemate Bank showed high CPUE in 2004 survey tows. The higher CPUE for the southern Bering Sea area was influenced by a large tow northwest of Unalaska Island.

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991, and previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. The 2002 EBS slope survey POP biomass estimate and its standard deviation were 76,685 t and 38,589 t, resulting in a CV of 0.53. The 2004 POP biomass estimate in the EBS slope survey was 112,279 t with a standard deviation of 42,684 t, resulting in a CV of 0.38. The slope survey results are not used in this assessment, and the feasibility of incorporating this time series will be evaluated in future years.

The following table summarizes the data available for the BSAI POP model:

Component	BSAI
Fishery catch	1960-2004
Fishery age composition	1977-82, 1990,1998,2000,2001, 2003
Fishery size composition	1964-72, 1983-1984,1987-1989,1991-1997,1999,2002
Fishery CPUE	1968-79
Survey length composition	2004
Survey age composition	1980, 83, 86, 91, 94, 97, 2000,2002
Survey biomass estimates	1980, 83, 86, 91, 94, 97, 2000, 2002, 2004

Biological Data

The surveys produce large numbers of samples for age determination, length-weight relationships, sex ratio information, and for estimating the length distribution of the population. The age compositions were determined by constructing age-length keys for each year and using them to convert the observed length frequencies from each year. Because the survey age data were based on the break and burn method of ageing Pacific ocean perch, they were treated as unbiased but measured with error. Kimura and Lyons (1991) give data on the percent agreement between otolith readers for Pacific ocean perch. The estimate of aging error was identical to that presented in Ianelli and Ito (1991). The assessment model uses this information to create a transition matrix to convert the simulated "true" age composition to a form consistent with the observed but imprecise age data.

Assessments of Pacific ocean perch have improved significantly because of improved methods of age determination. Historically, Pacific ocean perch age determinations were done using scales and surface readings from otoliths. These gave estimates of natural mortality of about 0.15 and 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.

Aleutian Islands survey data from years 1980, 1983, 1986, 1991, 1994, 1997, and 2000 were used to estimate growth curves; previous assessments using the otoliths from the 1981, 1982 and 1991 eastern Bering Sea surveys have indicated little differences in size at age between the Aleutian Islands and the eastern Bering Sea (Spencer and Ianelli 2003). The resulting von Bertalanffy growth parameters were $L_{inf} = 40.07$ cm, $k = 0.166$, and $t_0 = -0.5762$. Growth information from the Aleutian Islands was used to convert estimated numbers at age within the model to estimated numbers at length.

The estimated length(cm)-weight(g) relationship for Aleutian Islands POP was estimated with survey information from the same years; previous assessments (Spencer and Ianelli 200x) have showed that the length-weight relationship in the eastern Bering Sea, based upon fishery data from 1975 to 1999, was similar to that in the Aleutian Islands. The Aleutian Island length-weight parameters were $a = 5.139 \times 10^{-5}$ and $b = 3.08$, where $weight = a * (length)^b$. The Aleutian Islands length-weight relationship was used to produce estimated weights at age. A combined-sex model was used, as the ratio of males to females varied slightly from year to year but was not significantly different from 1:1 (Ianelli and Ito 1991). The proportion mature at age schedule used is identical to that used in the Gulf of Alaska POP assessment.

ANALYTIC APPROACH

Model Structure

An age-structured population dynamics model, implemented in the software program ADModelbuilder, was used to obtain estimates of recruitment, numbers at age, and catch at age. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \quad 3 \leq a < A, \quad 1960 \leq t \leq T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population (defined as 25), and T is the terminal year of the analysis (defined as 2003). The numbers at age A are a “pooled” group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

The numbers at age in the first year are estimated as

$$N_a = R_0 e^{-M(a-3) + \gamma_a}$$

where R_0 the number of age 3 recruits for an unfished population and γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to the recruitment standard deviation (σ). The previous stock synthesis model estimated the first year numbers at age to be in equilibrium with an historical catch of 400 t, and required estimation of a historic fishing mortality rate parameter. The equilibrium assumption implied that the recruitment strengths of all cohorts in the first year were equivalent, whereas the estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1960 to 1996 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν is a time-variant deviation. The recruitments from 1997 to 2003 are set the median recruitment, e^{μ_r} .

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) and a year-specific fully-selected fishing mortality rate f . The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ϵ_t), thus $F_{t,a}$ is

$$F_{t,a} = fishsel_a * f_t \equiv fishsel_a * e^{(\mu_f + \epsilon_t)}$$

Given the similarity between the two fisheries in terms of depth and management area fished (Tables 11.4 and 11.5), a single fishery selectivity curve was used. A double logistic fishery selectivity curve been used in some previous assessments, as an asymptotic selectivity pattern for the fishery was originally found to be inadequate in describing the observed data (Ianelli and Ito 1992). A variety of

fishery selectivity curves were evaluated in the 2001 assessment (Spencer and Ianelli 2001), with the asymptotic fishery selectivity curve chosen as the preferred model.

The mean numbers at age for each year was computed as

$$\bar{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. Twenty-five length bins were used, ranging from 15 cm to 39+ cm. The transition matrix was based upon an estimated von Bertalanffy growth relationship, with the variation in length at age interpolated from between the first and terminal ages in the model.

Both unbiased and biased age distributions are used in the model. For unbiased age distributions, aging imprecision is inferred from studies indicating that the percent agreement between readers varies from 60% for age 3 fish to 13% for age 25 fish (Kimura and Lyons 1991). The information on percent agreement was used to derive the variability of observed age around the “true” age, assuming a normal distribution. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions. Similarly, estimated biased age distributions are computed by multiplying the mean number of fish at age by a biased aging error matrix, which was derived from data in Tagart (1984).

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

$$pred_biom_t = qsurv \sum_a \left(\bar{N}_{t,a} * survsel_a * W_a \right)$$

where W_a is the population weight at age, $survsel_a$ is the survey selectivity, and $qsurv$ is the trawl survey catchability. We use the Aleutian Islands trawl survey biomass estimates in a relative sense rather than in an absolute sense by allowing $qsurv$ to be estimated in the model rather than fixed at 1.0. Similarly, the predicted catch per unit effort index was computed as

$$pred_cpue_t = qcpue \sum_a \left(\bar{N}_{t,a} * fishsel_a * W_a \right)$$

where $qcpue$ is the scaling factor for the CPUE index.

Parameters Estimated Independently

The parameters estimated independently include the biased and unbiased age error matrices, the age-length transition matrix, individual weight at age, and natural mortality. The age error matrices were obtained from information in Kimura and Lyons (1991) and Tagart (1984), and are identical to those used in the previous assessments. The age-length transition matrix was derived from the von Bertalanffy growth parameters discussed above, which were combined with the length-weight relationship to obtain estimates of individual weights. The natural mortality rate M was fixed at 0.05, consistent with studies on POP age determination (Chilton and Beamish 1982, Archibald et al. 1981). The standard deviation of log recruitment (σ) was fixed, as the estimation of variance parameters could increase the potential for model instability, and a variety of choices were evaluated.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that maximize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \left[\sum_t \frac{\left(v_t + \frac{\sigma^2}{2} \right)^2}{2\sigma^2} + n \ln(\sigma) \right]$$

The adjustment of adding $\sigma^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment.

The log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$n_{f,t,l} \sum_{s,t,l} p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l})$$

where n is the square root of the number of fish measured, and $p_{f,t,l}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2cv_t^2$$

where obs_biom_t is the observed survey biomass at time t , cv_t is the coefficient of variation of the survey biomass in year t , and λ_2 is a weighting factor. The log-likelihood of the CPUE index is computed in a similar manner, and is weighted by λ_3 . The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_4 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2$$

where obs_cat_t and $pred_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision than other variables, λ_4 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function. The overall negative log-likelihood function is

$$\begin{aligned}
& \lambda_1 \left(\sum_t \left(\frac{v_t + \sigma^2 / 2}{2\sigma^2} \right)^2 + n \ln(\sigma) \right) + \\
& \lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2 * cv_t^2 + \\
& \lambda_3 \sum_t (\ln(obs_cpue_t) - \ln(pred_cpue_t))^2 / 2 * cv_{CPUE}^2 + \\
& n_{f,t,l} \sum_{s,t,l} p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l}) + \\
& n_{f,t,a} \sum_{s,t,l} p_{f,t,a} \ln(\hat{p}_{f,t,a}) - p_{f,t,a} \ln(p_{f,t,a}) + \\
& n_{surv,t,a} \sum_{s,t,a} p_{surv,t,a} \ln(\hat{p}_{surv,t,a}) - p_{surv,t,a} \ln(p_{surv,t,a}) + \\
& n_{surv,t,l} \sum_{s,t,a} p_{surv,t,l} \ln(\hat{p}_{surv,t,l}) - p_{surv,t,l} \ln(p_{surv,t,l}) + \\
& \lambda_4 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2
\end{aligned}$$

For the model run in this analysis, λ_1 , λ_2 , λ_3 , and λ_4 were assigned weights of 1, 1, 0.5, and 500, reflecting a de-emphasis of the CPUE index and strong emphasis on fitting the catch data. The sample sizes for the age and length compositions were set to the square root of the number of fish measured or otoliths read. The negative log-likelihood function was minimized by varying the following parameters:

<u>Parameter type</u>	<u>Number</u>
1) fishing mortality mean (μ_f)	1
2) fishing mortality deviations (ϵ_f)	45
3) recruitment mean (μ_r)	1
4) recruitment deviations (v_r)	38
5) historic recruitment (R_0)	1
6) first year recruitment deviations	22
7) Biomass survey catchability	1
8) CPUE index catchability	1
9) fishery selectivity parameters	2
<u>10) survey selectivity parameters</u>	<u>2</u>
Total parameters	114

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on total biomass, spawning biomass, and recruitment strength are presented.

RESULTS

Model Selection

In order to evaluate the effect of σ , a series of models in which σ was fixed at either 0.5, 0.75, 1.0, and 1.25 were evaluated (Table 11.9). Allowing recruitment variability to vary more freely with higher levels of σ produced larger negative log-likelihoods for the recruitment and fishery biased age composition components, which is countered by lower negative log-likelihoods for the fishery length composition. The fit to the AI survey age composition also improves as σ increases. The log-likelihood of the fishery length composition was reduced by 15 units between the runs where $\sigma = 0.5$ and $\sigma = 0.75$, as the run with $\sigma = 0.75$ had the lowest overall log-likelihood and was chosen as the preferred model; the results below refer to this base case.

The fit to the age and size composition data can be inferred from the comparison of the average input sample sizes (set to square root of the number of samples), by data type, to the effective sample size (Table 11.9). The effective sample size can be interpreted as the sample size that would be consistent with the fit produced by the model, and data components where the effective sample size exceeds the input sample size can be interpreted as good fits. The average effective sample size for all age and length composition components of the likelihood exceeds their average input sample weights. In particular, the average effective sample size for the AI survey length composition was approximately 3.5 times larger than the average input sample weights, and had the largest effective sample size. This data component consists of only the 2004 length composition, as data from previous AI trawl surveys have been aged.

Biomass Trends

The estimated survey biomass index begins with 795,299 t in 1960, declines to 111,773 t in 1978, and increases to 523,356 t in 1995 and remains at approximately that level, with a 2004 estimate of 525,663 t (Figure 11.2). The survey point estimates are used in a relative sense rather than in an absolute sense, with a survey catchability (q) estimated at 1.55 rather than fixed at 1.0. Because the Aleutian Islands survey biomass estimates are taken as an index for the entire BSAI area, it is reasonable to expect that the q would be below 1.0 to the extent that the total BSAI biomass is higher than the Aleutian Islands

biomass. One factor that may cause an increase in survey catchability is the expansion of survey trawl estimates to untrawlable areas (Kreiger and Sigler 1996). The fit to the CPUE index is shown in Figure 11.3.

The total biomass showed a similar trend as the survey biomass, with the 2004 total biomass estimated as 378,600 t. The estimated time series of total biomass and spawning biomass, with 95% confidence intervals obtained from MCMC integration, are shown in Figure 11.4. Total biomass, spawning biomass, and recruitment are given in Table 11.10. The estimated numbers at age are shown in Table 11.11.

Age/size compositions

The fishery age compositions, biased and unbiased, are shown in Figures 11.5 and 11.6 respectively. The observed proportion in the binned age 25+ group for years 1981 and 1982 is higher than the estimated proportion. Although the fits improve in 2000 and 2001, in 2003 the estimated proportion in the 25+ group was larger than that observed (Figure 11.6). The fishery length compositions are shown in Figure 11.7; some of the lack of fit in the mid- to late-1980s is attributable to the low sample size of lengths observed from a reduced fishery. The survey age compositions (Figure 11.8) show a similar pattern as the unbiased fishery age compositions in that the age 25+ group is fit better in recent years (1994-2002) than earlier years (1980-1986). The model also shows a good fit to the 2004 survey length composition (Figure 11.9). The estimated age at 50% selection for the survey and fishery selectivity curves were 5.42 and 6.73 years, respectively (Figure 11.10).

Fishing Mortality

The estimates of instantaneous fishing mortality for POP range from highs during the 1970's to low levels in the 1980's (Figure 11.11). Relative to the estimated $F_{35\%}$ level, BSAI POP were overfished during considerable portions of this period. Fishing mortality rates since the early 1980's, however, have moderated considerably due to the phase out of the foreign fleets and quota limitations imposed by the North Pacific Fishery Management Council. The average fishing mortality from 1965 to 1980 was 0.26, whereas the average from 1981 to 2002 was 0.03. The scatterplot of estimated fishing mortality rates and spawning stock biomass plotted in reference to the harvest control rules (Figure 11.12) indicate that BSAI POP would be considered overfished during much of the period from the mid-1960s to the mid-1980s, although it should be noted the current definitions of B40% are based on the estimated recruitment of the post-1977 year classes.

Recruitment

For both the eastern Bering Sea and Aleutian Islands, year class strength varies widely (Figure 11.13; Table 11.10). The relationship between spawning stock and recruitment also displays a high degree of variability (Figure 11.14). The 1962 year class is particularly large, more than twice any other estimated recruitment. Recruitment appears to be lower in early 1990s than in the mid-1980s, but the recent observations are based upon cohorts that have not been extensively observed in the available data.

Projections and Harvest Alternatives

The reference fishing mortality rate for Pacific ocean perch is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2001 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an

estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 142,262 t. The year 2005 spawning stock biomass is estimated as 133,351 t. Since reliable estimates of the 2004 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B < B_{0.40}$ (133,351 t < 142,262 t), POP reference fishing mortality is defined in tier 3b. For this tier, F_{ABC} is constrained to be $\leq F_{0.40}$, and F_{OFL} is constrained to be $\leq F_{0.35}$; the values of $F_{0.40}$ and $F_{0.35}$ are 0.048 and 0.058, respectively. Under the guidelines of tier 3b of Amendment 56, we calculate the F_{ABC} as $\{F_{0.40} \times (SPB_{2002}/SPB_{0.40} - 0.05)/(1 - 0.05)\}$. This procedure produces an F_{ABC} of 0.045 and an ABC estimate for the Aleutian Islands region of approximately 14,615 t. This ABC is approximately 1,318 t higher than last year's recommendation of 13,297 t. The estimated catch level for year 2005 associated with the overfishing level of $F = 0.054$ is 17,330 t. A summary of these values is below.

2005 SSB estimate (B)	=	133,351 t
$B_{0.40}$	=	142,262 t
$F_{0.40}$	=	0.048
F_{ABC}	=	0.045
$F_{0.35}$	=	0.058
F_{OFL}	=	0.054

Harvest rates producing maximum sustainable yield for many stocks of rockfish off the west coast of the continental U.S. may be lower than the commonly used $F_{0.40}$ values, based upon a Bayesian meta-analysis of stock-recruitment relationships (Dorn 2002). For example, the MSY rate for the west coast stock of POP was $F_{0.70}$. However, Dorn's analysis also indicates that eastern Bering Sea and Aleutian Islands POP were the most resilient stocks in his analysis, and produced MSY harvest rates of less than $F_{0.30}$. Thus, the $F_{0.40}$ harvest rates used in this assessment appear to be appropriate, although examination of the spawner-recruit relationships should be re-evaluated as more data is collected.

Projections and Harvest Alternatives

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow (" $max F_{ABC}$ " refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to $max F_{ABC}$. (Rationale: Historically, TAC has

been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of $\max F_{ABC}$, where this fraction is equal to the ratio of the F_{ABC} value for 2004 recommended in the assessment to the $\max F_{ABC}$ for 2003. (Rationale: When F_{ABC} is set at a value below $\max F_{ABC}$, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of $\max F_{ABC}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1999-2003 average F . (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC} .)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and five-year projections of the mean harvest and spawning stock biomass for the remaining four scenarios are shown in Table 11.12

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Pacific ocean perch stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL} . (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2005, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, F is set equal to $\max F_{ABC}$, and in all subsequent years, F is set equal to F_{OFL} . (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2007 under this scenario, then the stock is not approaching an overfished condition.)

The projections of the mean spawning stock biomass, fishing mortality rate, and harvest for these scenarios are shown in Table 11.12. The results of these two scenarios indicate that the BSAI Pacific ocean perch stock is neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2005 of scenario 6 is 1.07 times its $B_{35\%}$ value of 124,479 t. With regard to whether Pacific ocean perch is likely to be overfished in the future, the expected stock size in 2007 of scenario 7 is 1.06 times the $B_{35\%}$ value.

