Section 1

SUMMARY OF CHANGES TO THE GULF OF ALASKA POLLOCK ASSESSMENT

Relative to the November 1999 edition of the SAFE report, the following changes have been made to the pollock chapter:

Additions to input data

1. 1999 triennial bottom trawl age composition.

2. 1999 fishery catch at age.

3. 2000 Shelikof Strait EIT survey biomass and length composition.

4. 2000 ADF&G crab/groundfish trawl survey biomass and length composition.

5. New estimates of weight at age for the Shelikof Strait EIT survey (1992-98), triennial bottom trawl survey (1984-1999), and fishery (1990-99).

Changes in the assessment model

1. The age-structured model developed using ADModel Builder (a C++ software language extension and automatic differentiation library) presented in the 1999 SAFE report is unchanged except for a few details.

2. Model exploration focused on improving treatment of the Shelikof Strait EIT survey by splitting the time series into two catchability periods to account for the use of a new acoustic system in 1992. In addition, a method for using the EIT survey estimates of age-1 abundance in stock projections is evaluated.

Changes in results

1. Projected age 3+ biomass in 2001 is 699,000 t.

2. The 2001 ABC recommendation for pollock in the Gulf of Alaska west of 140° W long. is 100,770 t . For pollock in southeast Alaska (East Yakutat and Southeastern areas) the ABC recommendation is unchanged at 6,460 t.

Response to SSC and AP comments

The AP requested a review of the method used to apportion the Gulf of Alaska pollock TAC by area. Although no work has been completed on alternative methods of apportioning the TAC, an appendix provides a detailed description of the current method used to apportion the ABC by season and area as required under the revised final RPAs.

WALLEYE POLLOCK

by
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INTRODUCTION

This report evaluates the current status and historical trends in abundance of walleye pollock in the Gulf of Alaska. Projections for establishing the 2001 Acceptable Biological Catch (ABC) are obtained using an age-structured population model. This assessment contains new information from the following sources: a) age composition from the 1999 triennial bottom trawl survey, b) biomass and length composition from the 2000 Shelikof Strait echo integration trawl (EIT) survey, c) age composition from the 1999 pollock fishery, and d) biomass and length composition from the 2000 Alaska Department of Fish and Game (ADF&G) crab/groundfish bottom trawl survey.

Walleye pollock (*Theragra chalcogramma*) is a semidemersal schooling fish widely distributed in the North Pacific in temperate and subarctic waters. Pollock in the Gulf of Alaska are managed as a single stock independently of pollock stocks in the Bering Sea and Aleutian Islands. Major spawning aggregations of pollock occur in late winter/early spring in Shelikof Strait, with smaller concentrations occurring near the Shumagin Islands, in the entrance to Prince William Sound (PWS), and near Middleton Island (Guttormsen and Wilson 1998, Bechtol 1998). Summer distributions based on bottom trawl surveys show large concentrations of pollock on the east side of Kodiak Island, along the eastern edge of the Shelikof sea valley, and in nearshore waters along the Alaska Peninsula.

The separation of pollock in Alaskan waters into Eastern Bering Sea and Gulf of Alaska stocks is supported by analysis of larval drift patterns from spawning locations (Bailey et al. 1997), genetic studies of allozyme frequencies (Grant and Utter 1980), mtDNA variability (Mulligan et al. 1992), and microsatellite allele variability (Bailey et al. 1997). Investigations of stock structure within the Gulf of Alaska are in progress by the Alaska Fisheries Science Center and ADF&G.

FISHERY

The commercial fishery for walleye pollock in the Gulf of Alaska started as a foreign fishery in the early 1970s (Megrey 1989). Catches increased rapidly during the late 1970s and early 1980s (Table 1.1, Table 4 in SAFE Summary Chapter). Large spawning aggregations of pollock were discovered in Shelikof Strait in 1981, and a fishery developed for which pollock roe was an important product. A domestic pollock fishery developed quickly in the Gulf of Alaska with only a short period of joint venture operations in the mid-1980s. The fishery was fully domestic by 1988. Historical fishing locations through 1992 (Fritz 1993) show the development of the Gulf pollock fishery from a foreign fishery along the shelf break to a domestic fishery on spawning aggregations and in nearshore waters.

Estimated catch was derived by the NMFS Regional Office from a blend of weekly processor reports and observer at-sea discard estimates (Table 1.2). Catches include the state-managed pollock fishery in Prince William Sound. In 1996-2000, the pollock Guideline Harvest Level (GHL) for the PWS fishery was deducted from the Total Allowable Catch (TAC) set by North Pacific Management Council (NPFMC).

In recent years, time and area restrictions have been imposed on the Gulf of Alaska pollock fishery to reduce interactions between the fishery and the western population of Steller sea lions, currently listed as endangered under the Endangered Species Act. The time and area allocations of TAC have changed several times during the last six years. In 1994, 1995, and 1996 the TACs were allocated based on the distribution of biomass in the 1993 bottom trawl survey: 49% Shumagin (area 610), 24.7% Chirikof (area 620), and 26.3% in Kodiak (area 630). The 1997-99 TACs were allocated on the basis of the biomass distribution from the 1996 bottom trawl survey (25% Shumagin, 42% Chirikof, and 33% Kodiak). In 1994 and 1995, the TAC was divided into four quarterly allocations with openings on January 20, June 1, July 1, and October 1. In 1996, the council approved Amendment 45 which allowed the third and fourth quarter releases to be combined and released on September 1, so that the seasonal allocations were 25%, 25%, and 50%. In 1998, the Council changed the seasonal allocation to 25% winter, 35% summer and 40% fall. In addition, the fall season was divided into two seasons with a 5 day stand down between openings.

In 2000, revised final Reasonable and Prudent Alternatives (RPAs) were implemented to reduce the potential for adverse modification of Steller sea lion foraging habitat. The RPAs divide the pollock TAC in the Western and Central Gulf of Alaska into four quarterly allocations with openings on Jan 20 (30%), March 15 (15%), August 20 (30%), and Oct 1 (25%). For the first two openings (A and B seasons), the TAC is further apportioned by region between Shelikof (51.1%), Shumagin (27.4%), Chirikof (2.0%), and Kodiak (19.5%) areas based on the most recent Shelikof Strait EIT survey and summer trawl survey biomass distribution. For the final two openings (C and D seasons), the TAC is apportioned by region between Shumagin (42%), Chirikof (25%), and Kodiak (33%) areas based on a four-year average of summer trawl survey biomass distribution. There is no separate allocation to the Shelikof area in the C and D seasons.

The annual Gulf of Alaska pollock TAC and total catch is given in Table 1.1. Annual research catches (1977-99) from NMFS longline, trawl, and echo integration trawl surveys are also given. Research catches of pollock in the Gulf of Alaska averaged 0.16% of fishery catches.

1999 Fishery

The gulfwide TAC for 1999 was 103,020 t, with 94,580 t in the Western and Central regions (which includes the GHL of 2,100 t for the state-managed fishery in Prince William Sound). The estimated pollock catch for 1999 was 93,828 t in the Western and Central Gulf of Alaska, and 1,763 t in the Eastern Gulf of Alaska (Table 1.2). The duration of pollock seasons in 1999 varied by region. In the Shumagin area, the winter, summer and fall seasons were open for 11, 6, and 6.75 days respectively. In the Chirikof area, the winter, summer and fall seasons were open for 28, 10, and 25.5 days respectively. In the Kodiak area, the winter, summer and fall seasons were open for 7, 9, and 6.5 days respectively. The spatial distribution of catches based on observer records by trimester is shown in Figure 1.1.

2000 Fishery

The TAC for 1999 was 94,960 t west of 140° W long. (which includes the GHL of 1,420 t for the state-managed fishery in Prince William Sound) and 6,460 t in southeast Alaska. As of October 7, 2000, the NMFS Regional Office reported that a total of 61,568 t of pollock was harvested west of 140° W long in the Gulf of Alaska and only trace quantities in southeast Alaska (<5 t). Because pollock outside Steller sea lion critical habitat are relatively uncommon, the August 7, 2000, Court Order banning all groundfish trawling inside critical habitat could result in a significant shortfall in pollock catches. Projections by NMFS inseason managers suggest that total harvest in 2000 will be approximately 73,000 t (T. Pearson, pers. comm. Oct 27, 2000). The duration of the first two pollock seasons in 2000 varied by region. In Shelikof area, the A and the B seasons were open for 21 and 10 days respectively. In the Shumagin area, the A and the B seasons were open for 11 and 3 days respectively. In the Chirikof area, the A season was open for 7 days, while the B season was not opened because the TAC was too small to support a directed fishery. In the Kodiak area, the A and the B seasons were open for 5 and 2 days respectively. Information concerning the C and the D seasons is not available at the time of this writing.

DATA USED IN THE ASSESSMENT

The data used in the assessment model consist of estimates of annual catch in tons, fishery age composition, triennial bottom trawl estimates of biomass and age composition, EIT survey estimates of biomass and age composition in Shelikof Strait, egg production estimates of spawning biomass in Shelikof Strait, and ADF&G bottom trawl estimates of biomass and length composition. Length composition data are used directly in the model when age composition estimates were unavailable, such as the fishery in the early part of the modeled time period and the 2000 Shelikof Strait EIT survey.

