SUMMARY OF CHANGES TO THE GULF OF ALASKA POLLOCK ASSESSMENT

Relative to the November 1998 edition of the SAFE report, the following changes have been made to the pollock chapter:

Changes to the input data

1. The stock assessment was extended eastward to 140° W long. to coincide with the area open for trawling in the Gulf of Alaska (statistical areas 610-640). The annual catch and triennial bottom trawl biomass estimates were revised to correspond to this area. A small adjustment (~1%) was made to the survey biomass time series to account for unsurveyed fish in Prince William Sound based on ADF&G survey data.

2. 1999 triennial bottom trawl biomass and length composition were included.

3. 1998 fishery catch at age were included in the model.

4. 1997 and 1998 Shelikof Strait echo integration trawl survey age composition were included. (No Shelikof Strait EIT survey was conducted in 1999.)

5. 1989-98 ADF&G coastal trawl survey biomass and length composition data were evaluated in the model.

Changes in the assessment model

1. An age-structured model developed using ADModel Builder (a C++ software language extension and automatic differentiation library), introduced in the 1998 SAFE report, is the primary assessment model.

Changes in results

1. Projected age 3+ biomass in 2000 is 588,000 t.

2. The 2000 ABC recommendation for pollock in the Gulf of Alaska west of 140° W long. is 111,306 t . For pollock in southeast Alaska (East Yakutat and Southeastern areas) the ABC recommendation is 6,460 t.

Response to SSC comments

At their December 1998 meeting, the SSC commented on the method used to apportion the pollock ABC in Eastern Gulf. In this assessment we have rectified the discrepancy between assessment and management areas by extending the area covered by the assessment model to include all of West Yakutat, and by providing a separate assessment and ABC for pollock in the no trawl zone in southeast Alaska.

In addition, the SSC encouraged coordination of NMFS and ADF&G surveys in Prince William Sound and adjacent waters. Although no comparative work was accomplished in 1999, the northern Gulf was surveyed by NMFS vessels within two weeks of the ADF&G survey in PWS. An interim approach of adding the biomass estimates from the ADF&G survey of Prince William Sound and the NMFS survey was adopted pending further comparative work

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 2000 Acceptable Biological Catch (ABC) are obtained using an age-structured population model. This assessment contains new information from the following sources: a) biomass estimates and length composition from the 1999 triennial bottom trawl survey, b) pollock age composition from the 1997 and 1998 Shelikof Strait echo integration trawl (EIT) surveys, and b) age composition and catch from the 1998 pollock fishery. A pollock biomass time series for 1989-98 from the Alaska Department of Fish and Game (ADF&G) coastal bottom trawl survey is also evaluated for consistency with other information on population trends.

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 concentrations 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 1998a). Summer distributions based on 1998 fishery data 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 (Fig. 1.1).

The separation of pollock stocks in Alaska into Eastern Bering Sea and Gulf of Alaska populations 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 by 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 evolution 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 of Gulf of Alaska pollock was derived by the NMFS Regional Office as a blend of weekly processor reports and observer at-sea discard estimates (Table 1.2). Catches included the state-managed pollock fishery in Prince William Sound. In 1996-99, the pollock quota 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 pollock fishery to reduce interactions between the fishery and marine mammals. The duration and intensity of a fishing season is a function of many factors including the TAC, the abundance of pollock in the region, the number of vessels operating in the region, the fishing capacity of the vessels, the proportion of the catch allowed in each season, and alternative fishing opportunities . Time and area allocations of TAC changed over the last six years making comparisons among years difficult. 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 NPFMC 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 NPFMC 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. The annual Gulf pollock TAC for 1977-99 is given in Table 1.1.

Annual scientific research catches will be reported beginning with the current SAFE report (Table 1.1) Research catches of pollock occur in NMFS longline, trawl, and echo integration trawl surveys and average less than 0.2% of the gulfwide pollock commercial catch.

1998 Fishery

The gulfwide TAC for 1998 was 124,730 t, with 119,150 t in the Western and Central Gulf of Alaska. The reported pollock catch for 1999 was 117,386 t in the Western and Central Gulf of Alaska, and 8,022 t in the Eastern Gulf of Alaska (Table 1.2). The duration of pollock seasons in 1998 varied by region. In area 610, the winter, summer and fall seasons were open for 6, 13, and 7 days, respectively. In area 620, the winter, summer and fall seasons were open for 13, 30, and 44 days, respectively. In area 630, the winter, summer and fall seasons were open for 18, 11, and 15.5 days, respectively (Table 1.3). The spatial distribution of catches by trimester is shown in Figure 1.1.

1999 Fishery

The gulfwide TAC for 1999 was 100,920 t, with 92,480 t in the Western and Central regions. As of November 12, 1999, the NMFS Regional Office reported that a total of 91,617 t of pollock was harvested in the Western and Central Gulf of Alaska, and 1,763 t was harvested in the Eastern Gulf of Alaska (Table 1.2). The duration of pollock seasons in 1999 varied by region. In area 610, the winter, summer and fall seasons were open for 11, 6, and 6.75 days, respectively. In area 620, the winter, summer and fall seasons were open for 28, 10, and 25.5 days, respectively. In area 630, the winter, summer and fall seasons were open for 7, 9, and 6.5 days, respectively.

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. ADF&G bottom trawl estimates of biomass and length composition were also evaluated in the model. Fisheries length composition data are used directly in the model during the early part of the time period (1964-71) when age data were unavailable.

Fishery Age and Length Composition

Estimates of age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths) and were combined for all seasons and statistical areas for the years 1964-98 (Table 1.4, Fig 1.2).