OTHER CONSIDERATIONS

This combination of the eastern Bering Sea and Aleutian Islands management areas motivates consideration of the criteria to be used to divide the ABC among the areas. Because the AI trawl survey spans the two management areas, one option is to use the proportional survey biomass from the two areas to partition the ABCs. The average biomass from 1991-2004 in the AI management area is 463,012 t, whereas the average from the southern Bering Sea is 23,534 t; thus 95% of the estimated Aleutians Islands survey biomass occurs in the Aleutian Islands management area. Because the Aleutian Islands

survey does not cover the EBS slope, it may be useful to consider the recent EBS slope survey biomass estimates of 72,665 t and 112,279 t in the 2002 and 2004 surveys, respectively. The average biomass of these two surveys is 92,472 t, and when added to the average of the southern Bering Sea area of the AI trawl survey produces an estimate of (23,534 t + 92,472 t = 115,006 t). This figure is 20% of the combined BSAI biomass from both surveys of 578,018 t. Thus, it is recommended that 20% of the ABC, or 2,923 t, be allocated to the EBS region and 80%, or 11,692 t, be allocated to the AI region.

As in previous years, it is recommended that the Aleutians Islands portion of the ABC be partitioned among management subareas in proportion to the estimated biomass. The recent trawl surveys (1991-2004) (Table 11.13), indicate that the average POP biomass was distributed in the Aleutian Islands region as follows:

	<u>Biomass (%)</u>
Eastern subarea (541):	27.5%
Central subarea (542):	27.1%
Western subarea (543):	45.4%
Total	100%

Under these proportions, the recommended ABCs are 3,216 t for area 541, 3,164 t for area 542, and 3,216 t for area 543.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Pacific ocean perch feed upon calanoid copepods, euphausiids, myctophids, and other miscellaneous prey (Yang 2003). From a sample of 292 Aleutian Island specimens collected in 1997, calanoid copepods, euphausiids, and myctophids contributed 70% of the total diet by weight. The diet of small POP was composed primarily of calanoid copepods (89% by weight), with euphausiids and myctophids contributing approximately 35% and 10% of the diet, respectively, of larger POP. The availability and abundance trends of these prey species are unknown.

2) Predator population trends

Pacific ocean perch are not commonly observed in field samples of stomach contents, although previous studies have identified sablefish, Pacific halibut, and sperm whales as predators (Major and Shippen 1970). The population trends of these predators can be found in separate chapters within this SAFE document.

3) Changes in habitat quality

Pacific ocean perch appear to exhibit ontogenetic shifts in habitat use. Carlson and Straty (1981) used a submersible off southeast Alaska to observe juvenile red rockfish they believed to be POP at approximately 90-100 m in rugged habitat including boulder fields and rocky pinnacles. Kreiger (1993) also used a submersible to observe that the highest densities of small red rockfish in untrawlable rough habitat. As POP mature, they move into deeper and less rough habitats. Length frequencies of the

Aleutian Islands survey data indicate that large POP (> 25 cm) are generally found at depths greater than 150 m. Brodeur (2001) also found that POP was associated with epibenthic sea pens and sea whips along the Bering Sea slope. There has been little information identifying how rockfish habitat quality has changed over time.

Fishery Effects on the ecosystem

Catch of prohibited species is reported in the 2003 SAFE for all BSAI rockfish fisheries, which in recent years has consisted only of the AI POP fishery. The rockfish fishery in the BSAI area contributed approximately 12% and 10% of the total bycatch of the red king crab in the BSAI area in 2001 and 2002, respectively. The rockfish fishery also contributed approximately 1% and 2% of the total bycatch of Pacific halibut during 2001 and 2002, respectively.

Estimates of non-targets catches in the rockfish fishery, obtained from applying the species compositions in the observer program to the total catch estimates by fishery, indicates that the proportion of the harvest of sea whips/sea pens, sponges, and tunicate has been highly variable from 2000 to 2002. For example, the proportion of the BSAI catch of sea whips/sea pens attributable to the rockfish fishery has been 0%, 0% and 22% from 2000 to 2002, whereas the proportion of BSAI sponge catch in the rockfish fishery has been 17%, 36%, and 45% over these years. Such variability is related to the total amount of catches during this time period, which ranged between 12 t and 77 t for sponges and was less than 0.1 t in any year for sea whips/sea pens. It is not currently known what effect this level of sponge harvest has on the larger BSAI ecosystem.

The POP fishery is not likely to diminish the amount of POP available as prey due to its low selectivity for fish less than 27 cm. Additionally, the fishery is not suspected of affecting the size-structure of the population due to the relatively light fishing mortality, averaging 0.03 over the last 5 years. It is not known what effects the fishery may have on the maturity-at-age of POP.

ACKNOWLEDGEMENTS

We thank Martin Dorn for his assistance with the text and programming for the analysis presented in the Appendix.

SUMMARY

The management parameters for Pacific ocean perch as presented in this assessment are summarized as follows:

Quantity	Value
M	0.05
Tier	3b
Year 2005 Total Biomass	381,768 t
Year 2005 Spawning stock biomass	133,351 t
$B_{100\%}$	355,654 t
$B_{40\%}$	142,262 t
$B_{35\%}$	124,479 t
F_{OFL}	0.058
Maximum F_{ABC}	0.045
Recommended F_{ABC}	0.045
OFL	17,330 t
Maximum allowable ABC	14,615 t
Recommended ABC	14,615 t

REFERENCES

- Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-79. *Can. Tech. Rep. Fish. Aquat. Sci.* 1048, 57 p.
- Chikuni, S. 1975. Biological study on the population of the Pacific ocean perch in the North Pacific. *Bull. Far Seas Fish. Res. Lab. (Shimizu)* 12:1-119.
- Chilton, D. E., and R. J. Beamish. 1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. *Can. Spec. Publ. Fish. Aquat. Sci.* 60, 102 p.
- Dorn, M.W. 2002. Advice on west coast rockfish harvest rates from Bayesian meta-analysis of stock-recruitment relationships. *N. Am. J. Fish. Aquat. Sci.* 22:280-300.
- Gelman, A., J.B. Carlin, H.S. Stern, and D.A. Rubin. 1995. Bayesian data analysis. Chapman and Hall, New York. 552 pp.
- Gharrett, A.J., A.K. Gray, and J. Heifetz. 2001. Identification of rockfish (*Sebastes* spp.) by restriction site analysis of the mitochondrial ND-3/ND-4 and 12S/16S rDNA gene regions. *Fish. Bull.* 99:49-62.
- Gunderson, D.R. 1972. Evidence that Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound for aggregations that have different biological characteristics. *J. Fish. Res. Bd. Can.* 29:1061-1070
- Gunderson, D. R. 1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte Sound region, and their response to fishing. *Fish. Bull., U.S.* 75(2): 369-403.
- Ianelli, J. N., and D. H. Ito. 1991. Stock assessment of Pacific ocean perch (*Sebastes alutus*) using an explicit age structured model. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 1992 (November 1991), 20 pp. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.
- Ianelli, J. N., and D. H. Ito. 1992. Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 1993 (November 1992), 36 pp. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.
- Ito, D. H. 1982. A cohort analysis of Pacific ocean perch stocks from the Gulf of Alaska and Bering Sea regions. NWAFC Processed Rep. 82-15, 157 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Bin C15700, Seattle, WA 98115.
- Ito, D. H. 1986. Pacific ocean perch. *In* R. G. Bakkala and L. L. Low (editors), Condition of groundfish

resources of the eastern Bering Sea and Aleutian Islands region in 1985, p. 101-132. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-104.

Kendall, A.W. Jr. 1991. Systematics and identification of larvae and juveniles of the genus *Sebastes*. *Env. Biol. Fish.* 30:173-190.

Kimura, D. K., and J. J. Lyons. 1991. Between-reader bias and variability in the age-determination process. *Fish. Bull.*, U.S. 89: 53-60.

Krieger, K. J., and M. F. Sigler. 1996. Catchability coefficient for rockfish estimated from trawl and submersible surveys. *Fish. Bull.*, U.S. 94: 282-288.

Megrey, B.A. and V.G. Wespestad. 1990. Alaskan groundfish resources: 10 years of management under the Magnuson Fishery Conservation and Management Act. *North American Journal of Fisheries Management* 10:125-143.

Park, L.K. and P. Moran. 1994. Developments in molecular genetic techniques in fisheries. *Reviews in Fish Biology and Fisheries* 4:272-299.

Rocha-Olivares, A. 1998. Multiplex haplotype-specific PCR: a new approach for species identification of the early life stages of rockfishes of the species-rich genus *Sebastes* Cuvier. *J. Exp. Mar. Biol. Ecol.* 231:279-290.

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.

Seeb, L.W. and A.W. Kendall, Jr. 1991. Allozyme polymorphisms permit the identification of larval and juvenile rockfishes of the genus *Sebastes*. *Env. Biol. Fish.* 30:191-201.

Spencer, P.D., and J.N. Ianelli. 2001. The implementation of an AD Modelbulder catch at age model for Bering Sea/Aleutian Islands Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region (September 2001), 36 pp. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Spencer, P.D. and J.N. Ianelli. 2003. Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 2002, pp. 563-610. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501.

Tagart, J.V. 1984. Comparison of final ages assigned to a common set of Pacific ocean perch otoliths. Washington Department of fisheries Technical Report 81, 36 pp. Olympia, WA.

Westrheim, S.J. 1970. Survey of rockfishes, especially of Pacific ocean perch, in the northeast Pacific

- ocean, 1963-66. J. Fish. Res. Brd. Can. 27:1781-1809.
- Westrheim, S.J. 1973. Age determination and growth of Pacific ocean perch (*Sebastes alutus*) in the northeast Pacific ocean. J. Fish. Res. Brd. Can. 30:235-247.
- Withler, R.E., T.D. Beacham, A.D. Schulze, L.J. Richards, and K.M. Miller. 2001. Co-existing populations of Pacific ocean perch, *Sebastes alutus*, in Queen Charlotte Sound, British Columbia. Mar. Biol. 139:1-12.
- Yang, M-S. 1996. Diets of the important groundfishes in the Aleutian Islands in summer 1991. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-60. 105 pp.
- Yang, M.S. 2003. Food habits of the important groundfishes in the Aleutian Islands in 1994 and 1997. U.S. Dep. Commer., AFSC Proc. Rep 2003-07. 233 pp.

Table 11.1. Estimated removals (t) of Pacific ocean perch (*S. alutus*) since implementation of the Magnuson Fishery Conservation and Management Act of 1976.

Year	Eastern Bering Sea			Aleutian Islands			BSAI
	Foreign	JVP	DAP	Foreign	JVP	DAP	Total catch
1977	2,654	--	--	8,080	--	--	10,734
1978	2,221	--	--	5,286	--	--	7,507
1979	1,723	--	--	5,487	--	--	7,210
1980	1,050	47	--	4,700	Tr	--	5,797
1981	1,221	1	--	3,618	4	--	4,844
1982	212	3	8	1,012	2	--	1,237
1983	116	97	7	272	8	--	500
1984	156	134	1,122	356	273	2	2,043
1985	35	32	629	Tr	215	72	983
1986	16	117	375	Tr	160	98	766
1987	5	50	768	0	500	391	1,714
1988	0	51	874	0	1,513	362	2,800
1989	0	31	2,570	0	Tr	2,101	4,702
1990	0	0	6,344	0	0	11,838	18,182
1991	0	0	5,099	0	0	2,785	7,884
1992	0	0	6,509	0	0	20,559	27,068
1993	0	0	3,764	0	0	13,375	17,139
1994	0	0	1,688	0	0	10,866	12,554
1995	0	0	1,207	0	0	10,303	11,511
1996	0	0	2,854	0	0	12,827	15,681
1997	0	0	681	0	0	12,648	13,328
1998	0	0	1,022	0	0	9,299	10,320
1999	0	0	421	0	0	12,483	12,904
2000	0	0	451	0	0	9,328	9,780
2001	0	0	896	0	0	8,557	9,453
2002	0	0	641	0	0	10,575	11,216
2003	0	0	1,151	0	0	12,761	13,912
2004*			701			10,331	11,032

Tr = trace, JVP = Joint Venture Processing, DAP = Domestic Annual Processing.

Source: PacFIN, NMFS Observer Program, and NMFS Alaska Regional Office.

*Estimated removals through October 2, 2004.

Table 11.2. Estimated retained and discarded catch (t), and percent discarded, of Pacific ocean perch from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions.

Year	EBS			AI			BSAI		
	Retained	Discarded	Percent Discarded	Retained	Discarded	Percent Discarded	Retained	Discard	Percent Discarded
1990	5,069	1,275	20.10	10,288	1,551	13.10	15,357	2,826	15.54
1991	4126	972	19.07	1815	970	34.82	5941	1942	24.63
1992	5464	1044	16.05	17332	3227	15.70	22797	4271	15.78
1993	2601	1163	30.90	11479	1896	14.18	14080	3059	17.85
1994	1187	501	29.69	9491	1374	12.65	10678	1876	14.94
1995	839	368	30.49	8603	1701	16.51	9442	2069	17.97
1996	2522	333	11.66	9831	2995	23.35	12353	3328	21.22
1997	420	261	38.35	10854	1794	14.18	11274	2055	15.42
1998	821	200	19.62	8282	1017	10.93	9103	1217	11.79
1999	277	144	34.28	10985	1499	12.01	11261	1643	12.73
2000	230	221	49.01	8586	743	7.96	8816	964	9.85
2001	399	497	55.45	7195	1362	15.92	7594	1859	19.66
2002	286	355	55.44	9315	1260	11.91	9601	1615	14.40
2003	549	603	52.35	10720	2040	16.00	11,269	2643	19.00
2004	113	72	38.95	4709	598	11.27	4822	670	12.20

Source: NMFS Alaska Regional Office; 2004 data is through July 17th, 2004

Table 11.3. Estimated catch (t) of Pacific ocean perch in Aleutian Islands and eastern Bering Sea trawl surveys, and the eastern Bering Sea hydroacoustic survey.

Year	Area		
	AI	BS	BS-Hydroacoustic
1977		0.01	
1978		0.13	0.01
1979		3.08	
1980	71.47	0.00	
1981		13.98	
1982	0.24	12.09	
1983	133.30	0.16	
1984		0.00	
1985		98.57	
1986	164.54	0.00	
1987		0.01	
1988		10.43	
1989		0.00	
1990		0.02	0.01
1991	73.57	2.76	0.00
1992		0.38	0.00
1993		0.01	0.00
1994	112.79	0.00	0.02
1995		0.01	0.01
1996		1.18	0.00
1997	177.94	0.73	0.15
1998		0.01	0.00
1999		0.19	0.00
2000	140.82	22.90	0.45
2001		0.11	
2002	130.31	13.18	0.31
2003		7.55	
2004	149.69	31.03	

Table 11.4. Proportional catch (by weight) of Aleutians Islands POP in the foreign/joint venture fisheries and the domestic fishery by depth.

Depth	Foreign and JV (1977-1988)	Domestic (1990-2003)
0-99	0.03	0.00
100-199	0.34	0.23
200-299	0.49	0.65
300-399	0.13	0.11
400-499	0.01	0.01
500-599	0.00	0.00
≥501	0.00	0.00
Observed catch	1,638	106,980
Total Catch	31,486	158,204
Sampling ratio	0.05	0.68

Table 11.5. Proportional catch (by weight) of Aleutians Islands POP in the foreign and joint venture fisheries and the domestic fishery by management area.

Area	Foreign and JV (1977-1988)	Domestic (1990-2003)
541	0.46	0.39
542	0.27	0.24
543	0.26	0.37
Observed catch	1,638	106,980
Total Catch	31,486	158,204
Sampling ratio	0.05	0.68

Table 11.6. Length measurements and otoliths read from the EBS and AI POP fisheries, from Chikuni (1975) and NORPAC Observer database.

Year	Length Measurements			Otoliths read		
	EBS	AI	Total	EBS	AI	Total
1964	24,150	55,599	79,749			
1965	14,935	66,120	81,055			
1966	26,458	25,502	51,960			
1967	48,027	59,576	107,603			
1968	38,370	36,734	75,104			
1969	28,774	27,206	55,980			
1970	11,299	27,508	38,807			
1971	14,045	18,926	32,971			
1972	10,996	18,926	29,922			
1973	1		1**			
1974	84		84**	84		84**
1975	1		1**	125		125**
1976	50		50**	114	19	133**
1977	1,059	2,778	3,837*	139	404	543
1978	7,926	7,283	15,209*	583	641	1,224
1979	1,045	10,921	11,966*	248	353	601
1980		3,995	3,995*		398	398
1981	1,502	7,167	8,669*	78	432	510
1982		4,902	4,902*		222	222
1983	232	441	673			
1984	1,194	1,210	2,404	72		72**
1985	300		300**	160		160**
1986		100	100**		99	99**
1987	11	384	395	11		11**
1988	306	1,366	1,672			
1989	957	91	1,048		19	19**
1990	22,228	47,198	69,426*	144	184	328
1991	8,247	8,221	16,468			
1992	13,077	24,932	38,009			
1993	8,379	26,433	34,812			
1994	2,654	11,546	14,200			
1995	272	11,452	11,724			
1996	2,967	13,146	16,113			
1997	143	10,402	10,545			
1998	989	11,106	12,095*		823	823
1999	289	3,839	4,128			
2000	284	3,382	3,666*		487	487
2001	327	2,388	2,715*		524	524
2002	78	3,671	3,749			
2003	247	4681	4928*	11	386	397

*Used to create age composition. **Not used.

Table 11.7. Pacific ocean perch estimated biomass (t) from the Aleutian Islands trawl surveys, by management area.

Year	Southern Bering Sea			Aleutian Islands			Total Aleutian Islands Survey		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1979									
1980	6003	9966	1.66	109022	27670	0.25	115025	29410	0.26
1981									
1982									
1983	97478	89946	0.92	144080	26338	0.18	241558	93723	0.39
1984									
1985									
1986	49562	26433	0.59	220614	39909	0.18	270176	47869	0.18
1987									
1988									
1989									
1990									
1991	1501	758	0.51	349592	79318	0.23	351093	79322	0.23
1992									
1993									
1994	18217	11685	0.64	365401	87600	0.24	383618	88376	0.23
1995									
1996									
1997	12099	7008	0.58	613174	96405	0.16	625272	96659	0.15
1998									
1999									
2000	18870	10150	0.54	492836	89535	0.18	511706	90109	0.18
2001									
2002	16311	6637	0.41	452277	76693	0.17	468588	76979	0.16
2003									
2004	74208	33397	0.45	504791	66600	0.13	578999	72722	0.13

Table 11.8. Length measurements and otoliths read from the Aleutian Islands surveys.