Fishery Age Composition

Estimates of fishery age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). Pollock otoliths collected during the 1999 fishery were aged using the revised criteria described in Hollowed et al. (1995). Catch age composition was estimated using methods described by Kimura and Chikuni (1989). Age samples were used to construct age-length keys by sex and stratum. These keys were applied to length frequency data to obtain stratum-specific age composition estimates, which were then weighted by the catch in numbers in each stratum to obtain an overall age composition. Changes in sampling protocols implemented in 1999 resulted a more even distribution of otolith sampling by stratum. Age and length samples from the 1999 fishery were stratified by trimester and statistical area as follows:

Time strata		Shumagin-610	Chirikof-620	Kodiak-630	PWS-649
1st trimester (Jan-Apr)	No. ages	166	242	250	181
	No. lengths	1,712	4,306	3,875	1,486
2nd trimester (May-Aug)	No. ages	170	253	241	----
	No. lengths	1,958	3,968	2,630	----
3rd trimester (Sep-Dec)	No. ages	149	204	239	----
	No. lengths	3,482	7,205	3,755	----

The 1994 and 1995 year classes (ages 4 and 5) were most abundant in nearly all strata in 1999 (Fig. 1.2). The 1988 and 1989 year classes (now ages 10 and 11) were evident as a secondary mode, but their relative abundance was much lower than in previous years, and ageing error has blurred their distinctness. Mean age increased from the Kodiak area (5.5 yrs) to the Shumagin area (6.6 yrs), suggesting greater dispersal of older fish to the west. In first and the third trimester, age composition in the Chirikof area closely resembled the age composition in the Kodiak area, while in the second trimester the Chirikof age composition more closely resembled the Shumagin age composition.

Fishery catch at age in 1976-99 is presented in Table 1.3 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.4.

Prince William Sound Fishery age composition

Estimates of age composition for the 1999 Prince William Sound fishery were available from two sources: NMFS observer sampling and ageing, and samples collected by ADF&G and aged by ADF&G age readers. The NMFS age composition of the PWS fishery was similar to the first trimester age composition in the Gulf of Alaska outside PWS (Fig. 1.4). The 1994 was the dominant year class in both cases, and there was second smaller mode spread over ages 9-11 representing the 1988 and 1989 year classes. Average age was greater in the PWS fishery (6.5 yrs versus 6.0 yrs in the gulf wide fishery), and age-11 fish were more abundant in PWS. The NMFS and ADF&G age composition in the PWS fishery both showed a mode at age 5, but the decline in relative abundance of the older fish is smoother in the ADF&G age composition, there is no evidence of a second mode at ages 9-11. However, mean age was nearly equal for the NMFS and ADF&G age composition, suggesting no severe discrepancies in ageing criteria at the two agencies.

NMFS and ADF&G estimates of length at age in the PWS fishery were similar, and indicated that pollock tended to be larger at age than in the Gulf of Alaska fishery outside PWS, particularly for ages 5-7 (Fig. 1.4). Interestingly, both younger and older fish showed smaller differences in length at age than intermediate aged fish. Differences in length at age could be a result of faster growth or length-dependent differences in spatial distribution.

Gulf of Alaska Bottom Trawl Survey

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) every three years (beginning in 1984) to assess the abundance of groundfish in the Gulf of Alaska (Table 1.5). The survey uses a stratified random design, with 49 strata based on depth, habitat, and management area (Martin 1997). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized Poly-Nor'eastern high opening bottom trawls rigged with roller gear. Surveying effort averages 750 tows, 75% of which contain pollock (Table 1.6). To provide information on biomass trends prior to the start of comprehensive gulfwide surveys, a biomass estimate for 1975 was obtained by expanding an area-swept biomass estimate from a trawl survey of the Chirikof area using a 400 mesh eastern trawl (Hughes and Hirschhorn, 1979). This estimate is included in triennial biomass time series in the assessment model.

The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140° W long, obtained by adding the biomass estimates for the Shumagin, Chirikof, Kodiak INPFC areas, and the western portion of Yakutat INPFC area. West Yakutat biomass was estimated by splitting strata and survey CPUE data at 140° W long. Biomass estimates for 1990, 1993, 1996 for this region were obtained by re-analysis of the survey data (M. Martin, AFSC, Seattle, WA, pers. comm. 1998). For surveys in 1975, 1984, and 1987, the average adjustment for West Yakutat the 1990, 1993, and 1996 surveys was applied (2% increase).

An adjustment was also made to the survey times series to account for unsurveyed pollock in Prince William Sound. This adjustment was derived from an area-swept biomass estimate for PWS from a trawl survey conducted by ADF&G in 1999, using a standard ADF&G 400 mesh eastern trawl. The 1999 biomass estimate for PWS was 6,304 t ± 2,812 t (95% CI) (W. Bechtol, ADF&G, 1999, pers. comm.). The PWS biomass estimate should be considered a minimum estimate because ADF&G survey gear is less effective at catching pollock compared to the triennial survey gear, based on limited trawl comparison studies (Brown and Zenger, 1998). For 1999, the biomass estimates for the triennial survey and the PWS survey were simply added to obtain a total biomass estimate. The adjustment factor for the 1999 survey, (PWS + Triennial)/Triennial, was applied to earlier triennial surveys, and increased biomass by 1.05%. We consider this an interim approach to assessing PWS pollock, and anticipate improvements from increased surveying effort in PWS and additional comparative work.

The most recent Gulf of Alaska trawl survey was in the summer of 1999. The estimate of pollock biomass west of 140° W long was 606,295 t after the adjustments, a 9% decline from 1996 (Table 1.5, see also Fig. 1.5). Several factors complicate interpretation of the 1999 biomass estimate. First, bottom temperatures in 1999 were as much as 2° C cooler than during other triennial surveys. The vulnerability of pollock to the bottom trawl survey may be temperature-related, either due to changes in vertical distribution, or due to inshore-offshore changes in spatial distribution. Second, estimates of total biomass and biomass distribution between statistical areas are strongly affected by a few large tows in the Shumagin area. The coefficient of variation of the gulfwide biomass estimate in 1999 (0.37), was nearly twice as large any previous triennial survey, suggesting that the spatial distribution of pollock may have been patchier in 1999 than in previous survey years.

Bottom Trawl Age Composition

Estimates of numbers at age from the bottom trawl survey were obtained from length-stratified otolith samples and length frequency samples (Table 1.7). Numbers at age were estimated for three strata: Western GOA (Shumagin INPFC area), Central GOA (Chirikof and Kodiak INPFC areas), Eastern GOA (Yakutat and Southeastern INPFC areas) using age-length keys and CPUE-weighted length frequency data. The combined Western and Central age composition was used in the assessment model. An additional estimate of the age composition of the population in 1973 was available from a bottom trawl survey of the Gulf of Alaska (Hughes and Hirshhorn, 1979).

Estimated numbers at age in the 1999 survey indicated a moderate 1998 year class (age-1), primarily in the Central and Eastern GOA (Fig. 1.6). The 1994 year class (age-5), which was very strong in the 1999 fishery age composition, did not show the same relative abundance in the survey age composition. It was still the most abundant year class in the Western GOA stratum, and second in abundance in the Central GOA strata after the age-1 fish. Large numbers of older fish were found in Western GOA stratum, but this may be due to the exceptionally large tows in the Shumagin area that also influenced the biomass estimates. Age composition in the Eastern GOA was very different than the age composition in the Western and Central GOA strata, showing smoothly declining abundance with age, and no evidence of a strong 1994 year classes at age 5.

Shelikof Strait Echo Integration Trawl Survey

Echo integration trawl surveys to assess the biomass of pollock in the Shelikof Strait area have been conducted annually since 1981 (except 1982 and 1999). Survey methods and results for 2000 are presented in an Appendix to the SAFE (Guttormsen and Wilson 2000). The 2000 biomass estimate for pollock in Shelikof Strait was 389,300 t, of which 54,363 t (4.2 billion) were age-1 pollock less than 17 cm (Guttormsen and Wilson, 2000). The 2000 biomass estimate represents a decline of 21% from the 1998 biomass. Biomass in Shelikof Strait has been declining continuously since 1996, and the 2000 estimate is nearly the lowest estimate in Shelikof Strait. However, the estimated number of age-1 fish is the second largest in the survey time series after the 1996 estimate, suggesting the 1999 year class is relatively strong.
In addition, the abundance of fish in the 17-24 cm range, a proxy for the abundance of age-2 fish, was the second largest since 1991 (after the 1997 survey).

The EK500 acoustic system has been used to estimate biomass since 1992. In previous assessments, the EK500 biomass time series was adjusted to allow comparison with estimates from earlier surveys (1981-91) which were generated with an older Biosonics acoustic system (Table 1.5). This adjustment was based on earlier work demonstrating that similar biomass estimates were obtained when the volume backscattering (S_v) threshold of the new system was adjusted to -58.5 dB (Hollowed et al. 1992). However, because of the newer system's lower noise level, abundance estimates since 1992 have been based on an S_v threshold of -69 dB. In this assessment, we evaluated a model where the Shelikof Strait EIT survey time series was split into two catchability periods corresponding to the two acoustic systems. For the 1992 and 1993 surveys, biomass estimates using both noise thresholds were used to provide to provide information on relative catchability.

Since the assessment model only includes individuals from age 2, the biomass time series was also adjusted to remove the biomass of age-1 fish in the 1995 and 2000 surveys, which were reduced by 15% and 14% respectively (Table 1.5). In all other surveys the biomass of age-1 fish was less than 2% of the total biomass.