Year	Length measurements	Otoliths read
1980	20796	872
1983	22873	2299
1986	14804	1860
1991	14262	807
1994	18922	788
1997	22823	1172
2000	21972	1219
2002	18980	337
2004	24949	NA

Table 11.9. Negative log likelihood fits of various model components for BSAI POP models with varying levels of the standard deviation of log recruits.

Likelihood Component	Standard deviation of log recruits			
	0.5	0.75	1.0	1.25
Recruitment	7.39	15.35	22.05	30.04
AI survey biomass	2.95	3.12	3.11	3.06
CPUE	24.87	24.05	23.96	24.05
Fishing mortality penalty	7.30	6.94	6.84	6.84
fishery biased age comps	10.40	12.72	14.10	14.96
fishery unbiased age comps	34.87	34.02	33.57	33.35
fishery length comps	199.21	185.02	181.63	180.02
AI survey age comps	54.15	51.42	50.41	49.91
AI survey length comps	3.06	3.20	3.42	3.67
- ln likelihood	324.47	314.92	317.25	323.40
Average Effective Sample Size				
Fishery biased ages	147.17	111.39	94.19	85.41
Fishery unbiased ages	61.39	65.39	66.65	67.11
Fishery lengths	243.99	280.79	295.75	303.39
AI Survey ages	64.03	65.32	65.48	65.47
AI Survey lengths	522.66	552.79	565.55	564.88
Average Sample Sizes				
Fishery biased ages	25.75	25.75	25.75	25.75
Fishery unbiased ages	20.50	20.50	20.50	20.50
Fishery lengths	155.04	155.04	155.04	155.04
AI Survey ages	33.00	33.00	33.00	33.00
AI Survey lengths	158.00	158.00	158.00	158.00
Root Mean Squared Error				
CPUE Index	0.79	0.78	0.78	0.78
survey	0.18	0.19	0.19	0.20
recruitment	0.61	0.77	0.91	1.04

Table 11.10. Estimated time series of POP total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

Year	Total Biomass (ages 3+)		Spawner Biomass (ages 3+)		Recruitment (age 3)	
	Assessment Year		Assessment Year		Assessment Year	
	2004	2003	2004	2003	2004	2003
1977	90,286	90,925	24,885	26,555	22,072	21,236
1978	87,941	88,399	23,881	25,160	38,585	37,263
1979	92,371	92,616	23,727	24,938	74,847	71,533
1980	99,411	99,143	23,764	24,792	71,803	67,753
1981	112,163	111,318	24,271	25,151	95,866	92,588
1982	124,941	123,164	25,775	26,285	38,376	35,573
1983	143,080	140,054	29,262	29,623	52,377	47,361
1984	170,604	165,824	33,762	34,091	157,308	143,137
1985	193,555	186,794	39,554	39,598	48,427	44,615
1986	218,920	209,979	46,428	46,171	63,853	59,282
1987	250,826	239,160	54,695	54,143	143,873	128,067
1988	279,397	264,486	65,054	63,977	69,553	58,403
1989	309,419	291,020	75,215	73,611	103,532	93,774
1990	334,987	313,356	84,369	83,112	58,218	54,562
1991	346,866	321,639	91,905	88,664	84,629	72,836
1992	365,635	336,503	100,266	97,354	41,805	35,540
1993	360,724	342,519	104,555	104,390	27,995	24,273
1994	362,246	341,462	110,897	109,384	22,851	19,908
1995	365,552	342,314	118,707	115,974	28,592	24,000
1996	367,410	341,632	125,419	121,896	32,078	23,869
1997	363,751	337,200	129,749	124,759	46,507	
1998	362,570	334,998	133,583	127,133		
1999	364,665	336,138	136,466	129,158		
2000	364,662	335,933	137,127	128,665		
2001	368,625	339,898	137,754	128,968		
2002	373,540	344,528	137,610	128,698		
2003	377,344	348,114	136,290	127,582		
2004	378,600		134,637			

Table 11.11. Estimated numbers (millions) of Pacific ocean perch in the BSAI region

Year	Age																								
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25+		
1960	31.5	19.1	21.9	23.8	23.6	913.9	20.4	18.5	16.8	15.3	14.1	13.1	12.3	11.3	10.7	10.1	9.6	9.0	8.5	8.1	7.8	7.5	48.9		
1961	212.8	30.0	18.1	20.9	22.6	22.3	859.3	19.2	17.4	15.8	14.4	13.2	12.3	11.4	10.7	10.0	9.5	9.0	8.4	8.0	7.7	7.3	53.0		
1962	41.4	202.4	28.5	17.2	19.6	20.2	19.4	748.3	16.7	15.2	13.7	12.5	11.5	10.7	10.0	9.3	8.7	8.2	7.8	7.3	6.9	6.7	52.5		
1963	29.3	39.4	192.6	27.1	16.3	18.2	18.6	17.8	685.1	15.3	13.9	12.6	11.5	10.6	9.8	9.1	8.5	8.0	7.5	7.2	6.7	6.4	54.2		
1964	173.4	27.8	37.5	182.9	25.4	14.6	15.9	16.2	15.5	597.0	13.3	12.1	11.0	10.0	9.2	8.5	7.9	7.4	7.0	6.6	6.3	5.8	52.8		
1965	439.6	165.0	26.5	35.5	167.6	20.5	10.9	11.7	11.9	11.4	440.1	9.8	8.9	8.1	7.4	6.8	6.3	5.9	5.5	5.1	4.8	4.6	43.2		
1966	28.5	418.1	156.8	25.0	32.1	127.8	14.1	7.4	8.0	8.1	7.8	298.5	6.7	6.0	5.5	5.0	4.6	4.3	4.0	3.7	3.5	3.3	32.4		
1967	44.2	27.1	397.5	148.3	22.5	24.0	85.3	9.3	4.9	5.2	5.3	5.1	195.8	4.4	4.0	3.6	3.3	3.0	2.8	2.6	2.4	2.3	23.4		
1968	95.4	42.1	25.7	376.0	133.9	17.0	16.3	57.1	6.2	3.3	3.5	3.5	3.4	130.9	2.9	2.7	2.4	2.2	2.0	1.9	1.7	1.6	17.2		
1969	27.1	90.8	40.0	24.3	336.2	96.9	10.9	10.2	35.7	3.9	2.0	2.2	2.2	2.1	81.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	11.8		
1970	26.1	25.8	86.3	37.9	22.2	268.1	71.2	7.9	7.4	25.9	2.8	1.5	1.6	1.6	1.5	59.4	1.3	1.2	1.1	1.0	0.9	0.8	9.3		
1971	25.8	24.8	24.5	81.6	33.9	16.1	170.7	44.6	4.9	4.6	16.2	1.8	0.9	1.0	1.0	37.1	0.8	0.8	0.7	0.6	0.6	0.6	6.4		
1972	25.1	24.5	23.6	23.2	75.3	28.2	12.6	132.3	34.5	3.8	3.6	12.5	1.4	0.7	0.8	0.8	0.7	28.7	0.6	0.6	0.5	0.5	5.4		
1973	27.0	23.9	23.3	22.3	21.2	59.9	20.6	9.1	95.7	24.9	2.8	2.6	9.1	1.0	0.5	0.6	0.6	0.5	20.8	0.5	0.4	0.4	4.2		
1974	23.3	25.7	22.7	22.2	20.9	18.7	50.9	17.5	7.7	81.0	21.1	2.3	2.2	7.7	0.8	0.4	0.5	0.5	0.5	17.6	0.4	0.4	3.9		
1975	26.3	22.2	24.5	21.5	20.1	16.2	13.3	35.7	12.2	5.4	56.6	14.8	1.6	1.5	5.4	0.6	0.3	0.3	0.3	12.3	0.3	0.3	3.0		
1976	20.7	25.0	21.1	23.2	19.7	16.2	12.1	9.8	26.2	9.0	4.0	41.6	10.8	1.2	1.1	3.9	0.4	0.2	0.2	0.2	0.2	0.2	2.4		
1977	22.1	19.7	23.8	19.9	20.9	14.7	10.8	8.0	6.4	17.3	5.9	2.6	27.4	7.1	0.8	0.7	2.6	0.3	0.1	0.2	0.2	0.2	7.5		
1978	38.6	21.0	18.7	22.6	18.5	17.9	12.0	8.8	6.5	5.2	14.0	4.8	2.1	22.2	5.8	0.6	0.6	2.1	0.2	0.1	0.1	0.1	6.2		
1979	74.8	36.7	20.0	17.8	21.1	16.4	15.3	10.2	7.5	5.5	4.4	11.9	4.1	1.8	18.9	4.9	0.5	0.5	1.8	0.2	0.1	0.1	5.4		
1980	71.8	71.2	34.9	19.0	16.6	18.7	14.0	13.0	8.7	6.4	4.7	3.8	10.1	3.5	1.5	16.1	4.2	0.5	0.4	1.5	0.2	0.1	4.7		
1981	95.9	68.3	67.7	33.2	17.8	14.9	16.4	12.3	11.4	7.6	5.6	4.1	3.3	8.8	3.0	1.3	14.0	3.7	0.4	0.4	1.3	0.1	4.2		
1982	38.4	91.2	65.0	64.3	31.2	16.2	13.3	14.5	10.9	10.1	6.8	4.9	3.6	2.9	7.8	2.7	1.2	12.5	3.2	0.4	0.3	1.2	3.8		
1983	52.4	36.5	86.7	61.8	61.1	29.4	15.2	12.5	13.6	10.2	9.5	6.3	4.6	3.4	2.7	7.3	2.5	1.1	11.7	3.0	0.3	0.3	4.7		
1984	157.3	49.8	34.7	82.5	58.7	57.9	27.8	14.3	11.8	12.9	9.6	8.9	6.0	4.4	3.2	2.6	7.0	2.4	1.0	11.0	2.9	0.3	4.7		
1985	48.4	149.6	47.4	33.0	78.3	55.2	54.1	26.0	13.4	11.0	12.0	9.0	8.4	5.6	4.1	3.0	2.4	6.5	2.2	1.0	10.3	2.7	4.7		
1986	63.9	46.1	142.3	45.1	31.4	74.1	52.2	51.1	24.6	12.7	10.4	11.4	8.5	7.9	5.3	3.9	2.8	2.3	6.1	2.1	0.9	9.7	7.0		
1987	143.9	60.7	43.8	135.4	42.8	29.8	70.2	49.4	48.4	23.2	12.0	9.9	10.8	8.0	7.5	5.0	3.7	2.7	2.2	5.8	2.0	0.9	15.9		
1988	69.6	136.9	57.8	41.7	128.6	40.5	28.1	66.1	46.5	45.6	21.9	11.3	9.3	10.1	7.6	7.0	4.7	3.4	2.5	2.0	5.5	1.9	15.8		
1989	103.5	66.2	130.2	54.9	39.6	121.3	38.1	26.3	62.1	43.7	42.8	20.6	10.6	8.7	9.5	7.1	6.6	4.4	3.2	2.4	1.9	5.1	16.6		
1990	58.2	98.5	62.9	123.8	52.1	37.2	113.3	35.5	24.6	57.9	40.8	40.0	19.2	9.9	8.1	8.9	6.6	6.2	4.1	3.0	2.2	1.8	20.2		
1991	84.6	55.4	93.7	59.8	116.5	47.3	33.0	100.4	31.5	21.8	51.3	36.1	35.4	17.0	8.8	7.2	7.9	5.9	5.5	3.7	2.7	2.0	19.5		
1992	41.8	80.5	52.7	89.1	56.6	108.8	43.8	30.6	92.8	29.1	20.1	47.5	33.4	32.7	15.7	8.1	6.7	7.3	5.4	5.1	3.4	2.5	19.9		
1993	28.0	39.8	76.6	50.0	83.6	50.7	94.8	38.0	26.5	80.5	25.2	17.5	41.2	29.0	28.4	13.6	7.0	5.8	6.3	4.7	4.4	2.9	19.4		
1994	22.9	26.6	37.8	72.8	47.2	76.6	45.7	85.2	34.2	23.8	72.4	22.7	15.7	15.7	26.0	25.5	12.3	6.3	5.2	5.7	4.2	3.9	20.1		
1995	28.6	21.7	25.3	36.0	68.8	43.7	70.1	41.8	77.9	31.2	21.8	66.1	20.7	14.3	33.8	23.8	23.3	11.2	5.8	4.7	5.2	3.9	21.9		
1996	32.1	27.2	20.7	24.1	34.0	64.0	40.2	64.4	38.4	71.5	28.7	20.0	60.7	19.0	13.2	31.0	21.9	21.4	10.3	5.3	4.4	4.8	23.7		
1997	46.5	30.5	25.9	19.7	22.7	31.4	58.2	36.5	58.4	34.8	64.9	26.0	18.1	55.1	17.3	11.9	28.2	19.8	19.4	9.3	4.8	4.0	25.8		
1998	64.1	44.2	29.0	24.6	18.6	21.1	28.7	53.1	33.3	53.4	31.8	59.3	23.8	16.6	50.3	15.8	10.9	25.7	18.1	17.7	8.5	4.4	27.2		
1999	64.1	61.0	42.1	27.6	23.3	17.3	19.4	26.5	49.0	30.7	49.2	29.3	54.6	21.9	15.3	46.4	14.5	10.1	23.7	16.7	16.4	7.9	29.1		
2000	64.1	61.0	58.0	40.0	26.1	21.6	15.8	17.8	24.2	44.7	28.1	44.9	26.8	49.9	20.0	13.9	42.4	13.3	9.2	21.7	15.2	14.9	33.8		
2001	64.1	61.0	58.0	55.1	37.9	24.3	19.9	14.6	16.4	22.3	41.3	25.9	41.4	24.7	46.0	18.5	12.9	39.1	12.2	8.5	20.0	14.1	44.9		
2002	64.1	61.0	58.0	55.1	52.2	35.3	22.5	18.4	13.5	15.1	20.6	38.1	23.9	38.3	22.8	42.5	17.0	11.9	36.1	11.3	7.8	18.4	54.5		
2003	64.1	61.0	58.0	55.1	52.2	48.5	32.5	20.6	16.9	12.4	13.9	18.9	35.0	21.9	35.1	20.9	39.0	15.6	10.9	33.1	10.4	7.2	66.9		
2004	64.1	61.0	58.0	55.1	52.1	48.2	44.3	29.6	18.8	15.4	11.3	12.7	17.2	31.8	20.0	32.0	19.1	35.5	14.2	9.9	30.2	9.5	67.5		

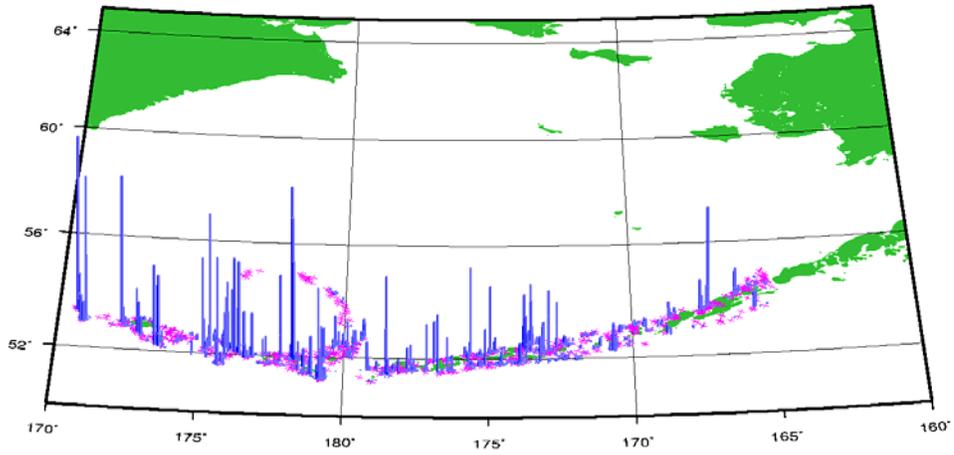
Table 11.12. Projections of BSAI spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 142,262 t and 124,479 t, respectively.

Sp. Biomass	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>	<i>Scenario 4</i>	<i>Scenario 5</i>	<i>Scenario 6</i>	<i>Scenario 7</i>
2004	134473	134473	134473	134473	134473	134473	134473
2005	133351	133351	134103	133655	134860	133065	133351
2006	132674	132674	136410	134177	140289	131285	132674
2007	132257	132257	138890	134915	146087	129864	131976
2008	132429	132429	141893	136218	152633	129112	131062
2009	133092	133092	145348	138019	159859	128922	130716
2010	133730	133730	148733	139792	167136	128786	130416
2011	134541	134541	152274	141741	174660	128898	130355
2012	135260	135260	155665	143588	182050	128998	130306
2013	136064	136064	159090	145512	189495	129250	130387
2014	136710	136710	162259	147250	196628	129415	130398
2015	137312	137312	165285	148906	203565	129587	130452
2016	137899	137899	168188	150504	210312	129786	130504
2017	138449	138449	170952	152020	216852	129984	130620
F	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>	<i>Scenario 4</i>	<i>Scenario 5</i>	<i>Scenario 6</i>	<i>Scenario 7</i>
2004	0.039125	0.039125	0.039123	0.039124	0.039123	0.039125	0.039123
2005	0.045166	0.045166	0.022583	0.036005	0	0.053777	0.045166
2006	0.044924	0.044924	0.022991	0.036005	0	0.053017	0.044924
2007	0.044775	0.044775	0.023429	0.036005	0	0.05241	0.053312
2008	0.044836	0.044836	0.02396	0.036005	0	0.052089	0.052922
2009	0.045074	0.045074	0.024177	0.036005	0	0.052008	0.052774
2010	0.045301	0.045301	0.024177	0.036005	0	0.05195	0.052646
2011	0.045592	0.045592	0.024177	0.036005	0	0.051998	0.05262
2012	0.045841	0.045841	0.024177	0.036005	0	0.05204	0.052596
2013	0.046091	0.046091	0.024177	0.036005	0	0.052146	0.052615
2014	0.046242	0.046242	0.024177	0.036005	0	0.052205	0.052593
2015	0.046337	0.046337	0.024177	0.036005	0	0.052256	0.052586
2016	0.046407	0.046407	0.024177	0.036005	0	0.052311	0.052576
2017	0.046462	0.046462	0.024177	0.036005	0	0.052364	0.052597
Catch	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>	<i>Scenario 4</i>	<i>Scenario 5</i>	<i>Scenario 6</i>	<i>Scenario 7</i>
2004	12580.8	12580.8	12580.4	12580.5	12580.4	12580.8	12580.3
2005	14615.3	14615.3	7387.86	11702.6	0	17329.7	14615.4
2006	14620.1	14620.1	7725.05	11870.4	0	17047.6	14620.2
2007	14639.5	14639.5	8063.56	12020.3	0	16813.2	17360.4
2008	14738.9	14738.9	8438.73	12174.9	0	16697.9	17197.1
2009	14919.1	14919.1	8714.41	12344.5	0	16697.1	17154
2010	15083	15083	8899.72	12499.7	0	16699.1	17110.4
2011	15275.7	15275.7	9084.77	12658.2	0	16752.9	17116.3
2012	15438.6	15438.6	9255.46	12800.5	0	16795.8	17121.2
2013	15607.4	15607.4	9424.89	12945	0	16872.9	17148.3
2014	15724.6	15724.6	9579.16	13072.4	0	16921.7	17151.1
2015	15814.4	15814.4	9723.84	13190.4	0	16964	17166.1
2016	15898.4	15898.4	9864.98	13307.7	0	17014.4	17176.2
2017	15971.6	15971.6	9998.03	13417.2	0	17059.4	17205.8

Table 11.13. Pacific ocean perch biomass estimates (t) from the 1991-2004 triennial trawl surveys broken out by the three management sub-areas in the Aleutian Islands region.

Year	Aleutian Islands Management Sub-Areas		
	Western	Central	Eastern
1991	214,137	79,911	55,545
1994	184,005	80,811	100,585
1997	225,725	166,816	220,633
2000	222,584	129,740	140,512
2002	202,124	140,358	109,795
2004	213,593	154,086	137,112
Average	210,361	125,287	127,364
Percentage	45.4%	27.1%	27.5%

1980-2002 AI Surveys POP CPUE (scaled wgt /km²)



2004 AI Survey POP CPUE (scaled wgt /km²)

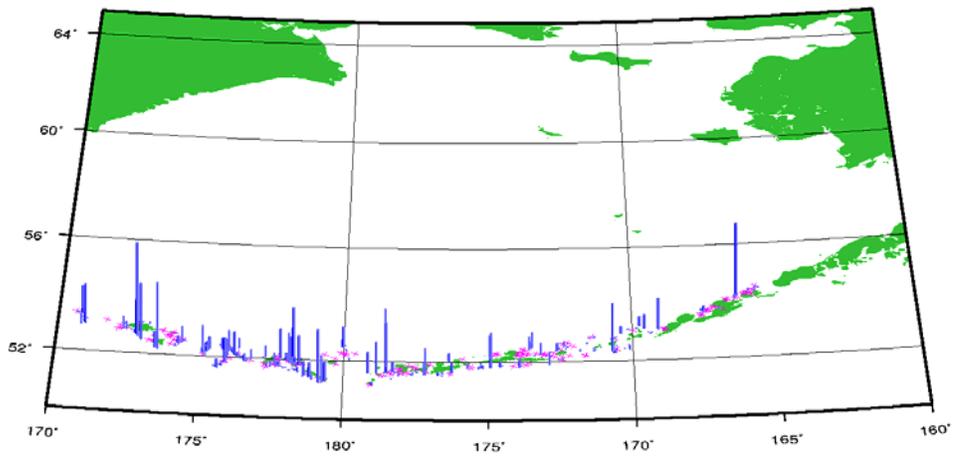


Figure 11.1. Scaled AI survey POP CPUE from 1980-2002 (top panel), and 2004 (bottom panel)

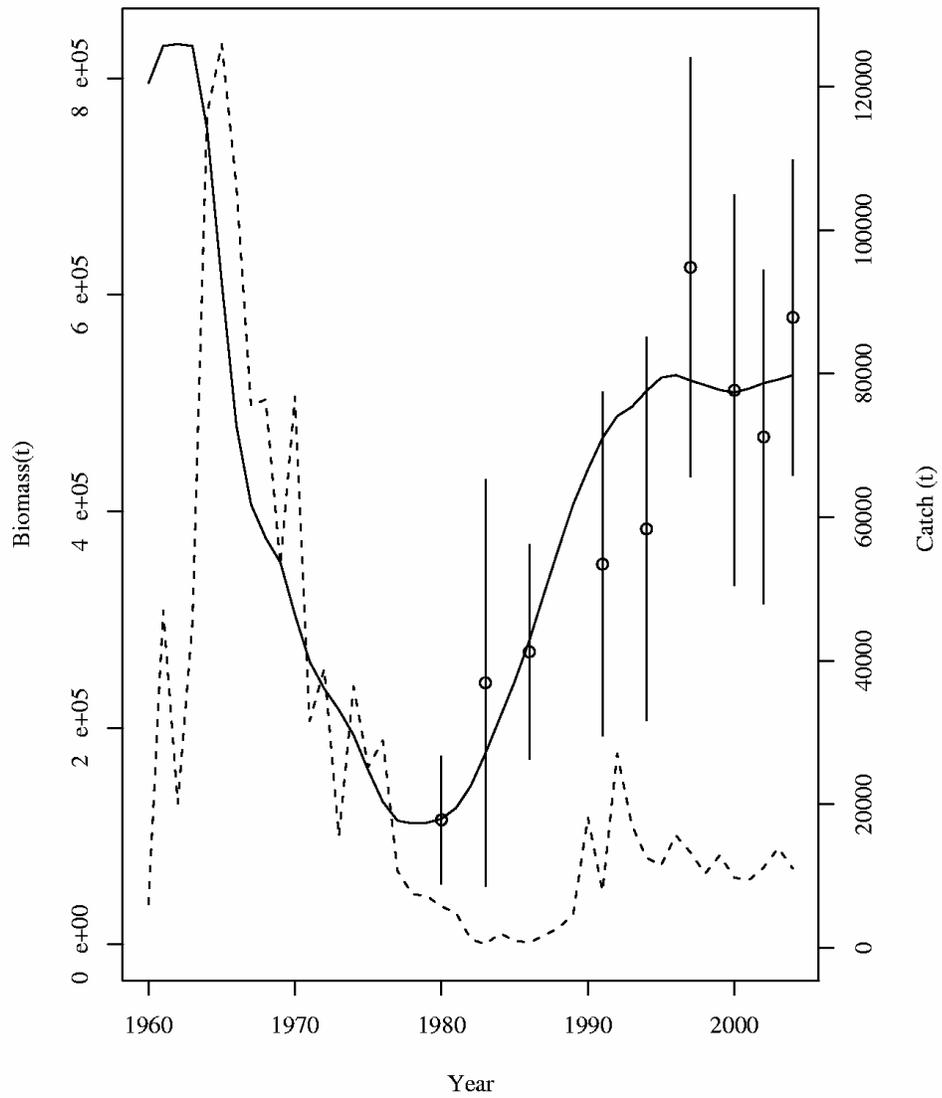


Figure 11.2. Observed AI survey biomass(data points, +/- 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

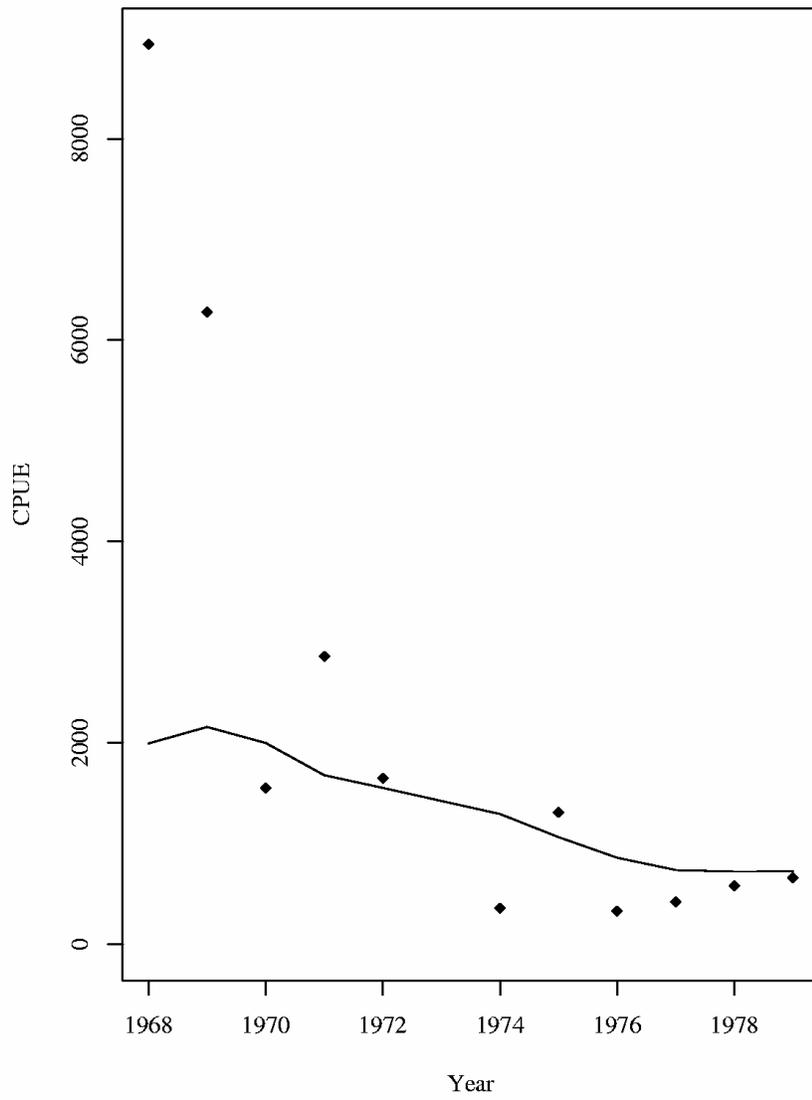


Figure 11.3. Observed AI CPUE (data points) and predicted CPUE (solid line) for BSAI POP.

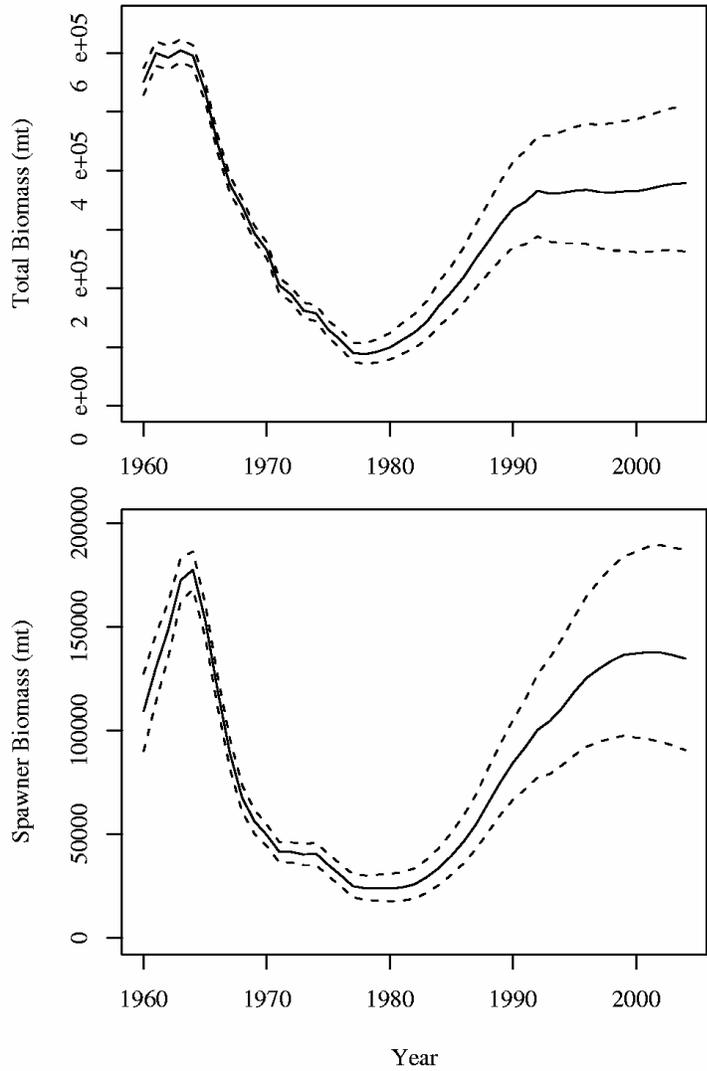


Figure 11.4. Total and spawner biomass for BSAI Pacific ocean perch, with 95% confidence intervals from MCMC integration.

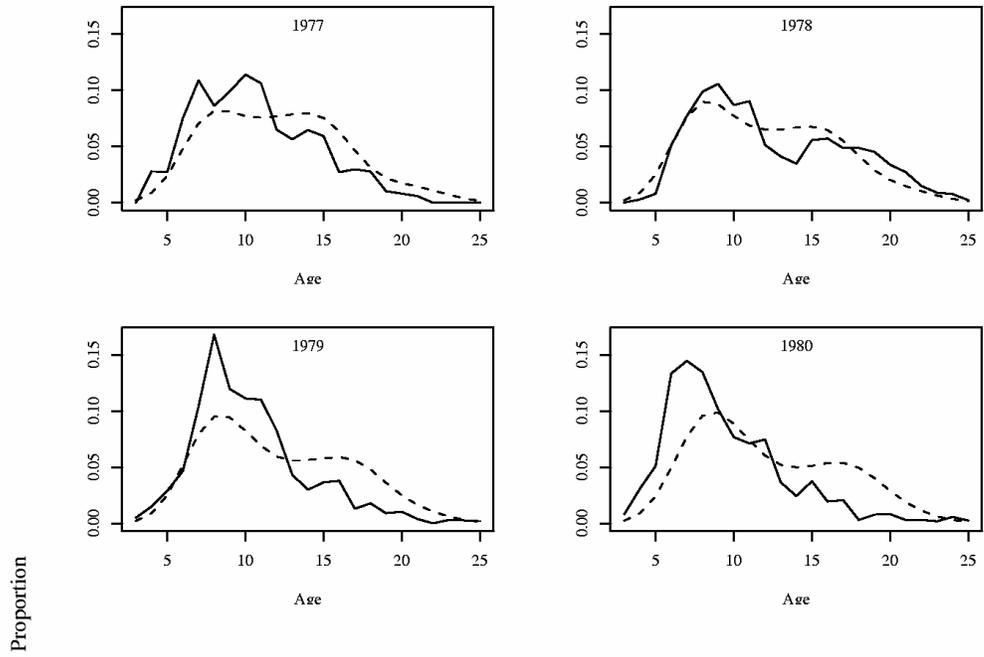


Figure 11.5. Fishery biased age composition by year (solid line = observed, dotted line = predicted)

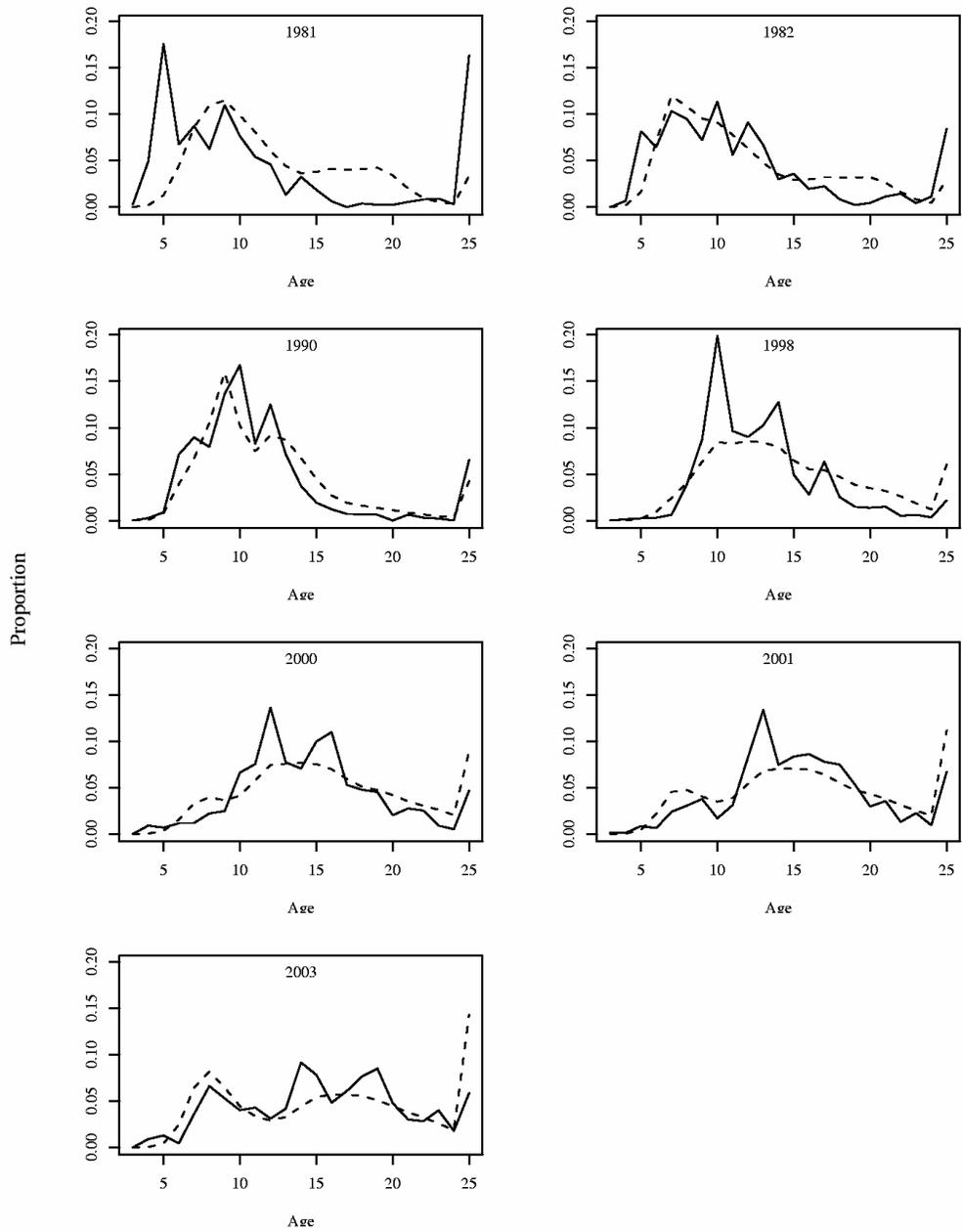


Figure 11.6. Fishery age composition by year (solid line = observed, dotted line = predicted)