Echo Integrated Trawl Survey Length Frequency

Annual length frequency distributions from the 1992 to 2000 acoustic mid-water trawl surveys in Shelikof Strait show the movement of the strong 1988 year class through the population (Fig. 1.7). In recent years, evidence of a strong 1994 year class was present. In the 2000 survey, the length frequency is dominated by the age-1 fish. Because ages were not yet available for the 2000 Shelikof Strait EIT survey, length frequency data was included in the assessment model.

Echo Integrated Trawl Survey Age Composition

Estimates of numbers at age from the Shelikof Strait EIT survey (1981 - 1991, 1994 -1998, Table 1.7) were used in the assessment model. Otoliths collected during the 1994 - 1998 EIT surveys were aged using the revised criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.5.

Egg Production Estimates of Spawning Biomass

Estimates of spawning biomass in Shelikof Strait derived from egg production methods were included in the assessment model. A complete description of the estimation process is given in Picquelle and Megrey (1993). The estimates of spawning biomass in Shelikof Strait show a pattern similar to the acoustic survey (Table 1.5). The annual egg production spawning biomass estimate for 1981 is questionable because of sampling deficiencies during the egg surveys for that year (Kendall and Picquelle 1990). Coefficients of variation (CV) associated with these estimates were included in the assessment model.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

The Alaska Department of Fish and Game (ADF&G) has conducted bottom trawl surveys of nearshore areas of the Gulf of Alaska since 1987. Although these surveys are designed to monitor population trends of Tanner crab and red king crab, walleye pollock and other fish are also sampled. Standardized survey methods using a 400 mesh eastern trawl were employed from 1987 to the present. The survey is designed to sample a fixed number of stations from mostly nearshore areas from Kodiak Island west to Unimak Pass, and does not cover the entire shelf area. The average number of tows completed during the survey is 360. Details of the ADF&G trawl gear and sampling procedures are in Blackburn and Pengilly (1994).

Biomass trends are reported for three regions (Kodiak, Chignik and South Peninsula). The highest pollock biomass occurs either in the Kodiak or the South Peninsula region. Estimates are available for all three areas during 1989-98, with the exception of 1991 and 1995 (Table 1.5). Last year, ADF&G survey data were evaluated using an assessment model where the combined region biomass time series was treated as an index of abundance. ABC recommendations were based on an assessment model that included the ADF&G biomass time series. In an effort to establish formal comparisons between survey results, AFSC and ADF&G conducted a comparative trawl survey in October 1997 on the east side of Kodiak Island. Estimates of correction factors will be provided in future SAFE reports.

ADF&G Survey Length Frequency

Pollock length-frequency for the ADF&G survey in 1989-1999 (excluding 1991 and 1995) typically show a primary mode at lengths greater than 45 cm (Fig. 1.8). The predominance of large fish in the ADF&G survey may result from the selectivity of the gear, or because of greater abundance of large pollock in the areas surveyed.

FOCI 2000 Year Class Prediction

Basis: This forecast is based on five data sources: three physical properties and two biological data sets. The sources are: 1) observed 2000 Kodiak monthly precipitation, 2) wind mixing energy at [57N, 156W] estimated from 2000 sea-level pressure analyses, 3) advection of ocean water in the vicinity of Shelikof Strait inferred from drogued drifters deployed during the spring of 2000, 4) rough counts of pollock larvae from a survey conducted in May 2000, and 5) estimates of age 2 pollock abundance from this years assessment.

Analysis: Precipitation at Kodiak was below the 30-year average (1962-1991) for January, May, and June (31%, 35%, and 91%, respectively, of the mean monthly precipitation), and above average for February through April (111%, 135%, and 166%, respectively). FOCI believes that Kodiak precipitation is a valid proxy for fresh-water runoff that contributes to the density contrast between coastal and Alaska Coastal Current water in Shelikof Strait. The greater the contrast, the more likely that eddies and other instabilities will form. Such secondary circulations have attributes that make them beneficial to survival of larval pollock. The low precipitation of January and May offset the benefits of high February through April precipitation toward production of fresh water runoff with its connection to enhanced potential for ocean eddies, thought conducive to pollock larvae survival. Based on this information, the forecast element for Kodiak rainfall has a score of 2.13. This is "average" on the continuum from 1 (weak) to 3 (strong).

For the third year in a row, monthly averaged wind mixing at the exit area of Shelikof Strait at [57N, 156W] was less than average for each of the first six months of the year (48%, 36%, 56%, 27%, 29%, and 54%, January through June). Strong winds in winter help mix nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak winter winds this year did not aid concentration of nutrients in the photic zone. Weak spring winds, as experienced especially during April and May, are thought to better enable first feeding pollock larvae to locate and capture food. The spring effect dominated the winter one in 2000, so the prediction is for stronger than average recruitment. The wind mixing score for this year is 2.46, which equates to "average to strong."

Data based on analysis of regional wind stress (correlated with transport in Shelikof Strait) for spring 2000 in the Gulf of Alaska and inferred from satellite tracked drifters indicate that advection was weak and circulation was sluggish, a sign of good recruitment. Advection was given a score of 2.34.

The larval index, based on late larval biological survey rough counts, look high; higher than last year. The larval index, which is based on rough counts in the range of 200-400 larvae/m^2, was scored as average-to-strong with a numerical score of 2.3.

The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition. The data set consisted of estimates of age 2 abundance from 1964-2000, representing the 1962-98 year classes. There were a total of 37 recruitment data points. The 33% and 66% percentile cutoff points were calculated from the full time series (33%=0.4352 billion, 66%=0.5921 billion) and used to define the three recruitment states of weak, average and strong. The lower third of the data points were called weak, the middle third average and the upper third strong. Using these definitions, nine transition probabilities were then calculated

Probability of a weak year class following a weak
Probability of a weak year class following an average
Probability of a weak year class following a strong

Probability of an average year class following a weak
Probability of an average year class following an average
Probability of an average year class following a strong

Probability of a strong year class following a weak
Probability of a strong year class following an average
Probability of a strong year class following a strong

The probabilities were calculated with a time lag of two years so that the 2000 year class could be predicted from the size of the 1998 year class. The 1998 year class was estimated to be 0.23 billion and was classified as weak. The probabilities of other recruitment states following a weak year class for a lag of 2 years (n=37) are given below:

2000YC		1998YC	Probability	Count
Weak	follows	Weak	0.2000	7
Average	follows	Weak	0.0571	2
Strong	follows	Weak	0.0286	1

The probability of a weak year class following a weak year class was the highest of the three so the prediction element from this data source was classified as weak and given a score of 1.0.

Each of the data elements was weighted equally. The larval index was used but was weighted equally with the other elements cause average-to-high larval numbers are promising of good recruitment but not necessarily so.

Conclusion: Based on these five elements and the weights assigned in the table below, the FOCI forecast of the 2000 year class is average.

	Weights	Score	Total
Time Sequence of Recruitment	0.20	1.00	0.200
Rain	0.20	2.13	0.426
Wind Mixing	0.20	2.46	0.492
Advection	0.20	2.34	0.468
Larval Index-abundance	0.20	2.30	0.468
Total	1.00		2.054 = Average

ANALYTIC APPROACH

Model description

Age-structured models for the period 1964 to 2000 (37 yrs) were used to assess Gulf of Alaska pollock. Population dynamics were modeled using standard formulations for exponential mortality and the catch equations (e.g. Fournier and Archibald 1988, Deriso et al. 1985, Hilborn and Walters 1992). Year- and age-specific fishing mortality was modeled as a product of a year effect, representing the full-recruitment fishing mortality, and an age effect, representing the selectivity of that age group to the fishery. The age effect was modeled using a double-logistic function with time-varying parameters (Dorn and Methot 1990, Sullivan et al. 1997). The model was fit to time series of catch biomass, survey indices of abundance, and estimates of age and length composition from the fishery and surveys. Details of the population dynamics and estimation equations are presented in an appendix.

Model parameters were estimated by maximizing the log likelihood of the data, viewed as a function of the parameters. Log-normal likelihoods were used for survey biomass and total catch estimates, and multinomial likelihoods were used for age and length composition data.

Model likelihood components and variance assumptions are shown below:

Likelihood component	Statistical model for error	Variance assumption
Fishery total catch (1964-2000)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-99)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-2000)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-98)	Multinomial	Sample size = 60
Shelikof EIT survey length comp. (2000)	Multinomial	Sample size = 60
Bottom trawl survey biomass (1975-99)	Log-normal	Survey-specific CV = 0.11-0.38
Bottom trawl survey age comp. (1973-99)	Multinomial	Survey-specific sample size = 38-74
Egg production biomass (1981-92)	Log-normal	Survey specific CV = 0.10-0.25
ADF&G trawl survey biomass (1989-2000)	Log-normal	CV = 0.2
ADF&G survey length comp. (1989-2000)	Multinomial	Sample size = 10
Fishery selectivity random walk process error	Log-normal Normal	Slope CV = 0.10 (0.001 for 1964-71) Inflection age SD = 0.40 (0.004 for 1964-71)
Recruit process error (1964-1968)	Log-normal	CV =1.0

Recruitment

In most years, year-class abundance at age 2 was estimated as a free parameter. Constraints were imposed on recruitment at the start of the modeled time period to improve parameter estimability. Rather than estimating the abundance of each age of the initial age composition independently, we parameterized the initial age composition as a mean log recruitment plus a log deviation from an equilibrium age structure based on that mean initial recruitment. A penalty was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period. We also used the same penalty for log deviations in recruitment for 1964-68. These relatively weak constraints were sufficient to obtain converged parameter estimates.

Fishery modeling

A four parameter double logistic equation was used to model fisheries selectivity. Rather than grouping years with similar selectivity patterns as in previous assessments (Hollowed et al., 1994, 1995, 1998), we allowed the parameters of the double logistic function to vary according to a random walk process (Sullivan et al. 1999). This approach allows selectivity to vary from one year to the next, but restricts the amount of variation that can occur. The resulting selectivity patterns are similar to those obtained by grouping years, but transitions between selectivity patterns occur gradually rather than abruptly. Constraining the selectivity pattern for a group of years to be similar can be done simply by reducing the year-specific standard deviation of the process error term. Since limited data are available from the Pacific Ocean perch fishery years (1964-71), the process error standard deviation for those years was assumed to be very small, so that annual changes in selectivity are not allowed during that period.

Survey modeling

Survey abundance was assumed to be proportional to total abundance as modified by the estimated survey selectivity pattern. Expected population numbers at age for the survey were based on the mid-date of the survey, assuming constant fishing and natural mortality throughout the year. Standard deviations in the log-normal likelihood were set equal to the sampling error CV (coefficient of variation) associated with each survey estimate of abundance (Kimura 1991). The CV for the EIT biomass estimate in 1992 was applied to all subsequent EIT surveys.

Survey catchability coefficients can be fixed or freely estimated. As in previous assessments, the AFSC bottom trawl survey catchability was fixed at one. This assumption has been used to provide management advice on Gulf pollock since 1993, and provides a precautionary constraint on the total biomass estimated by the model. Pollock are known to form pelagic aggregations and occur in nearshore areas not intensively sampled by the AFSC bottom trawl survey. Catchability coefficients for other surveys were estimated as free parameters. Egg production estimates of spawning stock biomass were included in the model by setting the age-specific selectivity equal to the estimated percent mature at age (Hollowed et al. 1991).

Ageing error

Ageing error for both survey and fishery age composition data was incorporated by use of a transition matrix (with elements associated with the probability of an observed age j being true age j'). This matrix was computed using the estimated percent-agreement levels based on standard deviations. That is, we computed the level of variance that would produce the observed level of agreement at different ages (Kimura and Lyons 1991). This took into account the probability that both readings were correct, both were off by one year in the same direction, or both were off by two years in the same direction. The probability that both agree and were off by more than two years was considered negligible.

Length frequency data

The assessment model was fit to length frequency data from various sources by converting predicted age distributions (as modified by age-specific selectivity) to predicted length distributions using an age-length transition matrix. Because seasonal differences in pollock length at age are large, several transition matrices were used. For each matrix, unbiased length distributions at age were estimated for several years using age-length keys, then averaged across years. A transition matrix was estimated using second and third trimester fishery age and length data during the years (1989-98) and was used for the ADF&G survey length frequency data.. The following length bins were used: 25 - 34, 35 - 41, 42 - 45, 46 - 50, 51 - 55, 56 - 70 (cm), so that the first three bins would capture most of the summer length distribution of the age-2, age-3 and age-4 fish, respectively. A transition matrix was estimated using 1992-98 Shelikof Strait EIT survey data and used for the 2000 survey length frequency data. The following length bins were used: 17 - 27, 28 - 35, 36 - 42, 43 - 50, 51 - 55, 56 - 70 (cm). Bin definitions were different for the summer and the winter transition matrices to account for the seasonal growth of the younger fish (ages 2-4). Finally, a transition matrix estimated by Hollowed et al. (1998) was used for the length-frequency data for the early period of the fishery.

Parameter estimation

A large number of parameters are estimated when using this modeling approach. More than half of these parameters are year-specific deviations in fishery selectivity coefficients. Parameters were fit using ADModel Builder, a C++ software language extension and automatic differentiation library. ADModel Builder estimates large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. The optimizer in ADModel builder is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1 x 10-4 for the pollock model). ADModel builder includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest.

A list of model parameters is shown below:

Population process modeled	Number of parameters	Estimation details
Initial age structure	Ages 3-10 = 8	Estimated as log deviances from the log mean; constrained by random deviation process error from an equilibrium unfished age structure
Recruitment	Years 1964-2000 = 37	Estimated as log deviances from the log mean; recruitment in 1964-68 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated
Fishing mortality	Years 1964-2000 = 37	Estimated as log deviances from the log mean
Mean fishery selectivity	4	Slope parameters estimated on a log scale
Annual changes in fishery selectivity	4 * (No. years -1) = 144	Estimated as deviations from mean selectivity and constrained by random walk process error
Survey catchability	No. of surveys + 1 = 6	AFSC bottom trawl survey catchability not estimated, other catchabilities estimated on a log scale. Two catchability periods were estimated for the EIT survey.
Survey selectivity	8 (EIT survey: 2, BT survey: 4, ADF&G survey: 2)	Slope parameters estimated on a log scale. The egg production survey uses a fixed selectivity pattern equal to maturity at age.
Total	99 conventional parameters + 144 process error parameters + 2 fixed parameters = 245	

Parameters Estimated Independently

Pollock life history characteristics, including natural mortality, growth, and maturity, were estimated independently of the assessment model. These parameters are used in the model to estimate spawning and population biomass, and obtain predictions of fishery and survey biomass conditional on model estimates of abundance:

! Natural mortality (M)

! Proportion mature at age.

! Weight at age and year by fishery and by survey

Hollowed and Megrey (1990) estimated natural mortality using a variety of methods including estimates based on: a) growth parameters (Alverson and Carney 1975, and Pauly 1980), b) GSI (Gunderson and Dygert, 1988), c) monitoring cohort abundance, and d) estimation in stock synthesis. These methods produced estimates of natural mortality that ranged from 0.24 - 0.30. The maximum age observed was 22 years. For the assessment modeling, natural mortality was assumed to be 0.3 for all ages.

Hollowed et al. (2000) developed a model for Gulf of Alaska pollock that accounted for predation mortality. The model suggested that natural mortality declines from 0.8 at age 2 to 0.4 at age 5, and then remains relatively stable with increasing age. In addition, stock size was higher when predation mortality was included. Clark (1999) did a theoretical analysis of a simple age-structured model that evaluated the effect of an erroneous M on both estimated abundance and target harvest rates. He found that "errors in estimated abundance and target harvest rate were always in the same direction, with the result that, in the short term, extremely high exploitation rates can be recommended (unintentionally) in cases where the natural mortality rate is overestimated and historical exploitation rates in the catch-at-age data are low." Cark (1999) suggested that this error could be avoided by using a conservative (low) estimate of natural mortality. This suggests that the current approach of using a potentially low but still somewhat credible estimate of M for assessment modeling is consistent with the precautionary approach. However, it should be emphasized that the role of pollock as prey in the Gulf of Alaska ecosystem cannot fully evaluated using a single species assessment model (Hollowed et al. 2000).

Maturity at age for Gulf of Alaska pollock was estimated by Hollowed et al (1991) as given below:

Age								
2	3	4	5	6	7	8	9	10+
0.034	0.116	0.325	0.639	0.867	0.960	0.989	0.997	1.000

New weight-at-age estimates were calculated for the Shelikof Strait EIT survey (1992-98), triennial bottom trawl survey (1984-1999), and fishery (1990-99) to update earlier analyses (Hollowed et al. 1995). For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a\ L^{b}$, were also estimated for each year and data source. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions.

There are large seasonal differences in pollock weight at age, particularly for the younger fish (Fig. 1.9). Pollock are lightest during the first trimeter of the fishery and during the Shelikof Strait EIT survey, and heaviest during the third trimeter of the fishery. For pollock less than age 6, there was a decline in average weight between the third trimester fishery and the first trimester of the following year.

Model selection and evaluation

Shelikof Strait EIT survey catchability

Model exploration focused on improving the treatment of the Shelikof Strait EIT survey time series in the assessment model. The EK500 acoustic system has been has been used by the AFSC RACE Division as its standard acoustic data collection system since 1992. In previous assessments, the EK500 biomass time series was adjusted to allow comparison with estimates from earlier surveys (1981-91) which were generated with an older Biosonics acoustic system. Since the newer system has a lower noise level, lower densities of pollock can be surveyed. We compared the approach used in previous assessments with a model where the Shelikof Strait EIT survey time series was split into two catchability periods corresponding to the two acoustic systems. The biomass estimates made using the higher noise threshold in 1992 and 1993 are included in the Biosonics time series to provide a direct comparison of the two systems.

The survey catchability using the adjusted EK500 biomass in a single time series was 0.70. When two catchability periods were defined, the catchability for the Biosonics system was 0.70, while for the EK500 system the catchability coefficient was 0.75, which implies an adjustment factor of 0.93. This suggests that adjusting the EK500 biomass estimates by a factor of 0.79 in previous assessments may have reduced the EK500 biomass by slightly too much. Comparison of model fits for the two models indicate that splitting the survey time series into two catchability periods produces relatively minor improvements to model fit (Fig 1.10). Splitting the acoustic time series decouples the EK500 biomass estimates from the biomass estimates in the early 1980's where there is a severe discrepancy between survey estimates and the model, and thus may improve the ability to make accurate short-term projections. Population biomass is similar for both models until after 1995, when the biomass for the two catchability period model is 0-10% higher (Fig 1.10).