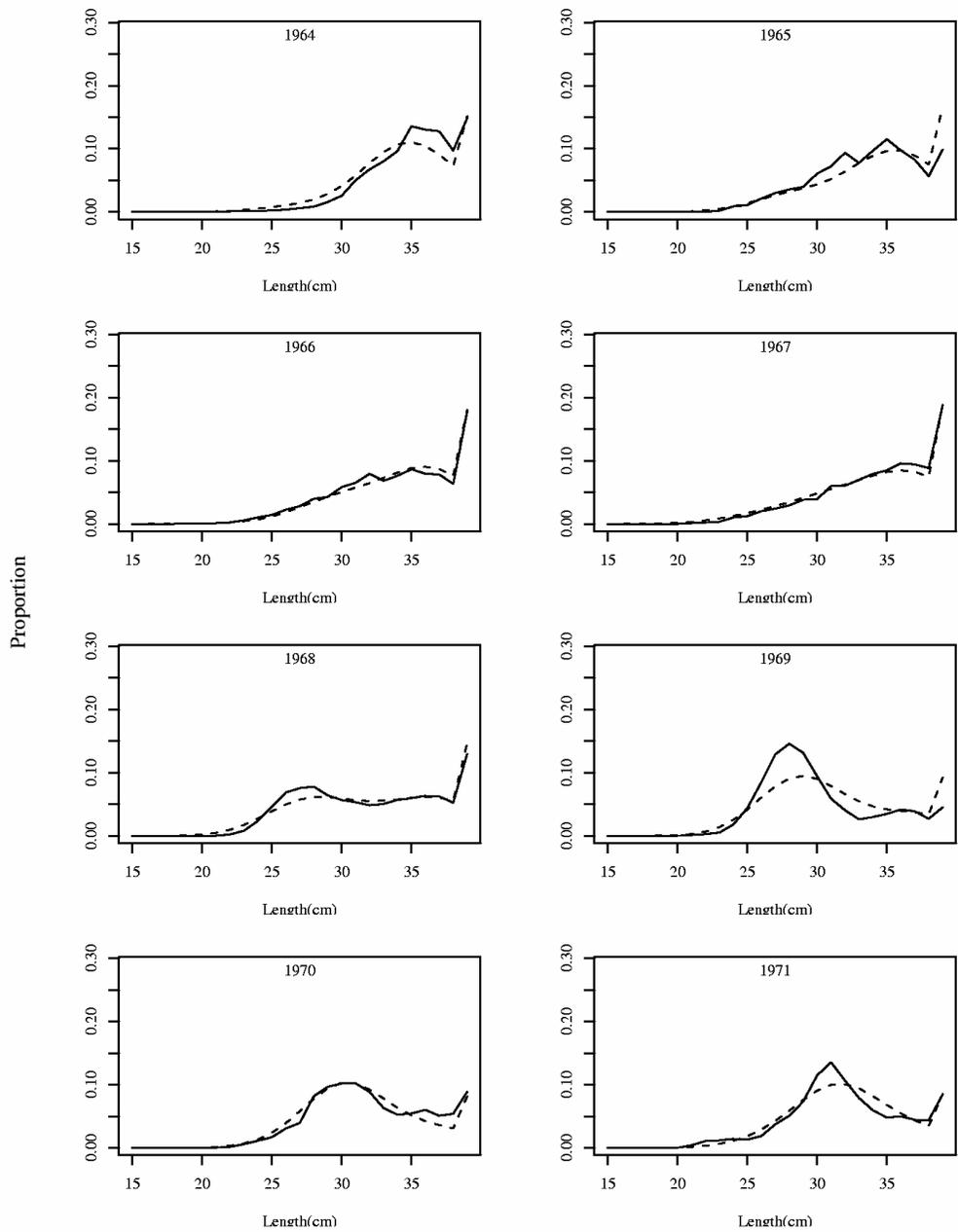


Figure 11.7. Fishery length composition by year (solid line = observed, dotted line = predicted)

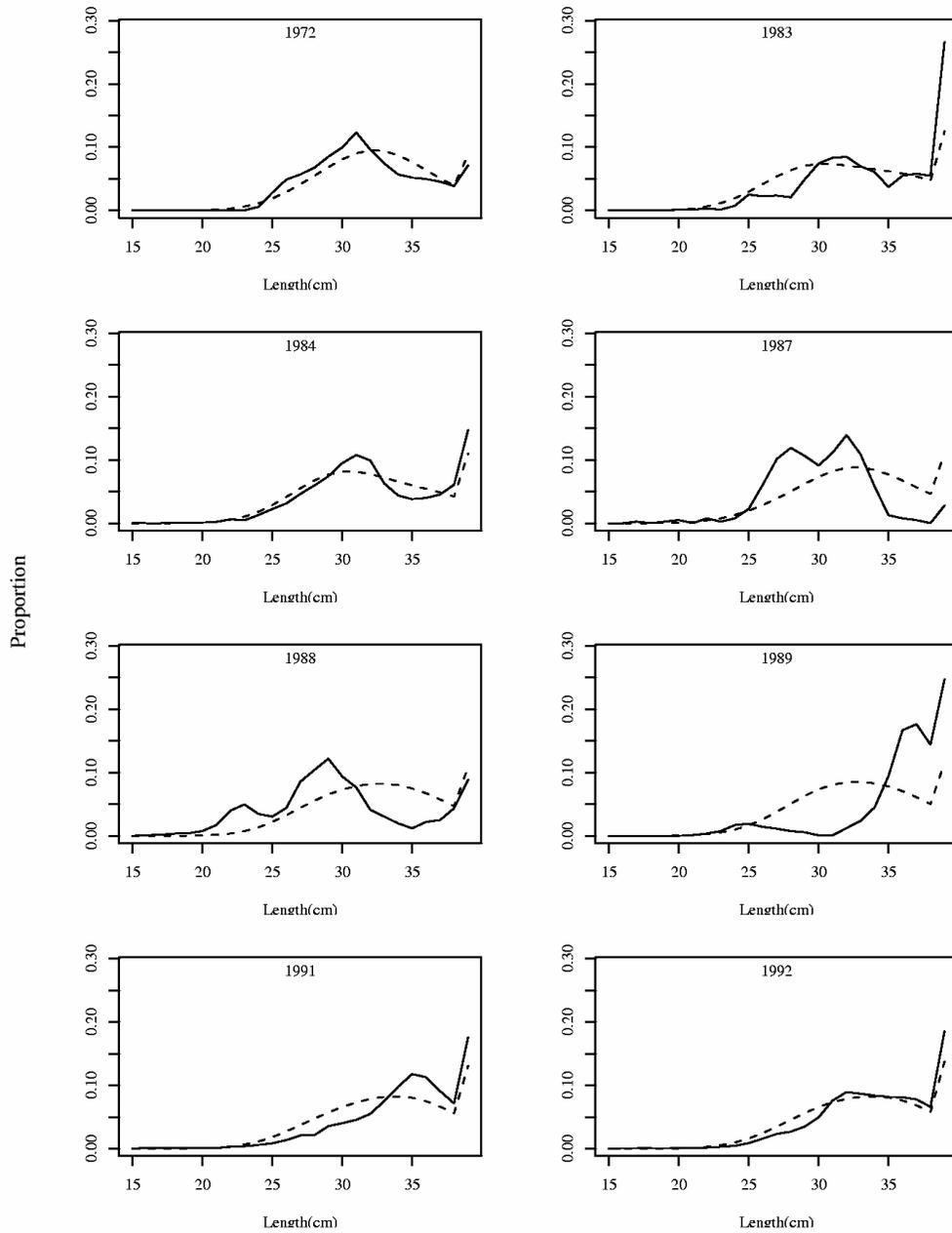


Figure 11.7 (continued). Fishery length composition by year (solid line = observed, dotted line = predicted)

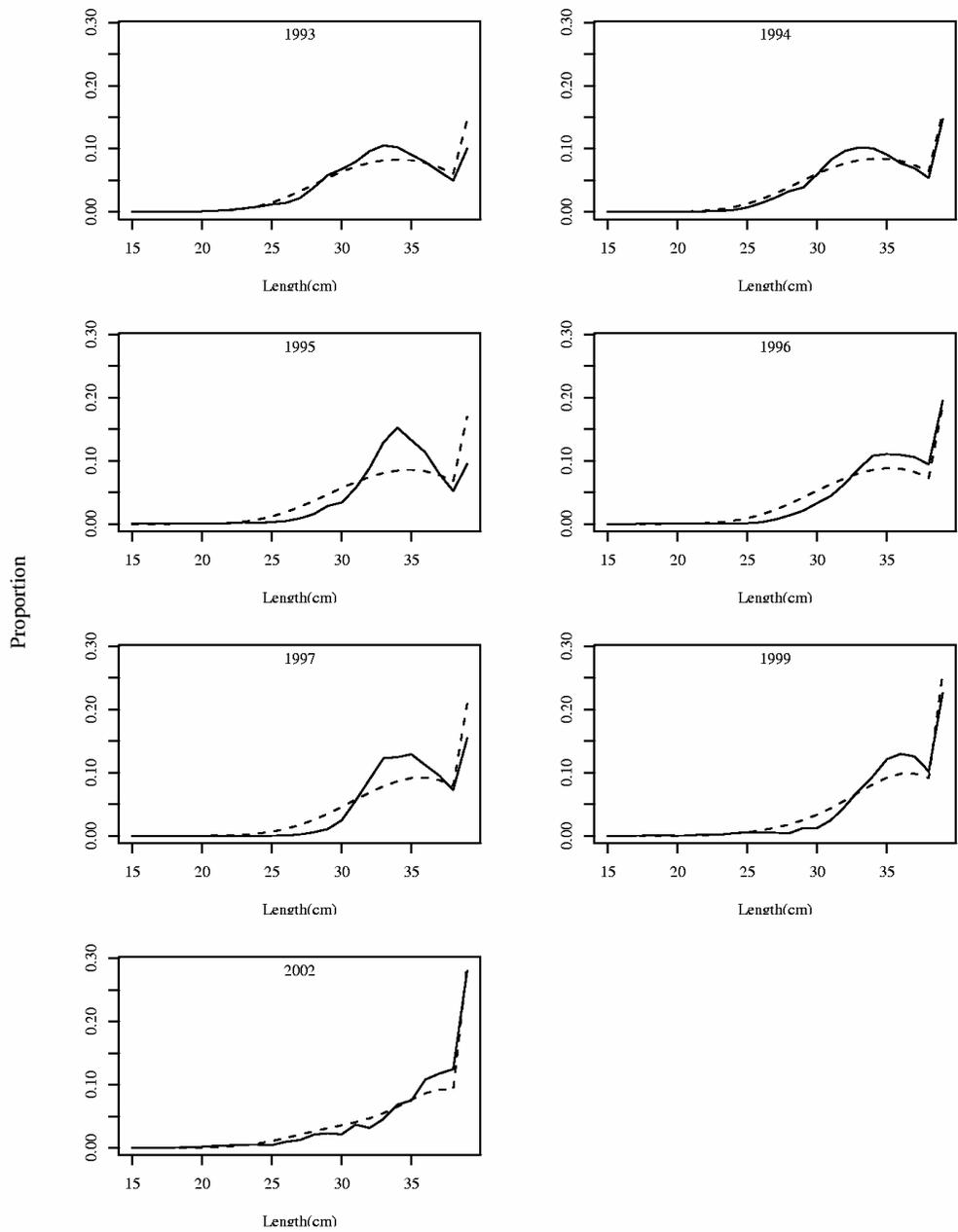


Figure 11.7 (continued). Fishery length composition by year (solid line = observed, dotted line = predicted)

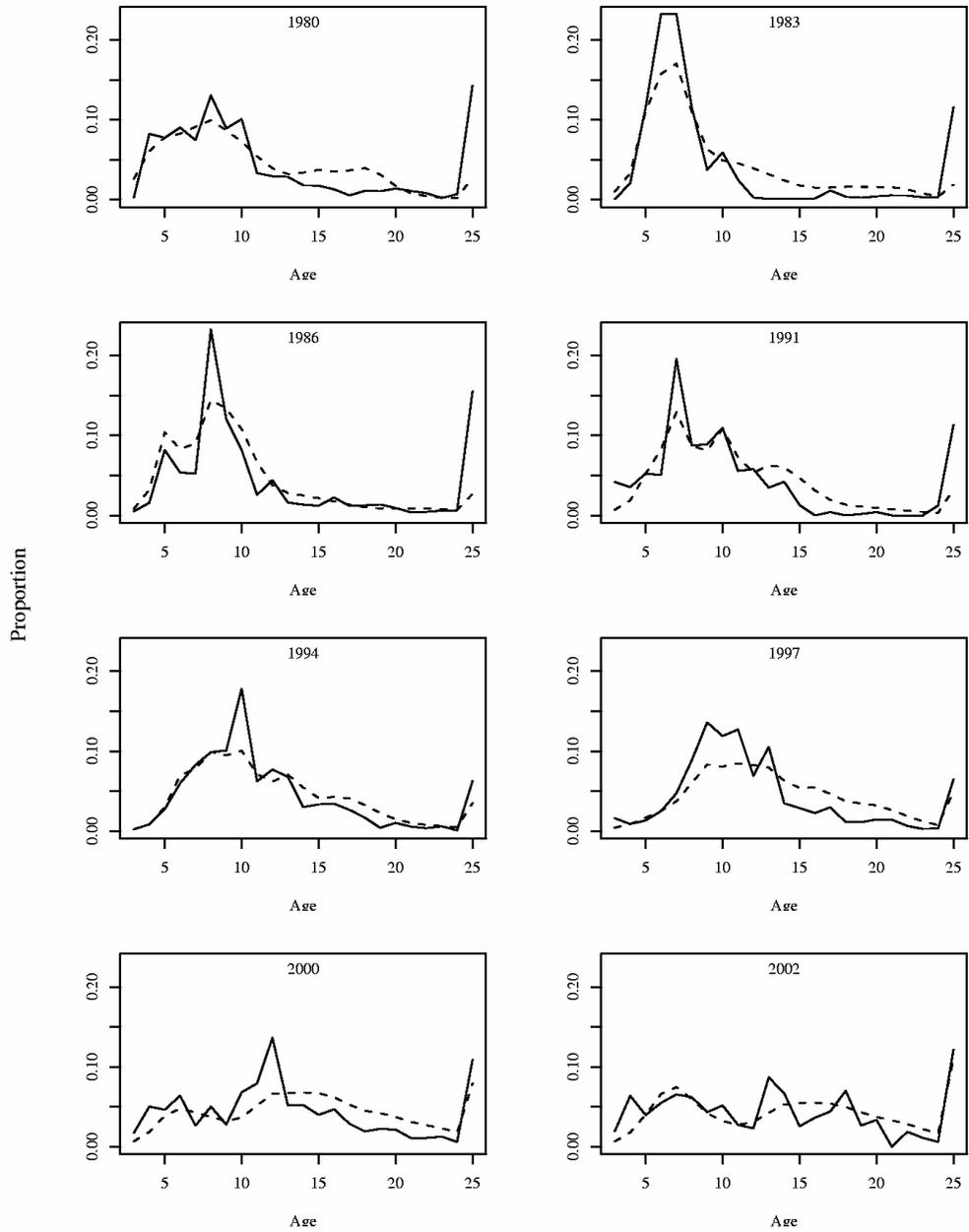
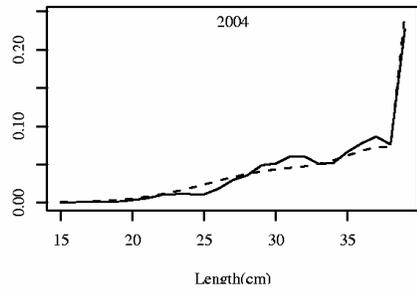


Figure 11.8. AI Survey age composition by year (solid line = observed, dotted line = predicted)



Proportion

Figure 11.9. AI Survey length composition by year (solid line = observed, dotted line = predicted)

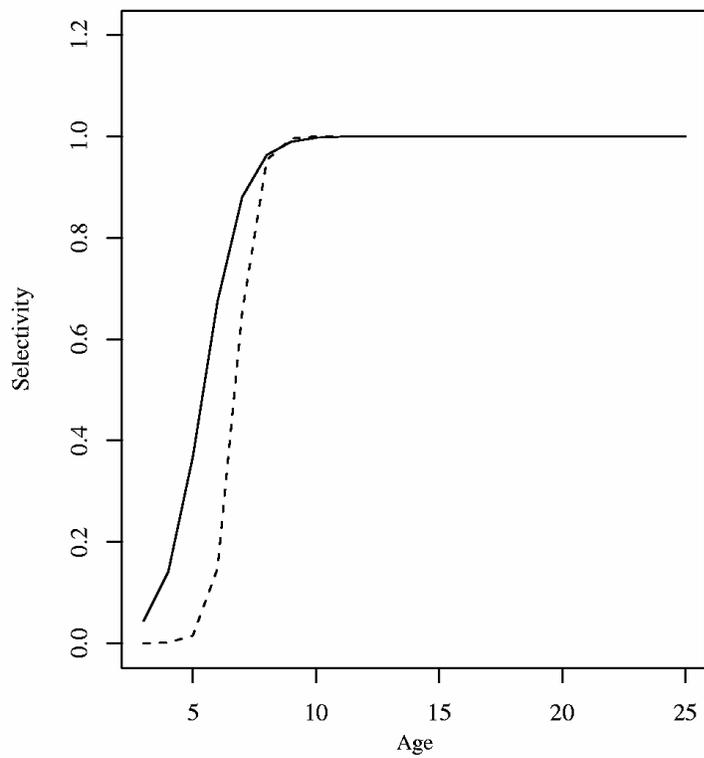


Figure 11.10. Estimated survey (solid line) and fishery (dashed line) selectivity curves for BSAI POP

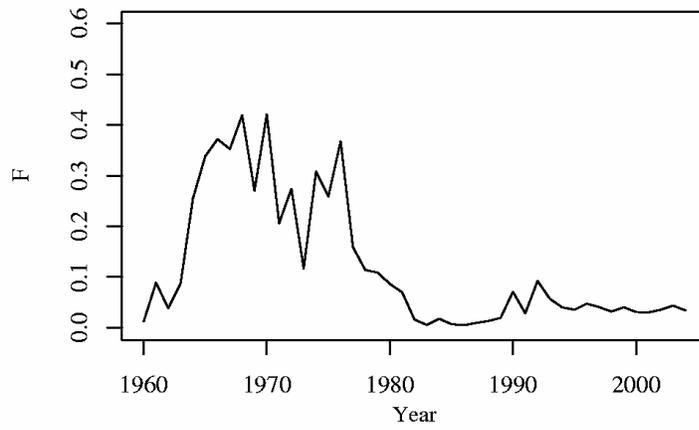


Figure 11.11. Estimated fully selected fishing mortality for BSAI POP.