Evaluation of the McKelvey (1996) age-1 index

McKelvey (1996) found a significant correlation between the abundance of age-1 pollock in the Shelikof Strait EIT survey and subsequent estimates of year-strength. We developed an approach to use this relationship quantitatively in the assessment model to provide estimates of recruitment at age-2 in the year following the most recent Shelikof Strait EIT survey. A similar method is used in the ICES arena to forecast year-class strength with multiple indices of recruitment (Shepherd 1997), except that index calibration and forecasts are done external to the assessment model. For a survey that produces an index of recruitment at age 2, R_i , predicted values from the model are

$$\hat{R}_i = q_1 \; N_{i2}^{q_2}$$

where q_1 is the catchability coefficient, and q_2 is a power term which allows for a non-linear relationship between recruitment and the index. Constant catchability is implied by $q_2 = 1$. Log-normal measurement error in the survey index gives a log-likelihood of

$$\log \, L_k = -\sum_i \, [\log(R_i) \; - \; \log q_1 - \; q_2 \log(N_{i2})]^2 \; / \; 2\sigma_i^2$$

where σ_i is the standard deviation of the logarithm of recruitment index. Since the index is obtained in the year prior to recruitment at age 2, the indices need to be shifted forward a year. We evaluated both constant catchability and power law relationships between recruitment and the McKelvey (1996) age-1 index. Results indicated that both relationships were similar, and that $q_2 = 0.85$ when a power law relationship was assumed (Fig. 1.11). Since the slope coefficient is less than one, this implies that high recruitment indices would indicate even larger recruitment strength than if a constant catchability model were appropriate. To predict the strength of the 1999 year class, the constant catchability model was used because the power law slope coefficient was close to one, and because the constant catchability model provided more conservative predictions.

Recruitment predictions should account for two sources of variability: random variation in recruitment (process error), and sampling variability of the survey index (measurement error). For example, if recruitment itself is not highly variable, an index that shows an extremely low or high value should be shrunk towards the mean, particularly if it is known that sampling variability for that index is large (Shepherd 1997). The tradeoff between these different sources of uncertainty is obtained by adding a log likelihood term for future recruitments in the final estimation phase. Assuming that both recruitment variability and sampling variability are log normal,

$$\log L_{Fut.\ Recr.} = -\frac{1}{2\sigma_r^2}\left[\log(N_{i2}) - \overline{\log(N_2)}\right]^2 - \frac{1}{2\sigma_s^2}\left[\log(q_k N_{i2}) - \log(R_i)\right]^2$$

where $\overline{\log(N_2)}$ is the mean log recruitment for 1977-2000 as estimated by the base-run model, σ_r is the standard deviation of log recruitment, and σ_s is the standard deviation of the log index from the survey, which is estimated using the prediction error of the index in the assessment model. The effect of this likelihood component is to obtain a recruitment prediction that is an inverse-variance weighted average of mean log recruitment and the log index. The standard deviation for log recruitment ($\sigma_r = 1.08$) is lower that the prediction error of log age-1 index ($\sigma_s = 1.83$), so that estimates of future recruitment will be shrunk more towards mean recruitment.

Model Evaluation

Residual plots were prepared to examine the goodness of fit of the base-run model to the age composition data. The Pearson residuals for a multinomial distribution are

$$r_i = \frac{p_i - \hat{p}_i}{\sqrt{(\hat{p}_i(1-\hat{p}_i)/m)}} \ ,$$

where p_i is the observed proportion at age, $\hat{p}_i$ is the expected proportion at age, and m is the sample size (McCullagh and Nelder 1983). Figures 1.12 and 1.13 show residuals of the fit to the fishery, the Shelikof Strait EIT survey, and the AFSC trawl survey age compositions. The residuals of the fit to the ADF&G crab/groundfish length composition is shown in Figure 1.14. Although there are large residuals for some ages and years, no severe pattern of residuals is evident in the fishery age composition. Two moderate patterns were apparent in the fishery data. The first is a tendency for strong year classes to gain strength from adjacent weaker year classes as they become older, producing a pattern of negative residuals for the adjacent year classes. This pattern is most apparent for the strong 1984 year class beginning in 1990 at age 6. In addition, there is a tendency for strong year classes to shift a year as they become older. This pattern is most obvious for the 1988 year class, which began to change into a 1989 year class in 1995. In the Shelikof Strait EIT survey age composition, there is a there is a fairly clear tendency of negative residuals for the age-4 and age-5 fish. In the 1999 AFSC trawl survey age composition, there is a pattern of negative residuals for the younger fish, and positive residuals for the older fish, suggesting that there were more old pollock were survey samples than is consistent with the population age structure in 1999. As noted earlier, the large numbers of older fish found in Western GOA survey stratum in 1999 may be due to the exceptionally large tows in the Shumagin area.

The model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 1999) (Fig. 1.15). Even though the Shelikof Strait EIT survey was split into two catchability periods, model is still unable to the fit high biomass estimates in early 1980's. The fit to trawl survey biomass is also relatively poor. Each expected biomass has been lower than the observed biomass since the 1987 survey. This suggests that by attempting to fit the trawl survey biomass in 1984, when age composition and Shelikof Strait EIT survey data indicated a much higher population size, the model may consistently underestimate biomass for subsequent triennial trawl surveys. Hollowed et al. (1996) note that excluding the 1984 biomass did not have a significant influence on model fit to other data sources, but did improve the fit to triennial trawl biomass time series.

Assessment Model Results

Parameter estimates and model output are presented in a series of tables and figures. Estimated selectivity for different periods in the fishery and for surveys is given in Table 1.8 (see also Fig. 1.16). Table 1.9 gives the estimated population numbers at age for the years 1964-2000. Table 1.10 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1964-2000 (see also Fig. 1.17). Stock size peaked in the early 1980s at approximately twice the average unfished stock size, and is currently below average under current NPFMC harvest policies at 30-40% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2000 is shown in Figure 1.18. The current estimated trend in spawning biomass for 1964-2000 is consistent with previous estimates. All time series show a similar pattern of increasing spawning biomass to the early 1980s, an abrupt decline, and then a gradual decrease since 1985. The confidence intervals on population biomass prior to 1970 are very wide (Fig 1.17), suggesting that stock size cannot be precisely estimated with available information. The estimated 2000 age composition from the current assessment is highly consistent with the estimated age composition in the 1999 assessment (Fig. 1.18).

PROJECTIONS AND HARVEST ALTERNATIVES

Reference Fishing Mortality and Yields

Estimates of FSPR harvest rates were obtained using the life history characteristics of Gulf pollock (Table 1.11). Equilibrium estimates of biomass and catch were based on mean 1979-2000 recruitment (845 million). Spawning was assumed to occur on March 15th , and female spawning biomass was calculated using the mean weight at age for the Shelikof Strait EIT survey in 1996-98 to estimate of current spawning potential. The SPR at F=0 was estimated as 0.738 kg/recruit. FSPR rates depend the selectivity pattern of the fishery. Selectivity in the Gulf of Alaska pollock fishery has changed as the fishery has evolved from a foreign fishery occurring along the shelf break to a domestic fishery on spawning aggregations and in nearshore waters (Fig. 1.1). Since 1990, Gulf of Alaska pollock have been managed with time and area restrictions, and selectivity has been fairly stable since 1992 (Fig 1.16). For SPR calculations, we used a selectivity pattern based on an average of the selectivity pattern during 1992-2000.

Gulf of Alaska pollock FSPR harvest rates are given below:

FSPR rate	Fishing mortality	Equilibrium under average 1979-2000 recruitment				
		Avg. Recr. (Million)	Total 3+ biom. (1000 t)	Female spawning biom. (1000 t)	Catch (1000 t)	Harvest rate
F100%	0.000	845	1926	624	0	0.0%
F50%	0.247	845	1244	312	159	12.8%
F45%	0.294	845	1173	281	174	14.9%
F40%	0.352	845	1102	250	189	17.1%
F35%	0.422	845	1028	218	203	19.7%

The B40% estimate of 250,000 t is similar to the estimate of 247,000 t in the 1999 assessment. The proxy for BMSY under tier 3 is B35% (218,000 t). The F40% equilibrium harvest rate (catch/age 3+ biomass) is 17%.

Information on recent year class strength

Model estimates of recruitment abundance for the 1996 and 1997 year classes (51 and 85 million respectively) suggest that they are weak year classes (in the lower third of the distribution). The model estimate of the 1998 year class, which is based primarily on length-frequency data from the 2000 Shelikof Strait EIT survey, was 887 million, suggesting that it is slightly above average abundance. The Shelikof Strait survey also showed very large numbers of age-1 fish (<17 cm), which has not occurred since the 1994 year class dominated the 1995 survey length composition. Anecdotal information suggests that the 1999 year class was relatively abundant in Prince William Sound as age-0 fish (J. Thedinga, ABL, 2000, pers. comm.), indicating that it is widely distributed in the Gulf of Alaska. In addition, relatively large numbers of age-1 pollock were found in August, 2000, off the east side of Kodiak Island during an EIT survey of Chiniak and Barnabas gullies to assess fishery-Steller sea lion interactions (C. Wilson, AFSC, 2000, pers. comm.). Thus the overall picture is suggestive of one or possibly two average-to-strong incoming year classes of pollock in the Gulf of Alaska that will help to stabilize population biomass and harvests over the next few years.

Information on recent recruitment to the Gulf pollock stock is summarized below:

Year of recruitment	2000	2001	2002
Year class	1998	1999	2000
FOCI prediction	Average	Average	Average
Survey information	1999 bottom trawl age-1 (<23 cm) estimate is 109.7 million (4th in abundance out of 7 surveys)	2000 Shelikof EIT survey age-1 estimate is 4.28 billion (2nd in abundance out of 17 surveys)	

Harvest and Abundance in 2001

Since 1997, Gulf pollock have been managed under Tier 3 of NPFMC harvest guidelines at the maximum permissible FABC harvest rate of F40%. If spawning biomass at the time of spawning (March 15) is below B40%, the fishing mortality rate is adjusted downwards as described by the harvest guidelines (see SAFE Summary Chapter). Spawning biomass in 2001 is projected to be 204,600 t, which is below B40% (250,000 t), thereby placing Gulf pollock in sub-tier “b” of Tier 3. Estimates of OFL and several 2001 ABC alternatives are provided for two models: a model that estimates the abundance of the 1999 year class (2.5 billion) based on inverse-variance weighting of mean recruitment and the age-1 Shelikof Strait survey estimate, and a second model where the 1999 year class is assumed to be average (845 million):

Harvest policy	Model projected recruitment in 2001: 2001 fishing mortality rate	Model projected recruitment in 2001: 2001 catch	Average recruitment in 2001: 2001 fishing mortality rate	Average recruitment in 2001: 2001 catch
F45% adjusted	0.24	90,970 t	0.24	85,730 t
F40% adjusted (Maximum permissible)	0.28	106,980 t	0.28	100,770 t
F35% adjusted (OFL)	0.34	125,100 t	0.34	117,750 t

The F45% adjusted harvest policy is defined equivalently to the F40% adjusted policy, except that F45% is used in place of F40% to obtain the target fishing mortality rate. It is provided as an option for SSC and Plan Team consideration as a further precautionary adjustment to the FMSY proxy of F35% that may be warranted given the assessment uncertainty and the importance of pollock in the Gulf of Alaska ecosystem. For the 2000 ABC, the SSC recommendation of an F45% harvest rate was adopted by the Council.

ABC recommendation

In our ABC recommendation, we considered the information on stock status provided by 2000 Shelikof Strait survey and the 2000 ADF&G crab/groundfish trawl survey. The Shelikof Strait survey showed a larger decline than model predictions, while the ADF&G survey showed a significant increase in 2000. We also considered how much reliance should be given to initial estimates of the 1998 and 1999 year classes, which are based primarily on length-frequency data and biomass estimates from the 2000 Shelikof Strait EIT survey. Since the 1999 year class will not yet be fully recruited to the fishable population, the 2001 ABC is not highly affected by its abundance. We regard the model projection of the 1999 year class as an improvement over using average recruitment, but recognize that this approach is new in this year's assessment, and has not yet been reviewed by the Plan Team and the SSC. Based on these considerations, we recommend a 2001 ABC of 100,770 t based on the F40% adjusted harvest policy and average recruitment in 2001.

The recommended ABC represents an increase of approximately 20% from the projected 2001 ABC in the 1999 assessment (Dorn et al. 1999). The higher 2001 ABC is caused by several factors:

1. The use of new estimates of Shelikof Strait EIT survey weight at age to calculate spawning biomass, and new fishery weight-at-age estimates to project yields. The target fishing mortality rate at F40% is lower with the new estimated of weight at age at spawning, but the average weight of fish taken in the fishery is higher, so that these changes act in opposition to each other (< 5% increase).

2. The use of two catchability periods to model the Shelikof Strait EIT survey. We consider this an improvement to model specification which should, at least in theory, improve our ability to estimate stock trends and to project yields (~15% increase). However, it should be noted for future reference that improved model specification does not always increase biomass and harvest.

3. Based on current estimates of pollock harvest in 2001, approximately 23,000 t of the TAC will not be harvested due to the August 7, 2000, Court Order banning trawling in critical habitat (~5% increase).

Although no work has been completed on alternative approaches to apportioning the ABC, an appendix provides a detailed description of the method used to apportion the ABC by season and area as required under the revised final RPAs. Since the assessment now explicitly includes the pollock biomass in Prince William Sound, the harvest guideline for PWS pollock should be subtracted from the total ABC prior to regional allocation.

Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the 2001 numbers at age as projected by the assessment model. 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 during 1979-2000 estimated by the assessment model. Spawning biomass is computed in each year based on the time of peak spawning (March 15) using the maturity and weight schedules in Table 1.11. 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 2001, 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 2001 recommended in the assessment to the *max* F_{ABC} for 2001.
>
> *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 1995-1999 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.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a 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.)

Scenario 7: In 2001 and 2002, *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.)

Results from scenarios 1-5 are presented in Table 1.12. Under all harvest policies, spawning biomass is projected to decline in 2002. Under an F40% adjusted harvest policy (the maximum permissible under Tier 3), spawning biomass is projected to be 27% of unfished in 2002. After 2002 spawning biomass and catches are projected to increase, but this result is strongly dependent on highly uncertain estimates of the 1998 and 1999 year class strength.

Scenarios 6 and 7 are used to make the MSFCMA's required status determination as follows:

Spawning biomass is projected to be 201,000 t in 2001 under an FOFL harvest policy, which is less than B35% (218,000 t), but greater than ½ of B35%. Under scenario 6, the projected mean spawning biomass in 2011 is 239,000 t, 109% of B35%. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2003 is 182,000 t, which is less than B35%, but greater than ½ of B35%. Projected mean spawning biomass in 2013 is 238,000 t, 109% of B35%. Therefore, Gulf of Alaska pollock is not approaching overfished condition.

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Literature Cited

Alverson, D. L. And M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. Cons. int. Explor. Mer, 133-143.

Bailey, K.M., P.J. Stabeno, and D.A. Powers. 1997. The role of larval retention and transport features in mortality and potential gene flow of walleye pollock. J. Fish. Biol. 51(Suppl. A):135-154.

Bailey, K.M., T.J. Quinn II, P. Bentzen, and W.S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theragra chalcogramma*. Advances in Mar. Biol. 37: 179-255.

Baranov, F.I. 1918. On the question of the biological basis of fisheries. Nauchn. Issed. Ikhtiologicheskii Inst. Izv. 1:81-128.

Bechtol, W. R. 1998. Prince William Sound walleye pollock: current assessment and 1999 management recommendations. Alaska Department of Fish and Game, Regional Information Report No. 2A98-41. 25p.

Blackburn, J. and D. Pengilly. 1994. A summary of estimated population trends of seven most abundant groundfish species in trawl surveys conducted by Alaska Department of Fish and Game in the Kodiak and Alaska Peninsula areas, 1988 through 1993. Alaska Department of Fish and Game, Regional Information Report No. 4K94-31. 19p.

Brown E., and H. Zenger. 1998. National Marine Fisheries Service/Alaska Department of Fish and Game trawl comparison study. Alaska Fisheries Science Center Quarterly Report, Jan.-March 1998, p3-6. Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, Washington 98115.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured model. Can. J. Fish. Aquat. Sci. 56:1721-1731.

Deriso, R.B., T.J. Quinn II, and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42: 815-824.

Dorn, M. W., and R. D. Methot. 1990. Status of the coastal Pacific whiting resource in 1989 and recommendation to management in 1990. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-182, 84 p.

Dorn, M.W. , A.B. Hollowed., E. Brown, B.A. Megrey, C. Wilson and J. Blackburn. 1999. Walleye pollock. 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. North Pacific Fisheries Management Council, Anchorage, AK.

Doubleday, W.G. 1976. A least-squares approach to analyzing catch at age data. Res. Bull. Int. Comm. Northw. Atl. Fish. 12:69-81.

Fournier, D. and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Fritz, L. W. 1993. Trawl locations of walleye pollock and Atka mackerel fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska from 1977-92. AFSC Processed Report 93-08. NMFS, AFSC, 7600 Sand Point Way, NE, Seattle, WA 98115. 162 p.

Grant, W.S. and F.M. Utter. 1980. Biochemical variation in walleye pollock *Theragra chalcogramma*: population structure in the southeastern Bering Sea and Gulf of Alaska. Can. J. Fish. Aquat. Sci. 37:1093-1100.

Greiwank, A., and G.F. Corliss (eds.) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. and Applied Mathematics, Philadelphia.

Gunderson, D. R. and P. H. Dygert. 1988. Reproductive effort as a predictor of natural mortality rate. J. Cons. int. Mer, 44:200-209.

Guttormsen , M. A. and C. D. Wilson. 1998. Echo integration-trawl survey of pollock in Shelikof Strait, Alaska in 1998. In Stock Assessment and Fishery Evaluation Report for Gulf of Alaska As Projected for 1998. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Guttormsen , M. A., and C. D. Wilson. 2000. Echo integration-trawl survey of pollock in Shelikof Strait, Alaska in 2000. In Stock Assessment and Fishery Evaluation Report for Gulf of Alaska. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York, N.Y. 570 p.