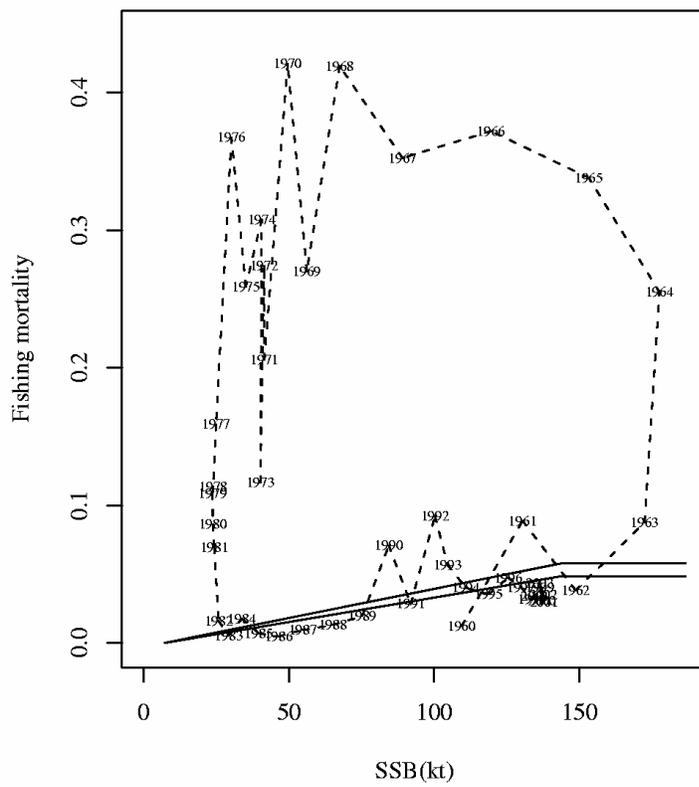


Figure 11.12. Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules

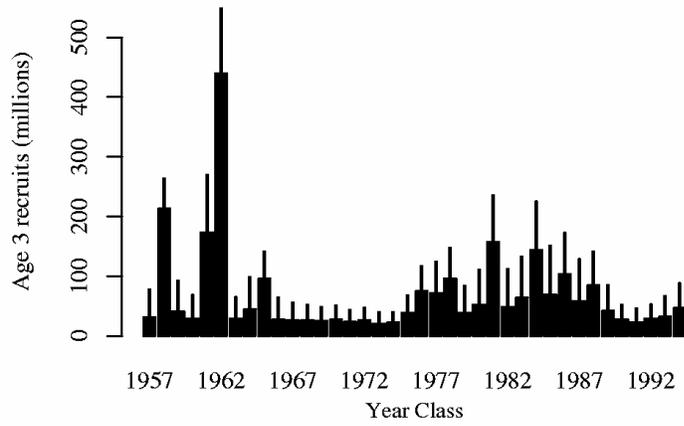


Figure 11.13. Estimated recruitment (age 3) of BSAI POP, with 95% CI limits obtained from MCMC integration.

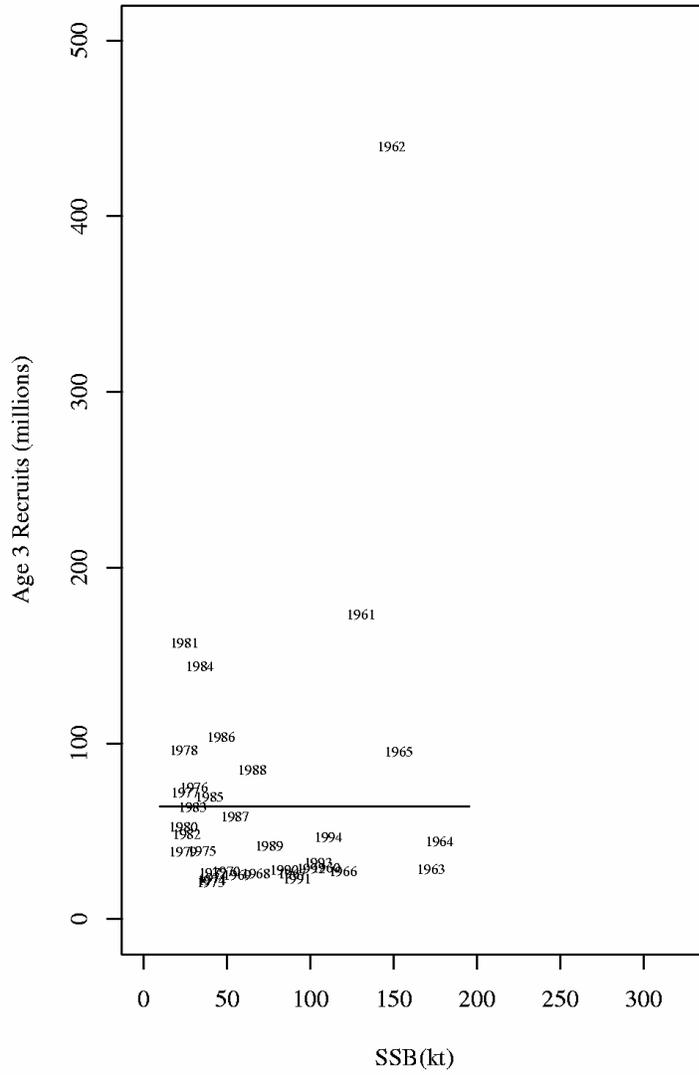


Figure 11.14. Scatterplot of BSAI POP spawner–recruit data; label is year class.

Appendix: The effect of maternal age of spawning on estimation of F_{msy} for Bering Sea/Aleutian Islands Pacific ocean perch.

The degree of conservation provided by current harvest strategies for Alaskan rockfish have received attention in recent years, and have prompted requests from the SSC for an evaluation of rockfish harvest strategies. An analysis which calculates F_{msy} for Bering Sea/Aleutian Islands Pacific ocean perch (POP) using Bayesian estimation techniques was presented to the SSC in December, 2003, with the conclusion that the existing stock-recruitment data and estimates of stock productivity do not suggest that the existing harvest control rules are unduly aggressive. The analysis used spawning stock biomass (SSB) as the measure of reproductive capacity, and implicitly assumed that populations with the same SSB are equivalent in terms of their reproductive capacity.

Recent research suggests that the reproductive capacity of rockfish populations is a function not only of the total SSB, but also the age structure of the population. In laboratory experiments with black rockfish (*Sebastes melanops*), Berkeley et al. (2004a) found that larval survival immediately following parturition increased with the maternal age, with older females producing larger oil globules in the larvae. The purpose of this appendix is to update the analysis presented to the SSC in December, 2003, by considering the effect of larval mortality on the estimation of stock productivity. First, we describe how relationships regarding fecundity and larval survival are developed based upon data from other regions. Second, we describe the methodology regarding Bayesian estimation of stock-recruitment parameters. Finally, we compare estimates of F_{msy} that explicitly consider maternal age-related differences in larval survival rates to estimates of F_{msy} obtained by using simply SSB.

Estimation of fecundity and larval survival

Little information is available regarding fecundity and the larval survival rates of Alaskan POP, and the approach taken here was to infer these relationships based upon work in other areas. Hart (1973) states that the fecundity of POP is 31000 at 32 cm and 7 years, and 305,000 at 44 cm and 20 years. Additionally, Leaman (1991) developed a fecundity-age relationship that suggests POP in a lightly exploited population would reach an asymptote of approximately 350,000 eggs at older ages. Phillips (1964) presents the fecundity-length relationships for 10 species of rockfish off the US west coast, and the species most closely matching the observations of Leaman (1991) and Hart (1973) were splitnose rockfish, for which a maximum fecundity of 304,000 eggs for a 346 mm fish was observed; the minimum and maximum lengths for which fecundity was observed were 195 mm and 365 mm, respectively. A fecundity at length relationship for Alaskan POP was developed by increasing the original splitnose rockfish length measurements by 30 mm to adjust for the larger size of POP. The original splitnose data, the fecundity-length relation for the splitnose rockfish data, and the adjusted fecundity-length relation used for POP are shown in Figure A.1; the corresponding fecundity at age relationship used for POP is shown in Figure A.2.

Berkeley et al. (2004a) develop an asymptotically increasing relationship between the length of time required for 50% mortality of black rockfish larvae and maternal age, suggesting that older black rockfish produce larvae with higher survival rates. A modified form of this relationship was used to model larval mortality rate for POP (Figure A.3). Relative to black rockfish, POP have both an older generation time and age at maturity. For example, the youngest black rockfish for which spawning was observed by Berkeley et al (2004) was 5 years,

whereas the youngest age of spawning for POP in the Gulf of Alaska is approximately 7 years (Hanselman et al. 2003). Although the larval mortality rates for black rockfish begins to approach values very close to the asymptote at approximately 14 years, it is hypothesized here that the larval mortality rate for POP ocean perch would approach their asymptote at older ages because of their longer generation time. The larval mortality curve for POP thus had a higher x-intercept and lower slope to reflect these considerations (Figure A.3). The larval mortality curve was then used to compute the instantaneous daily larval mortality rate as a function of maternal age, which was used to calculate the proportion of larvae surviving two weeks (Figure A.4). The fecundity and larval survival curves were applied to the age structure of the population from 1960-1994 (obtained from the 2004 stock assessment) to calculate the time series of two-week old larvae. The two-week period was arbitrarily chosen so as to provide some contrast in the larval survival rates of POP females, and the two-week old larvae are used here as an index of the “viable” reproductive output and used in the spawner-recruit analysis.

Bayesian stock-recruit model

The Beverton-Holt curve was re-parameterized using R_0 , the expected recruitment consistent with the reproductive capacity of an unfished stock S_0 (measured in viable larvae), and a parameter that measures the resiliency of the stock, h , defined as the proportion of R_0 that recruits when the reproductive capacity of the stock is reduced to 20% of S_0 (i.e., the “steepness” parameter of Mace and Doonan (1988)). The Beverton-Holt curve with these new parameters is given by

$$R = \frac{0.8 R_0 h S}{0.2 \varphi_0 R_0 (1 - h) + (h - 0.2) S},$$

where $S_0 = \varphi_0 R_0$, and φ_0 is viable larvae per recruit for an unfished stock, which is estimated independently by conventional larvae per recruit equations. Steepness ranges between 0.2 (recruits related linearly to viable larvae) to 1.0 (recruits independent of larvae).

Variability around the stock-recruit relationship was assumed lognormal. The assumption of lognormal errors in S-R models is based on both theoretical considerations (Hilborn and Walters 1992) and empirical studies (Peterman 1981, Myers et al. 1995). A lognormal probability density for recruitment is

$$p(R/\hat{R}(S, R_0, h), \sigma^2) = \frac{1}{R \sqrt{2\pi} \sigma} \exp \left[-\frac{1}{2\sigma^2} \left(\log R - \log \hat{R} + \frac{\sigma^2}{2} \right)^2 \right],$$

where $\hat{R}(S, R_0, h)$ is the expected recruitment as a function of the S-R parameters and spawning biomass, and σ^2 is a shape parameter. Note that the mean of the lognormal variate is used here rather than the usual parameterization with the median, $m = \hat{R} \exp(-\sigma^2/2)$.

There are three parameters for which priors need to be developed, R_0 , h , and σ^2 . The prior

for steepness was modeled by assuming the logit of h was normally distributed (after rescaling h into the interval $(0,1)$, $(h_k - 0.2) / 0.8$, and simplifying),

$$\beta = \log\left(\frac{h - 0.2}{1 - h}\right), \beta \sim N(\mu, \xi^2).$$

For h in the interval $(0.2, 1.0)$, the logit β ranges from $-\infty$ to $+\infty$. The use of the logit transformation makes it straightforward to specify a prior mean and variance.

A normal prior was used for R_0 ,

$$R_0 \sim N(\bar{R}_0, \omega^2),$$

where \bar{R}_0 is prior mean, and ω^2 is the prior variance. For σ^2 , a locally uniform prior for σ on a log scale was used. The negative log-likelihood is proportional to

$$-\log L_1 = \sum_i \frac{(\log R_i - \log \hat{R}_i(S_i, R_0, h) + \sigma^2 / 2)^2}{2\sigma^2} + n \log \sigma.$$

Note that we assume no correlation in recruitment and no error in estimates of viable larvae, i.e., the usual simplifying assumptions in analyses of S-R data.

The negative log-prior is proportional to

$$-\log L_2 = \frac{1}{2\xi^2} (\beta - \mu)^2 + \frac{1}{2\omega^2} (R_0 - \bar{R}_0)^2.$$

The log joint posterior distribution is the sum of the log-likelihood and the log prior,

$$L = \log L_1 + \log L_2.$$

The mode of the joint posterior distribution was obtained using the AD Model Builder nonlinear optimization software (Otter Research 1996).

Obtaining posterior distributions using the Markov Chain Monte Carlo algorithm

To estimate F_{MSY} , the marginal posterior distribution of the stock-recruit parameters is needed, obtained by integrating joint posterior distribution with respect to the other parameters. Rather than attempting to evaluate this integral analytically, we used a MCMC algorithm to obtain random samples from the joint distribution. From these samples it is an easy matter to

obtain empirical histograms that approximate the marginal distribution of any parameter of interest. The MCMC algorithm generates a Markov chain of random samples (i.e., each sample is conditionally dependent on the preceding sample) whose stationary distribution is the joint posterior distribution. Gelman et al. (1995) provides a good introduction to MCMC methods, including the Hastings-Metropolis algorithm provided in the AD Model Builder software (see 30 January 1998 <http://otter-rsch.com/cc/cctoc.html> for additional details). Marginal posterior distributions were obtained by subsampling every 1000th sample from a chain of length 1,000,000 of the MCMC algorithm after discarding the first 50,000 cycles.

Estimates of F_{MSY}

Let $h_{(C)}$, $R_{0(C)}$ be a sample of the stock-recruit parameters from the joint posterior distribution generated by the MCMC algorithm. For each sample, the equilibrium recruitment $R^{EQ}(p)$ is obtained for a sequence of harvest rates where larvae per recruit (LPR) is reduced to a fraction p of unfished LPR ($p = 1.00, 0.99, 0.98, \dots, 0.10$),

$$R^{EQ}(p) = \max \left(0, R_{0(C)} \frac{0.8 h_{(C)} p - 0.2 (1 - h_{(C)})}{p (h_{(C)} - 0.2)} \right).$$

Some combinations of LPR rate and sampled stock-recruit parameters result in negative equilibrium recruitment, indicating that the LPR rate is not sustainable--hence the use of the *max* function in the above equation.

Equilibrium yield, $Y^{EQ}(p)$, and equilibrium viable larvae, $L^{EQ}(p)$, at LPR rate p are

$$Y^{EQ}(p) = \eta_p R^{EQ}(p), \text{ and}$$

$$L^{EQ}(p) = p \varphi_0 R^{EQ}(p),$$

where η_p is the yield per recruit when LPR is reduced to a fraction p of unfished LPR.

F_{MSY} can be regarded as the fishing mortality rate at which expected yield is maximized,

$$LPR_{F_{MSY}} = \max_p E(Y^{EQ}(p)).$$

The expected yield at a particular LPR rate is obtained by averaging the equilibrium yield for each of the MCMC samples drawn from the joint posterior distribution.

Extension to the Ricker stock-recruit curve

Kimura (1988) re-parameterized the Ricker curve in relation to R_0 , the expected recruitment for an unfished stock S_0 , and a curvature parameter, α . The Ricker curve with

parameters R_0 and α is

$$R = \frac{S}{\varphi_0} \exp \left[\alpha \left(1 - \frac{S}{R_0 \varphi_0} \right) \right].$$

Note that e^α is the potential increase in reproductive success relative to an unfished stock, so that additive changes in α imply multiplicative changes in reproductive success at low levels of reproductive capacity. We modeled the prior distribution for the curvature parameter with a normal distribution,

$$\alpha \sim N(\mu, \tau^2).$$

Values for μ and τ^2 were the same as those developed for the Beverton-Holt curve.