Hollowed, A.B. and B.A. Megrey. 1990. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for the 1991 Gulf of Alaska Groundfish Fishery. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Hollowed, A.B., B.A. Megrey, P. Munro, and W. Karp. 1991. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for the 1992 Gulf of Alaska Groundfish Fishery. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Hollowed, A. B., B.A. Megrey, and W. Karp. 1992. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for the 1993 Gulf of Alaska Groundfish Fishery. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Hollowed, A.B., C. Wilson, E. Brown, and B.A. Megrey. 1994. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for the 1995 Gulf of Alaska Groundfish Fishery. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Hollowed, A.B., E. Brown, P. Livingston, B.A. Megrey and C. Wilson. 1995. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for Gulf of Alaska As Projected for 1996. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Hollowed A.B., E. Brown, B.A. Megrey and C. Wilson. 1996. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for Gulf of Alaska As Projected for 1997. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Hollowed, A.B., E. Brown, J. Ianelli, B.A. Megrey and C. Wilson. 1998. Walleye pollock. 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. North Pacific Fisheries Management Council, Anchorage, AK.

Hollowed, A.B., J.N. Ianelli, P. Livingston. 2000. Including predation mortality in stock assessments: a case study for Gulf of Alaska pollock. ICES J. Mar. Sci. 57:279-293.

Hughes, S. E. and G. Hirschhorn. 1979. Biology of walleye pollock, *Theragra chalcogramma*, in Western Gulf of Alaska. Fish. Bull., U.S. 77:263-274.

Kendall, A.W. Jr. and S.J. Picquelle. 1990. Egg and larval distributions of walleye pollock *Theragra chalcogramma* in Shelikof Strait, Gulf of Alaska. Fish. Bull., U.S. 88:133-154.

Kimura, D.K. 1989. Variability, tuning, and simulation for the Doubleday-Deriso catch-at-age model. Can. J. Fish. Aquat. Sci. 46:941-949.

Kimura, D.K. 1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47:2364-2374.

Kimura, D.K. 1991. Improved methods for separable sequential population analysis. Unpublished. Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, Washington 98115.

Kimura, D. K. and S. Chikuni. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. *In* R.J. Beamish and G.A. McFarlane (eds.), Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108:57-66.

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

Martin, M.H. 1997. Data Report: 1996 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-82, 235 p.

McCullagh, P., and J. A. Nelder. 1983. Generalized linear models. Chapman and Hall, London. 261 p.

McKelvey, D. 1996. Juvenile walleye pollock, *Theragra chalcogramma*, distribution and abundance in Shelikof Strait–What can we learn from acoustic survey results? p. 25-34. *In* U.S. Dep. Commer. NOAA Tech. Rep. NMFS 126.

Megrey, B.A. 1989. Exploitation of walleye pollock resources in the Gulf of Alaska, 1964-1988: portrait of a fishery in transition. Proc. International Symp. on the Biology and Management of Walleye Pollock, Lowell Wakefield Fisheries Symp., Alaska Sea Grant Rep. 89-1, 33-58.

Mulligan, T.J., Chapman, R.W. and B.L. Brown. 1992. Mitochondrial DNA analysis of walleye pollock, *Theragra chalcogramma,* from the eastern Bering Sea and Shelikof Strait, Gulf of Alaska. Can. J. Fish. Aquat. Sci. 49:319-326.

Pauly, D.. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. int. Explor. Mer, 39(2):175-192.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. 1992. Numerical recipes in C. Second ed. Cambridge University Press. 994 p.

Picquelle, S.J., and B.A. Megrey. 1993. A preliminary spawning biomass estimate of walleye pollock, *Theragra chalcogramma*, in Shelikof Strait, Gulf of Alaska, based on the annual egg production method. Bulletin of Marine Science 53(2):728:749.

Saunders, M.W., G.A. McFarlane, and W. Shaw. 1988. Delineation of walleye pollock (*Theragra chalcogramma*) stocks off the Pacific coast of Canada. Proc. International Symp. on the Biology and Management of Walleye Pollock, Lowell Wakefield Fisheries Symp., Alaska Sea Grant Rep. 89-1, 379-402.

Schnute, J.T. and L.J. Richards. 1995. The influence of error on population estimates from catch-age models. Can. J. Fish. Aquat. Sci. 52:2063-2077.

Shepherd, J.G. 1997. Prediction of year-class strength by calibration regression analysis of multiple recruit index series. ICES J. Mar. Sci. 54:741-752.

Sullivan, P.J., A.M. Parma, and W.G. Clark. 1999. Pacific halibut assessment: data and methods. Int. Pac. Halibut Comm. SCI. Rept. 97. 84 p.

Tables

Appendix A: Southeast Alaska pollock

Bottom trawl surveys indicate a substantial reduction in pollock abundance east of 140° W. long. Stock structure in this area is poorly understood. Bailey et al. (1999) suggest that pollock metapopulation structure in southeast Alaska is characterized by numerous fiord populations. In the 1996 and 1999 bottom trawl surveys, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Pollock size composition in the 1993, 1996 and 1999 surveys was dominated by smaller fish (<40 cm) (Martin 1997). These juvenile pollock are unlikely to influence the population dynamics of pollock in the central and western Gulf of Alaska. Ocean currents are generally northward in this area, suggesting that juvenile settlement is a result of spawning further south. Spawning aggregations of pollock have been reported from the northern part of Dixon Entrance (Saunders et al. 1988).

Historically, there has been very little directed fishing for pollock in southeast Alaska (Fritz 1993). During 1991-98, pollock catch the Southeast and East Yakutat statistical areas averaged 27 t (Table 1.2). The current ban on trawling east of 140° W. long. would preclude the development of a trawl fishery for pollock in Southeast Alaska.

Pollock biomass estimates from the bottom trawl survey are highly variable, in part due to year-to-year differences in survey coverage. The 1996 and 1999 surveys had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Fig. 1.22). We recommend placing southeast Alaska pollock in Tier 5 of NPFMC harvest policy, and basing the ABC and OFL on natural mortality (0.3) and the biomass >30 cm (a proxy for exploitable biomass) for the 1999 survey. Biomass in southeast Alaska was estimated by splitting survey strata and CPUE data in the Yakutat INPFC area at 140° W. long. and combining the strata east of the line with comparable strata in the Southeastern INPFC area. This gives a **2000 ABC of 6,460 t** (28,709 t * 0.75 M), and a **2000 OFL of 8,613 t** (28,709 t * M). To assist the Council in setting the TAC for this stock, we note that the pollock catch in the Southeast and East Yakutat has never exceeded 100 t during 1991-98, and was less than 50 t in all but one year.

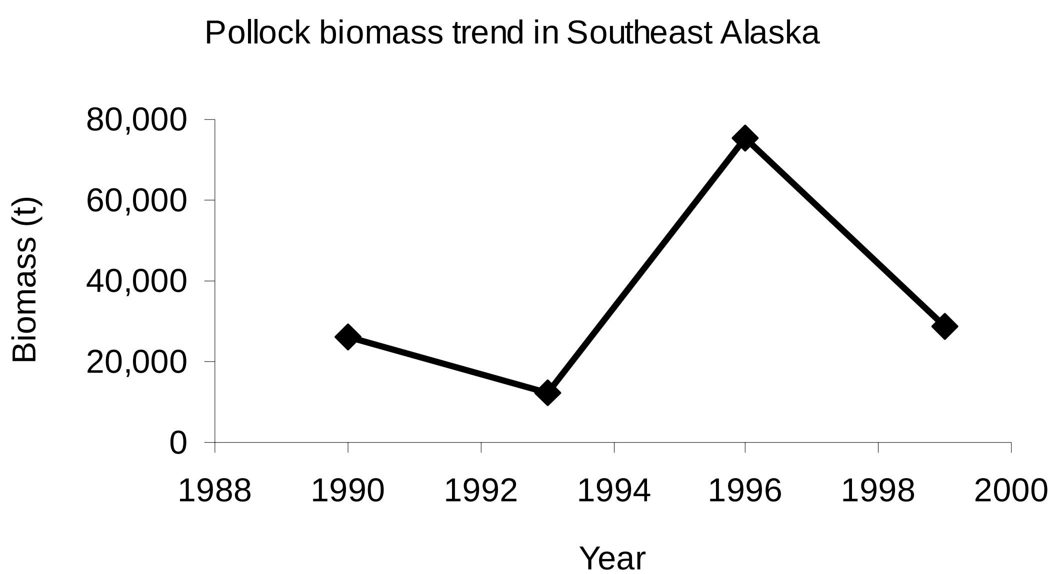

Figure 1.19--Pollock biomass trend in southeast Alaska from triennial surveys in 1990-1999.

Appendix B. Derivation of seasonal and spatial apportionment of pollock TAC in the Gulf of Alaska

As a fully utilized resource the Advisory Panel (AP) and the North Pacific Regional Management Council (Council) have usually recommended that TAC levels be set equal to ABC levels. Due to shifts in the distribution of pollock from survey to survey between management areas and the high variance in the 1999 trawl survey, Dorn et al. (1999) recommended that the distribution of pollock be based upon the four most recent triennial surveys (1990, 1993, 1996, and 1999) over a nine year period. This results in an average biomass distribution of 41%, 24.4%, 32.1%, and 2.5% in areas 610, 620, 630, 640. Since the pollock assessment now explicitly includes the pollock biomass in PWS it was further recommended that the state's GHL for pollock in PWS should be deducted prior to seasonal and area allocations. The Plan Team at its November 1999 meeting and the SSC at its December 1999 meeting concurred with these recommendations.