Equilibrium recruitment for the Ricker curve is given by

$$R^{EQ}(p) = \frac{R_0}{p} \left(1 + \frac{\log p}{\alpha} \right).$$

Finally, as a basis for comparison it is useful to carry out the stock-recruitment analysis with spawning stock biomass as the measure of reproductive capacity. The equations above are identical with the only change being in the units of reproductive capacity and the equilibrium spawner-per-recruit equations.

Specification of prior means and variances

A Bayesian analysis is a formal process for combining prior knowledge with data, with the data dominating posterior distribution when they are highly informative. We developed priors for β and α that are consistent with perceptions of rockfish productivity and proxies used to manage tier 3 stocks; the prior for R_0 was based upon estimates of this parameter in the most recent assessment.

Priors for β and α

The derivation of $F_{35\%}$ as a proxy for F_{MSY} is from a theoretical analysis by Clark (1991). Clark initially considered S-R curves the Beverton-Holt and Ricker models that differed by the potential increase in reproductive success (R/S at the origin) relative to an unfished stock (R_0/S_0). Potential increases in reproductive success by factors of 4, 8, and 16 (steepness = 0.50, 0.67, and 0.80, respectively) were considered plausible, while factors of 2 and 32 (steepness = 0.33, and 0.89, respectively) were considered implausible. Dorn et al (2003) generated a prior distribution from these considerations by using a potential increase in reproductive success of 8 ($\beta = 0.34$) as the midpoint of the distribution, and setting the prior variance so that factors 4 and 16 were located at the 10th and 90th percentiles of the distribution.

For BSAI POP, the same variance was used but the midpoint of the distribution was lowered to reflect a potential increase in reproductive success of 4 ($\beta = -0.51$), thus reflecting the perceived lower productivity of rockfish relative to the values considered by Clark 1991 (Table A.1). The midpoint of this distribution corresponds to a steepness of 0.50, closer to the value of 0.39 found for five rockfish stocks in a meta-analysis by Myers et al. (1999). The variance of the prior for α was also taken from Dorn et al (2003), with the midpoint lowered to correspond to a potential maximum increase in reproductive success of 4 rather than 8, yielding a level of α of 1.386.

Prior for R_0

The estimated level of age-3 recruits consistent with the stock size in the first year of the model, obtained from the 2004 BSAI POP assessment, was 0.0205 billion fish, and was used as the midpoint of the prior distribution for R_0 . A relatively large coefficient of variation of 0.22 is used for this prior distribution.

Results

An interesting intermediate result of this analysis is the calculation of the fishing mortality rates that would conserve a certain percentage of either the spawning stock biomass or the viable larvae relative to an unfished population, and the fishing mortality rates as a function of the percentage conserved for these two measures of reproductive output is shown in Figure A.5. The additional level of conservation provided by preserving unfished viable larvae increases as the target percentage of the unfished stock decreases; at $F_{40\%}$ the difference between conserving spawning stock biomass or viable larvae translates to F rates of 0.048 and 0.040, respectively. Of course, these calculations assume an equilibrium population with no reductions in recruitment with increasing fishing rates.

Fits of the Beverton-Holt and Ricker models to the viable larvae and recruitment data are shown in Figure A.6. The Ricker curve is dome-shaped with a slightly lower slope at the origin and R_0 than the Beverton-Holt curve, and predicts considerably larger recruitment than the Beverton-Holt model for most values of viable larvae. The estimate of steepness and R_0 were approximately 6% and 41% larger, respectively, in the Beverton-Holt model as compared to the Ricker model (Table A.2). Fits of the Beverton-Holt and Ricker models to the spawning stock biomass and recruitment data show a similar patterns to that seen with the viable larvae data (Figure A.7), with the estimates of steepness and R_0 being approximately 8% and 18% larger in the Beverton-Holt model. The estimates of F_{msy} in the four stock-recruitment models range from 0.081 to 0.121, higher than the currently used reference point of $F_{40\%}$ (based on spawning stock biomass) of 0.048.

The posterior distributions of β for the Beverton-Holt curve and α for the Ricker curve have higher means and lower variances than their prior distributions, indicating that the stock-recruitment data for BSAI Pacific ocean perch are informative regarding the rate of recruitment at low stock sizes (Figure A.8). This information results from the relatively large recruitments in the 1981, 1984, and 1986 year classes, which were produced from relatively small spawning stock sizes.

The slight difference in the estimated F_{msy} for each model type between the two different measures of reproductive capacity suggest that viable larvae is linearly related to spawning stock biomass, as shown in Figure A.8. The strong recruitments in the early 1960s contributed younger spawners to the population and led to spawning stock biomass increasing faster than viable larvae. The heavy fishing in the beginning in the mid 1960s rapidly reduced both the

spawning stock biomass and viable larvae. Lower levels of fishing mortality beginning in the early 1980s, coupled with strong recruitments from several year classes in the early to mid-1980s, have allowed the accumulation of fish in the 25+ group, accounting for the faster increase in viable larvae relative to SSB in recent years.

Some Tentative Conclusions

Based on the Bayesian analysis using either measure of reproductive capacity, the use of $F_{35\%}$ as a proxy for F_{MSY} appears to be consistent with the available stock recruitment data for BSAI POP. The results of this analysis are consistent with a meta-analysis of rockfish stock recruitment data (Dorn 2002), which found that expected equilibrium yield of Aleutian Islands POP (at that time, Aleutian Islands POP were assessed separately from eastern Bering Sea POP) was maximized at fishing SPR rates of $F_{26\%}$ to $F_{29\%}$, depending upon model form and error structure. The stock-recruitment data are relatively informative regarding the resilience of this stock and do not suggest that harvest rates of $F_{35\%}$ and $F_{40\%}$ are too aggressive; sensitivity analysis using alternative prior distributions with higher levels of α and β consistent with the midpoint of Clark's (1991) analysis produced results nearly identical to those presented here.

The observed resiliency of the BSAI POP is largely influenced by several strong year-classes in the early 1980s, and it is not clear whether this observed resiliency reflects an inherent density-dependent response of these stocks or climatic conditions during this time period in Alaskan waters. Dorn's (2002) meta-analysis focused primarily upon west coast rockfish stocks and found that resiliency for rockfish was lower than that observed for other taxonomic groups such as gadids and clupeids, although the recruitment declines for west coast rockfish also correspond to decreased productivity of the California current (McGowen et al. 1998). If rockfish stock-recruitment patterns are strongly influenced by environmental factors, the observation of Dorn (2002) that Alaskan POP show greater resiliency than many of the west coast rockfish may reflect the generally inverse relation between west coast and Alaskan oceanic production. A related concern is the autocorrelation in the residuals of the stock-recruitment fits, suggesting other factors beyond spawning stock biomass are influencing recruitment dynamics.

The estimates of viable larvae are necessarily obtained from the current stock assessment model, as fishery-independent estimates of the age-structure of the population in the 1960s do not exist. Ages greater than or equal to 25 were binned into a single age group within the model, as POP older than this vary little in length and thus pose difficulties in inferring age composition from length composition. It is possible that the effects of truncation of the age structure are masked by the coarse binning of older fish into the 25+ group. The degree to which this may become important is dependent upon the nature of the larval survival curve and how quickly this curve reaches values close to its asymptote before the maximum age. Further research on the shape of this curve for POP may be useful, in addition to modeling efforts that evaluate robust proxies for F_{msy} (analogous to the $F_{xx\%}$ proxies developed for conserving spawning stock biomass) that consider a variety of possible forms of larval survival rates.

The most appropriate use of this examination of harvest policy is not to suggest the use of a specific point estimate of F_{msy} , but rather use these results in a qualitative sense to evaluate the level of conservatism in the current harvest policy. The available data for BSAI POP do not suggest that current harvest policy control rules that have maximum harvest rates of either $F_{35\%}$ or $F_{40\%}$ are too aggressive, despite the use of prior information incorporating the perceived low rockfish productivity. It is important to note that the current control rules use these proxies as upper bound for stocks that are above $B_{40\%}$, and reduction in harvesting rates from these proxies

occur if the stock is reduced to below $B_{40\%}$.

As with other groundfish stocks, caution should be exercised in developing rockfish harvest policies because of the largely unknown role of environmental variability and the mechanisms by which they may affect rockfish recruitment. Specifically, it is unclear how likely strong recruitments at low stock sizes will be in future years under differing environmental regimes. This modeling exercise was an attempt to examine more closely one factor that may be important to rockfish recruitment, and it should be recognized that many other important factors exist. For example, Berkeley et al. (2004b) note that variability in the timing and location of spawning by age class can serve as a bet-hedging mechanism that allows rockfish to survive long periods of unproductive oceanic conditions, and investigation of these factors represent important future research topics.

REFERENCES

- Berkeley, S.A., C. Chapman, and S.M. Sogard. 2004a. Maternal age as a determinant in the growth and survival in a marine fish, *Sebastes melanops*. *Ecology* 85:1258-1264.
- Berkeley, S.A., M.A. Hixon, R.J. Larson, and M.S. Love. 2004b. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries* 29(8):23-32.
- Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. *Can. J. Fish. Aquat. Sci.* 48:734-750.
- Dorn, M.W. 2002. Advice on west coast rockfish harvest rates from Bayesian meta-analysis of stock-recruit relationships. *N. Am. J. Fish. Man.* 21:280-300.
- Dorn, M, S. Barbeaux, M. Guttormsen, B. Megrey, A. Hollowed, M. Wilkins, and K. Spalinger. 2003. Assessment of walleye pollock in the Gulf of Alaska. In *Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska*, Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.
- Gelman, A., J.B. Carlin, H.S. Stern, and D.A. Rubin. 1995. *Bayesian data analysis*. Chapman and Hall, New York.
- Hanselman, D., J. Heifetz, J.T Fujioka, and J.N. Ianelli. 2003. Pacific ocean perch. In *Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska*, as projected for 2004, pp 429-479. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.
- Hart, J.L. 1973. *Pacific fishes of Canada*. Fisheries Research Board of Canada, Bulletin 180. 741 pp.
- Hilborn, R. and C.J. Walters. 1992. *Quantitative fisheries stock assessment: choice, dynamics, and uncertainty*. Chapman and Hall, New York. 570 pp.
- Kimura, D.K. 1988. Stock-recruitment curves used in the stock reduction analysis model. *Journal du Conseil, International Council for the Exploration of the Sea* 44:253:258.
- Leaman, B.M. 1991. Reproductive styles and life history variables relative to exploitation and management of *Sebastes* stocks. *Env. Biol. Fish.* 30:253-271.
- Mace, P.M. and I.J. Doonan. 1988. A generalized bioeconomic simulation model for fish population dynamics. *New Zealand Fishery Assessment Research Document No 88/4*.
- McGowen, J.A., D.R. Cayan, and L.M. Dorman. 1998. Climate-ocean variability and ecosystem response in the northeast Pacific. *Science* 281:210-217.

- Myers, R.A., K.G. Bowen, and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population size. *Can J. Fish. Aquat. Sci.* 56:2404:2419.
- Myers, R.A., A.J. Bridson, and N.J. Barrowman. 2002. summary of worldwide stock and recruitment data. *Can. Tech. Rep. of Fish. and Aquat. Sci.* 2024.
- Otter Research. 1996. An introduction to AD Model Builder. PO Box 2040, Sidney, B.C. V8L 3S3 Canada.
- Peterman, R.M. 1981. Form of random variation in salmon smolt-to-adult relations and its influence on production estimates. *Can. J. Fish. Aquat. Sci.* 38:1113-1119.
- Phillips, J. B. 1964. Life history studies on ten species of rockfish (genus *Sebastes*). *Calif. Dept. Fish and Game, Fish Bull.* 126, Sacramento, CA, 70 p.

Table A.1. Prior values used in a Bayesian analysis of BSAI POP stock-recruit data.

S-R model	β or α mean	β or α standard deviation	R_θ mean	R_θ CV
Beverton Holt	-0.51	0.63	0.02052	0.22
Ricker	1.386	0.54	0.02052	0.22

Table A.2. Posterior means of S-R and management parameters for a Bayesian analysis of BSAI POP stock-recruit data. For the Ricker model, the reported steepness is given by $h = \exp(\alpha)/(\exp(\alpha) + 4)$, which is the steepness of a B-H curve with the same slope at the origin as the Ricker curve. F_{MSY} is defined as the fishing mortality rate at which expected yield is maximized, considering uncertainty in the S-R relationship.

S-R model	Reproductive			Percent unfished	
	Measure	steepness	R₀ (billion)	F_{msy}	SPR or LPR at $F_{msy\%}$
Ricker	Viable larvae	0.84	0.027	0.120	12
Ricker	SSB	0.79	0.032	0.121	17
Beverton Holt	Viable larvae	0.89	0.038	0.081	20
Beverton Holt	SSB	0.85	0.038	0.084	25

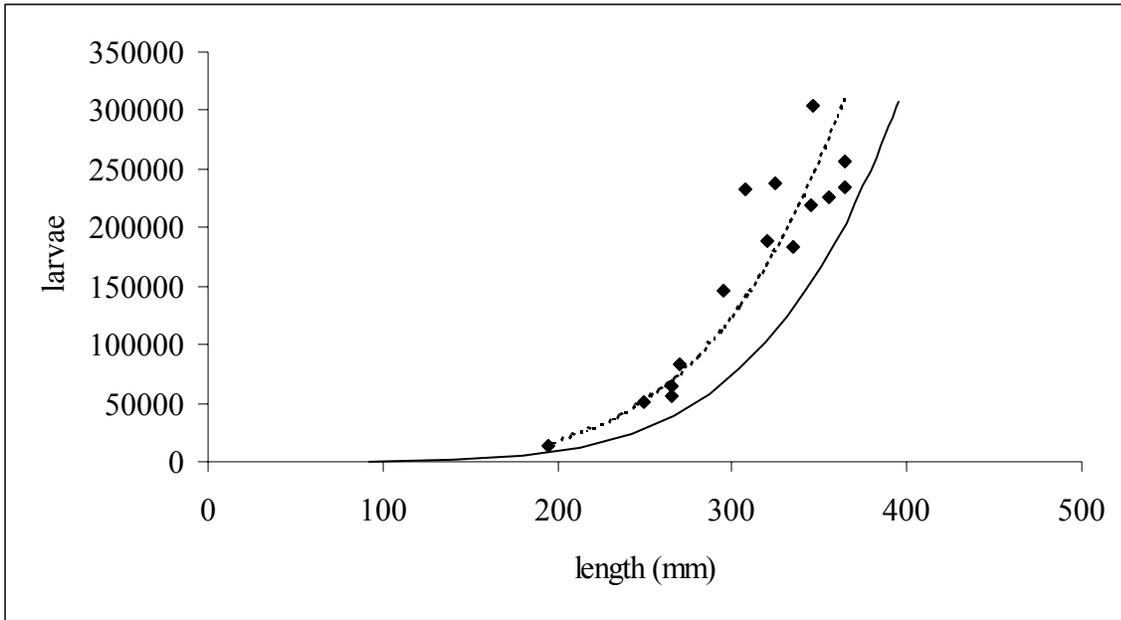


Figure A.1 Relationships between larval production and length for splitnose rockfish (data points and dashed line) and hypothesized for POP (solid line).

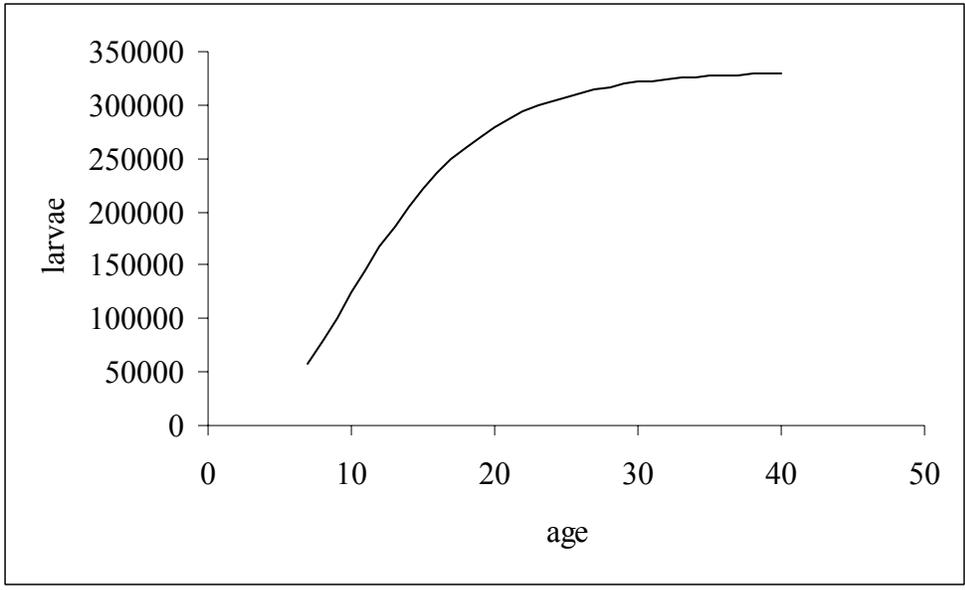


Figure A.2. Hypothesized relationship between larval production and age for POP.