The final RPAs to protect Steller sea lions were put in place in 2000 by interim emergency rule. This action established four (designated A, B, C, and D) seasons in the Western and Central Gulf of Alaska and apportioned the annual TAC at 30%, 15%, 30%, and 25% to the A, B, C, and D seasons respectively. During the A and the B seasons a separate TAC was established for the Shelikof Strait conservation area (this area straddles a portion of both the 620 and 630 reporting areas) and for areas 620 and 630 outside Shelikof Strait.

The TAC for the Shelikof Strait conservation area is determined by calculating a ratio equal to the most recent estimate of pollock biomass from the Shelikof Strait EIT survey divided by the estimate of total Gulf of Alaska biomass in that year. This ratio is multiplied by the amount of the Western and Central Gulf of Alaska TAC available in the A and B seasons. The remainder of the combined TAC in the A and B seasons is then apportioned to areas 610, 620, and 630 outside Shelikof Strait based on the relative distribution of pollock biomass outside Shelikof Strait, which is 56 %, 4%, and 40 % respectively. During the C and D seasons pollock is apportioned based on the relative distribution of pollock biomass at 42%, 25%, and 33% in areas 610, 620, and 630 respectively.

Calculation of 2001 Seasonal and Area TAC Apportionments

1) Deduct the Prince William Sound pollock GHL and the West Yakutat region (area 640) annual TAC from the combined annual TAC for the W/C/WYK area.
2) Calculate seasonal apportionments of TAC for the A, B, C, and D seasons at 30 %, 15%, 30%, and 25 % of the annual TAC for the W/C area.
3) For the A and B season TACs, the allocation to the Shelikof Strait conservation area is based on the most recent survey results (2000 survey = 334,900 t, 2000 total Gulf of Alaska pollock biomass in this assessment = 705,700 t; 47.46%). Since age-1 fish are not included in the total pollock biomass, 54,400 t of age-1 fish have been deducted from the Shelikof Strait EIT survey biomass.

A season	0.4746 x A season TAC
B season	0.4746 x B season TAC

4) The remainder is then allocated to areas 610, and those portions of 620 and 630 outside the Shelikof Strait conservation area based on a four-survey average biomass distribution (summer surveys) outside Shelikof Strait.

610	0.5609 x (Total A season TAC - Shelikof A season TAC)
	0.5609 x (Total B season TAC - Shelikof B season TAC)
620	0.0408 x (Total A season TAC - Shelikof A season TAC)
	0.0408 x (Total B season TAC - Shelikof B season TAC)
630	0.3983 x (Total A season TAC - Shelikof A season TAC)
	0.3983 x (Total B season TAC - Shelikof B season TAC)

5) The apportionment for the C and D seasons for the Western and Central regions is based upon the most recent four survey average biomass distribution of pollock biomass after subtracting the 2.5 % allocated the West Yakutat region. There is no separate allocation to Shelikof Strait in the C and D seasons.

610	0.410/0.975 = 42.05%
620	0.244/0.975 = 25.03%
630	0.321/0.975 = 32.92%

610	0.4205 x C season TAC
	0.4205 x D season TAC
620	0.2503 x C season TAC
	0.2503 x D season TAC
630	0.3292 x C season TAC
	0.3292 x C season TAC

Appendix C: Description of Gulf pollock stock assessment model (SAM)

Population dynamics: The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 10, with age 10 defined as a "plus" group, i.e., all individuals age 10 and older. The model extends from 1964 to 1999 (36 yrs). The Baranov (1918) catch equations are assumed, so that

$$c_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}} [1 - \exp(-Z_{ij})]$$

$$N_{i+1\ j+1} = N_{ij} \exp(-Z_{ij})$$

$$Z_{ij} = \sum_k F_{ij} + M$$

except for the plus group, where

$$N_{i+1,10} = N_{i,9} \exp(-Z_{i,9}) + N_{i,10} \exp(-Z_{i,10})$$

where N_{ij} = population abundance at the start of year *i* for age *j* fish, F_{ij} = fishing mortality rate in year *i* for age *j* fish, and c_{ij} = catch in year *i* for age *j* fish. A constant natural mortality rate, *M*, irrespective of year and age, is assumed.

Fishing mortality is modeled as a product of year-specific and age-specific factors (Doubleday 1976)

$$F_{ij} = s_j f_i$$

where s_j = age-specific selectivity, and f_i = the annual fishing mortality rate. To ensure that the selectivities are well determined, we require that $\max(s_{jk}) = 1$ for each fishery. Following previous assessments, a scaled double-logistic function (Dorn and Methot 1990) was used to model age-specific selectivity

$$s_j^{/} = \left(\frac{1}{1 + \exp[-\beta_1(j - \alpha_1)]} \right) \left(1 - \frac{1}{1 + \exp[-\beta_2(j - \alpha_2)]} \right)$$

$$s_j = s_j^{/} \Big/ \max_j \left(s_j^{/}\right)$$

where α_1 = inflection age, β_1 = slope at the inflection age for the ascending logistic part of the equation, and α_2 , β_2 = the inflection age and slope for the descending logistic part.

Measurement error

Model parameters were estimated by maximum likelihood (Fournier and Archibald 1982, Kimura 1989, 1990, 1991). Fishery observations consist of the total annual catch in tons, C_i, and the proportions at age in the catch, p_{ij} . Predicted values from the model are obtained from

$$\hat{C}_i = \sum_j w_{ij} \; c_{ij}$$

$$\hat{p}_{ij} = c_{ij} \; / \; \sum_j c_{ij}$$

where w_{ij} is the weight at age j in year i . Year-specific weights at age are used when available.

Log-normal measurement error in total catch and multinomial sampling error in the proportions at age give a log-likelihood of

$$\log L_k = -\sum_i [\log(C_i) - \log(\hat{C}_i)]^2 \; / \; 2\sigma_i^2 + \sum_i m_i \sum_j p_{ij} \log(\hat{p}_{ij} \; / \; p_{ij})$$

where σ_i is standard deviation of the logarithm of total catch (~ CV of total catch) and m_i is the size of the age sample. In the multinomial part of the likelihood, the expected proportions at age have been divided by the observed proportion at age, so that a perfect fit to the data for a year gives a log likelihood value of zero (Fournier and Archibald 1982). This formulation of the likelihood allows considerable flexibility to give different weights (i.e. emphasis) to each estimate of annual catch and age composition. Expressing these weights explicitly as CVs (for the total catch estimates), and sample sizes (for the proportions at age) assists in making reasonable assumptions about appropriate weights for estimates whose variances are not routinely calculated.

Survey observations consist of a total biomass estimate, B_i, and survey proportions at age π_{ij}. Predicted values from the model are obtained from

$$\hat{B}_i = q \sum_j w_{ij} \; s_j \; N_{ij} \; \exp[-\varphi_i \; Z_{ij}]$$

where q = survey catchability, w_{ij} is the survey weight at age j in year i (if available), s_j = selectivity at age for the survey, and φ_i = fraction of the year to the mid-point of the survey. Although there are multiple surveys for Gulf pollock, a subscript to index a particular survey has been suppressed in the above and subsequent equations in the interest of clarity. Survey selectivity was modeled using a either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the ith year are given by

$$\hat{\pi}_{ij} = s_j \; N_{ij} \; \exp[-\varphi_i \; Z_{ij}] \; / \; \sum_j s_j \; N_{ij} \; \exp[-\varphi_i \; Z_{ij}]$$

Log-normal errors in total biomass and multinomial sampling error in the proportions at age give a log-likelihood for survey k of

$$\log \, L_k \; = \; -\sum_i [\log(B_i) \; - \; \log(\hat{B}_i)]^2 \; / \; 2\sigma_i^2 \; + \; \sum_i \; m_i \sum_j \; \pi_{ij} \; \log(\; \hat{\pi}_{ij} \; / \; \pi_{ij})$$

where σ_i is the standard deviation of the logarithm of total biomass (~ CV of the total biomass) and m_i is the size of the age sample from the survey.

Process error

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the pollock model, these annual recruitment and fishing mortality parameters are generally estimated as free parameters, with no additional error constraints. We use a process error to describe changes in fisheries selectivity over time. To model temporal variation in a parameter γ , the year-specific value of the parameter is given by

$$\gamma_i \; = \; \overline{\gamma} \; + \; \delta_i$$

where $\overline{\gamma}$ is the mean value (on either a log scale or linear scale), and δ_i is an annual deviation subject to the constraint $\sum \delta_i = 0$. For a random walk where annual *changes* are normally distributed, the log-likelihood is

$$\log \, L_{Proc.\; Err.} \; = \; -\sum \frac{(\delta_i \; - \; \delta_{i+1})^2}{2\sigma_i^2}$$

where σ_i is the standard deviation of the annual change in the parameter. We use a process error model for all four parameters of the fishery double-logistic curve.

The total log likelihood is the sum of the likelihood components for each fishery and survey, plus a term for process error,

$$Log \;\; L \; = \; \sum_k \; Log \;\; L_k \; + \; \sum_p \; Log \;\; L_{Proc.\; Err.} \; .$$