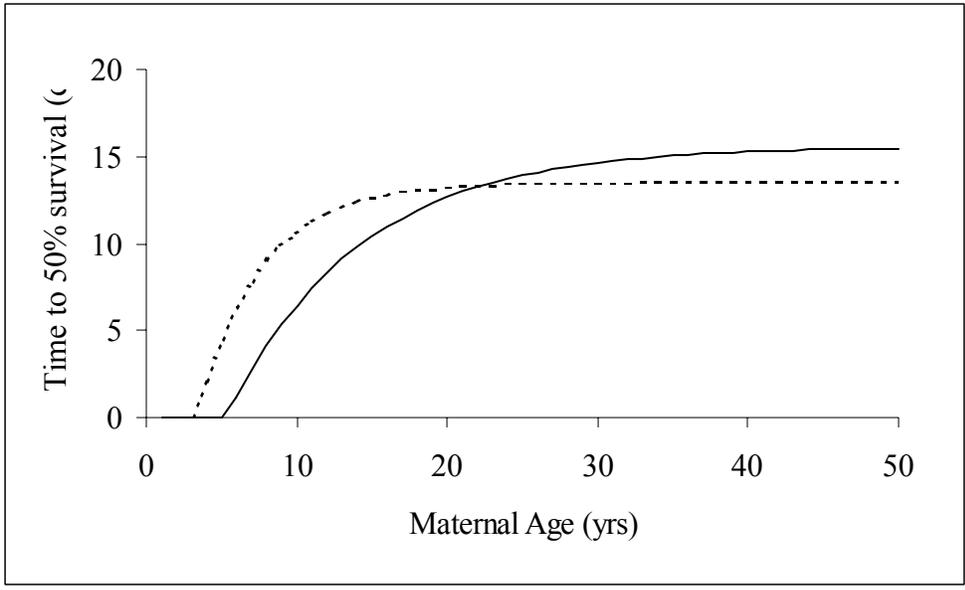


Figure A.3. Time to 50% survival observed by Berkeley (2004a) for black rockfish (dashed line) and hypothesized relationship for POP (solid line).

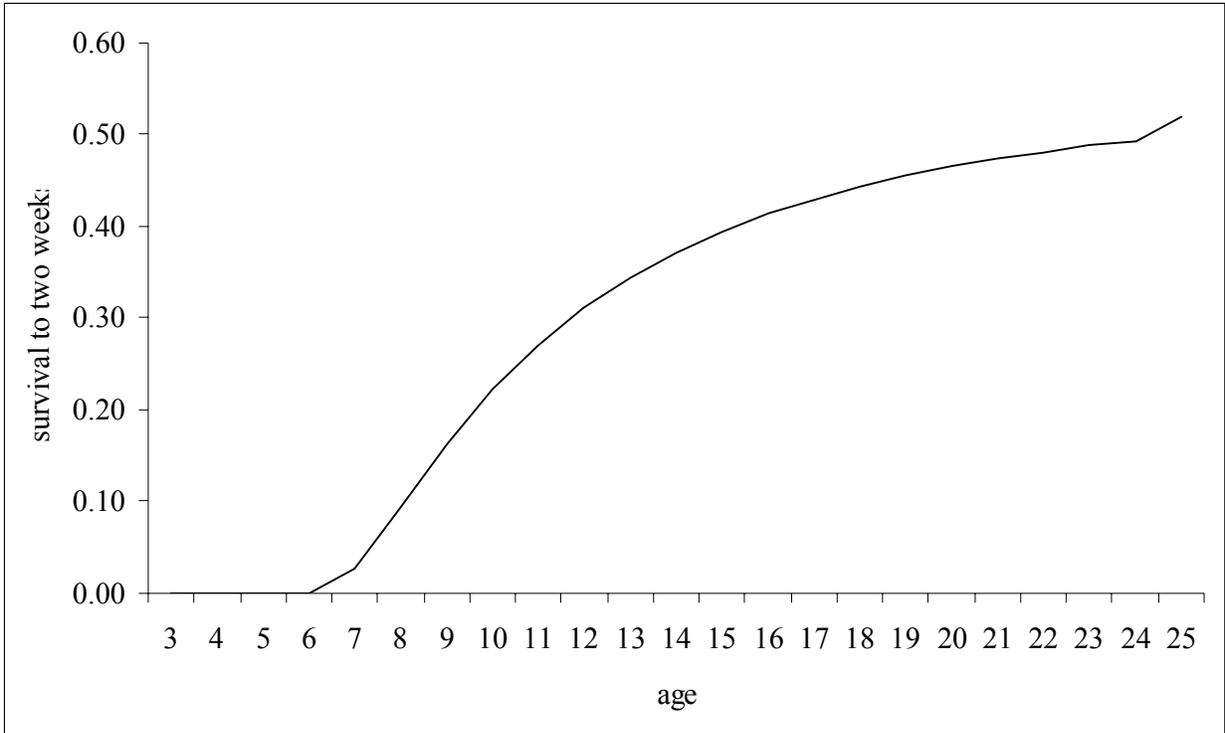


Figure A.4. Hypothesized relationship between proportion of larvae surviving to two weeks as a function of maternal age.

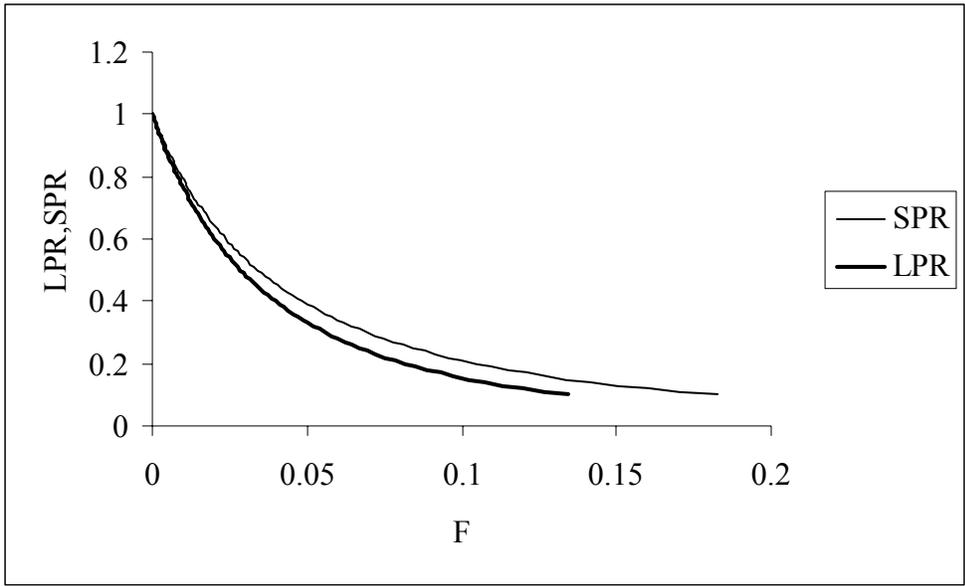


Figure A.5. Fishing mortality rates associated with conserving proportions of unfished larval per recruit (LPR) and spawning biomass per recruit (SPR).

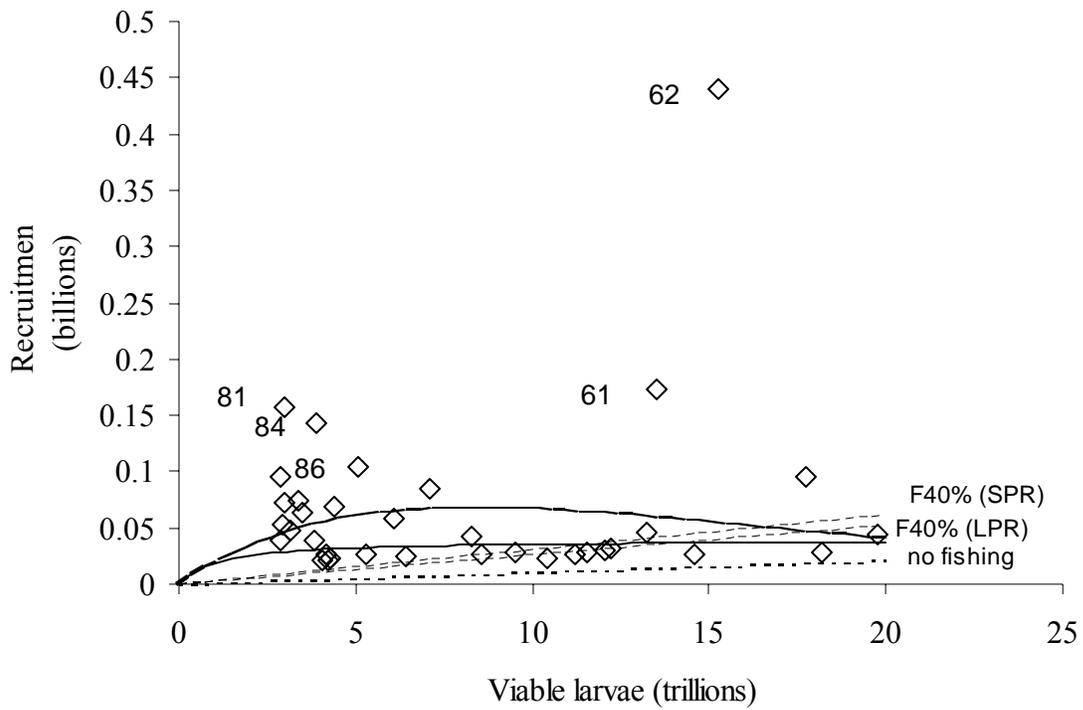


Figure A.6. BSAI POP stock-recruit estimates, and mean stock-recruit curves based on posterior parameter means for Beverton-Holt (solid line) and Ricker (dashed line) models, with reproductive capacity measured as viable larvae. The replacement lines for no fishing and F40% (based on either spawner per recruit or larvae per recruit analyses) are shown with dotted lines, and the labels are year classes.

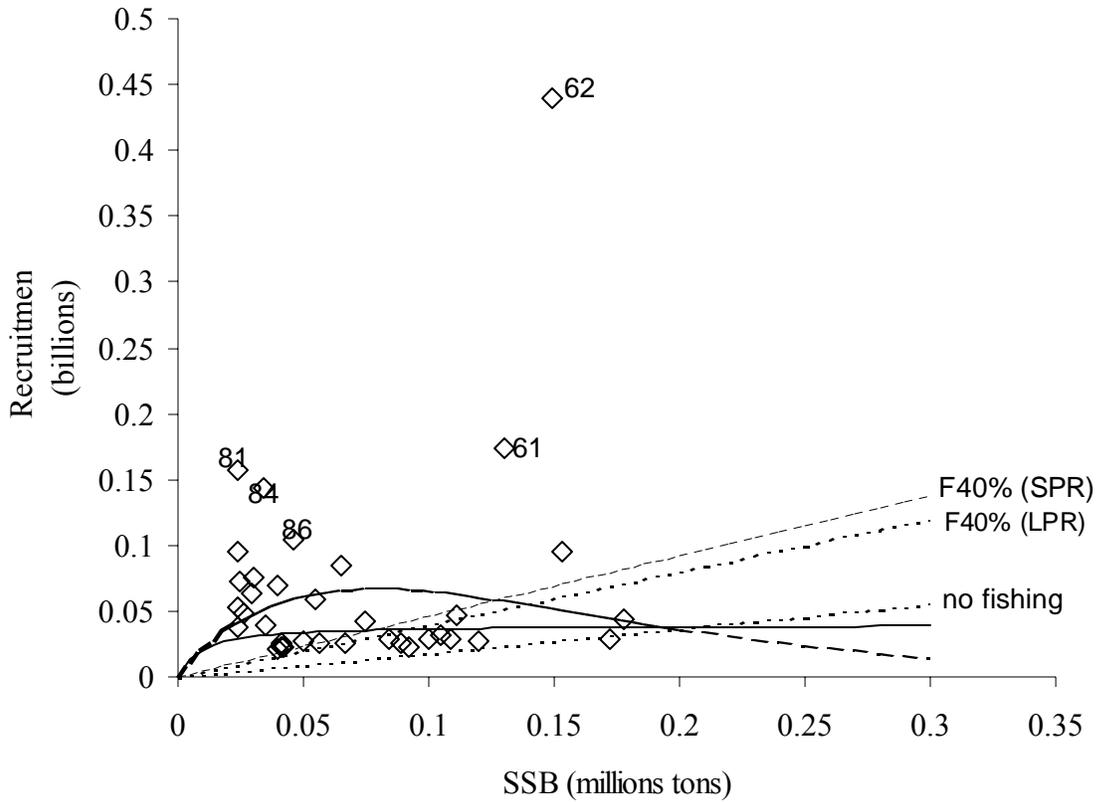


Figure A.7. BSAI POP stock-recruit estimates, and mean stock-recruit curves based on posterior parameter means for Beverton-Holt (solid line) and Ricker (dashed line) models, with reproductive capacity measured as spawning stock biomass. The replacement lines for no fishing and F40% (based on either spawner per recruit or larvae per recruit analyses) are shown with dotted lines, and the labels are year classes.

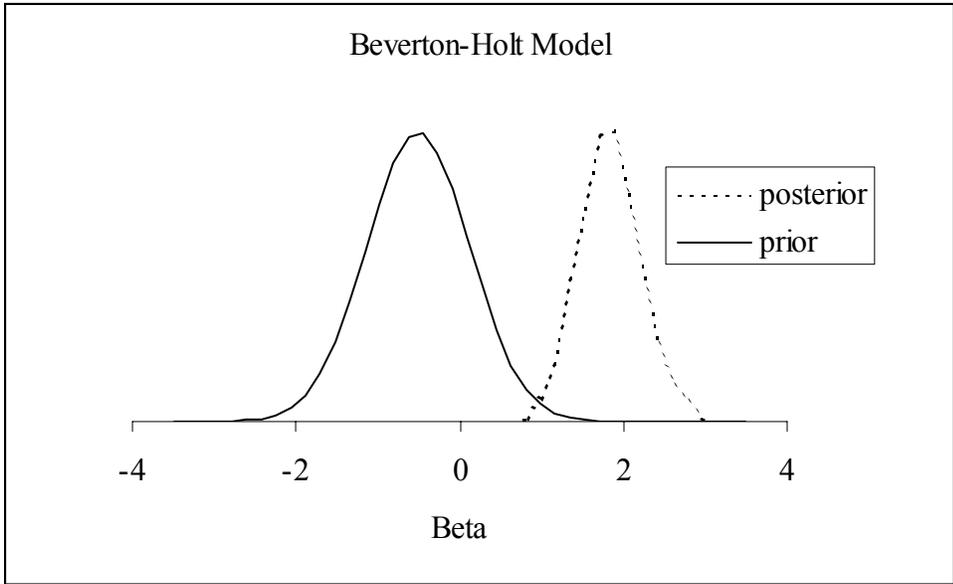
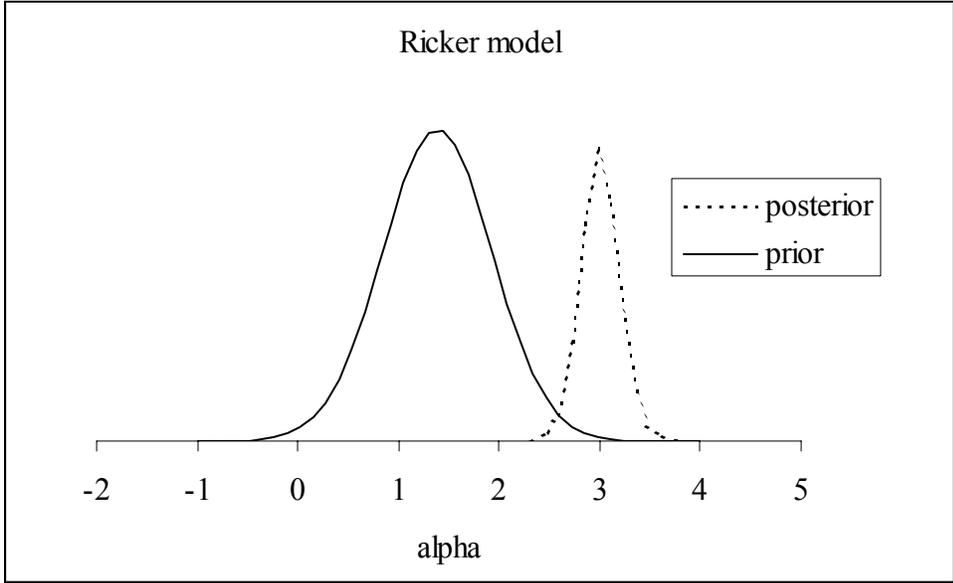


Figure A.8. Prior and posterior distributions for α and β in the Ricker and Beverton-Holt model, respectively, based upon viable larvae being used as the measure of reproductive capacity.

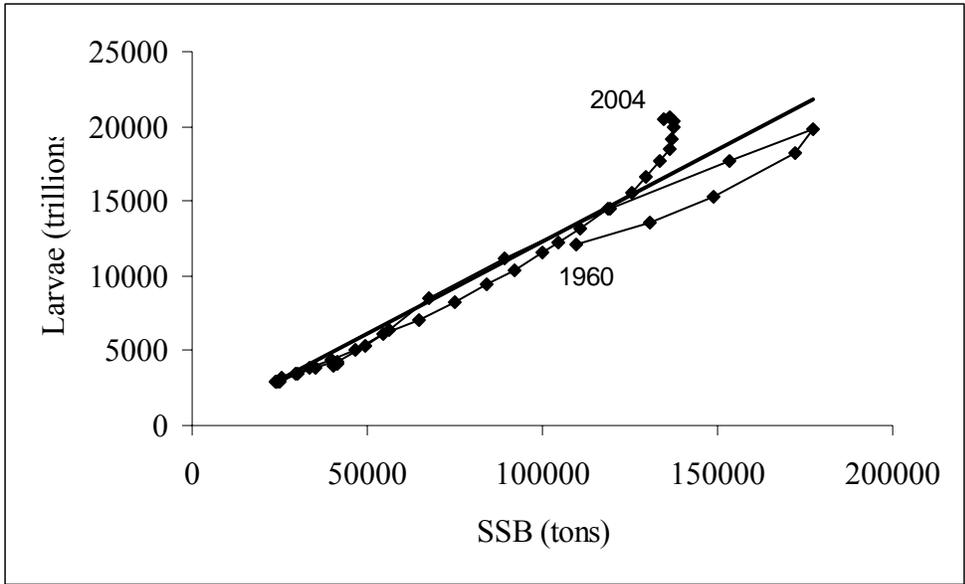


Figure A.9 Estimated time series of viable larvae and SSB for BSAI POP from 1960-2004, with a linear trend denoted by the solid bold line.

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