Fishery Catch at Age

Pollock otoliths collected during the 1998 fishery were aged using the revised criteria described in Hollowed et al. (1995). Age samples were used with length-frequency samples to estimate catch at age using age-length keys (Kimura 1989). Age and length samples from the 1998 fishery were stratified by trimester and statistical area (when possible):

Time strata	Number aged		Number measured	
	Males	Females	Males	Females
1st trimester	393	413	19,874	19,907
2nd trimester	347	376	25,374	28,501
3rd trimester	184	200	33,707	34,752

The 1998 catch-at-age data showed strong 1988 and 1989 year classes, but also an influx of younger fish, primarily age 3-5 (Table 1.4 and Fig. 1.3). The 1988 and 1989 year classes (ages 9 and 10) were most abundant in the first trimester catch. In the second trimester, the 1994 year class was dominant in areas 620 and 630, while the 1995 year was dominant in area 610. The 1994 year class was most common in the third trimester catch in all areas (Fig 1.3). The 1995 year class was unexpected because this year class had not been particularly common in earlier Shelikof Strait EIT surveys. However, age-1 fish were relatively common in the 1996 bottom trawl survey. Younger pollock were usually surface-aged, while the break-and-burn technique was used to age older fish. As a check to ensure that the age-3 fish in the otolith samples were not mis-aged from the strong 1994 year class, a sample of otoliths (n = 69) that had originally been assigned age 3 or 4 were re-aged using the break-and-burn technique. The resulting ages were highly consistent with the surface ages (97% agreement). The age-3 fish were most common in area 610 in 1998, suggesting a parallel with the unexpected appearance 1989 year class.

Prince William Sound Fishery Length Frequency

ADF&G provided length frequency data from the fishery on spawning aggregations in the entrance to Prince William Sound in 1996, 1997 and 1998. These data were dominated by large pollock in all three years (Fig. 1.4). In 1997 and 1998, there is evidence of a second mode of smaller fish, which may represent recruitment of the 1994 year class to the spawning population in PWS.

Triennial Bottom Trawl Survey

The Alaska Fisheries Science Center's (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted the sixth comprehensive triennial bottom trawl survey during the summer of 1999. For the first time since 1987, the 1999 bottom trawl survey included deep water strata. This survey was conducted from chartered commercial bottom trawlers. All vessels used standard RACE Division Poly-Nor'eastern high opening bottom trawls rigged with roller gear. These trawls are constructed with 5" stretched-mesh polyethylene web with a 1-1/4" mesh nylon liner in the cod end. Trawl tows were 15 min. in duration. A total of 764 successful tows were achieved throughout the survey area. A biomass estimate for 1975 is 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), and was included in triennial biomass time series to provide information on biomass trends prior to the inception of gulfwide surveys in 1984.

The 1999 gulfwide biomass estimate of pollock was 632,763 t (95% Confidence Interval (CI) 158,246 t 1,107,279 t) (Table 1.5) . 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 change for the 1990, 1993, and 1996 surveys was applied (2% increase).

An adjustment was 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 from 28 June to 12 July, 1999, using a standard ADF&G 400 mesh eastern trawl. The survey occurred within two weeks of the NMFS survey in adjacent waters outside PWS. The preliminary biomass estimate for the PWS survey was 6,304 t ± 2,812 t (95% CI) (W. Bechtol, ADF&G, 1999, pers. comm.). This biomass represents a large decrease from the biomass estimate of 21,220 t from the ADF&G trawl survey in summer of 1997 (Bechtol 1998b). 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%. Since this adjustment factor is based on a single year, it probably does not adequately describe the mean distribution of biomass in PWS relative to the rest of the Gulf. However, 1999 is the only year that simultaneous surveys occurred inside and outside PWS. We consider this an interim approach to assessing PWS pollock, and anticipate clarification of the relationship between pollock in PWS and the adjacent waters of the northern Gulf of Alaska from research in progress. However, additional comparative work is needed to incorporate the ADF&G surveys more accurately in the assessment. Changing to a biennial Gulf survey schedule will also facilitate greater coordination with the ADF&G biennial schedule.

The 1999 point estimate of pollock biomass west of 140° W long was 606,295 t, a 9% decline from 1996 (Table 1.6). The long term trend in pollock biomass west of 140° W long been very stable (Fig. 1.5). However, several factors complicate interpretation of the 1999 biomass estimate. First, bottom temperatures in 1999 were generally cooler than during other triennial surveys (Fig. 1.6). 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 (Fig. 1.7). For example, a single tow of 10.9 t in the Davidson Bank survey strata resulted in a CPUE approximately seven times larger than the next largest tow. We assessed sensitivity to this large catch by setting the CPUE equal to the next largest CPUE, and re-estimating the biomass (Miller 1986). This "winsorized"estimate was 30% lower than the stratified random estimate. Large catches of pollock also occurred during earlier triennial surveys. For example, a tow in 1987 yielded a pollock CPUE that was 71% as large as this tow. However, the coefficient of variation of the gulfwide biomass estimate in 1999, CV = 0.38, is more than double any previous triennial survey, suggesting that the spatial distribution of pollock may have been patchier in 1999 than during previous survey years.

Despite these concerns, it is clear that regional distribution of pollock shifted between the 1996 and 1999 bottom trawl surveys. In 1999 the largest concentration of pollock biomass was estimated to be in the Shumagin area (72%), followed by the Kodiak (18%), Chirikof (9%) and West Yakutat areas (1%). Relative to 1996, pollock biomass estimates in southeast Alaska (east Yakutat and Southeast areas combined) decreased by 46% (see appendix).

Bottom Trawl Age Composition

Estimates of numbers at age from the bottom trawl surveys (1984, 1987, 1990, 1993 and 1996, Table 1.7) were 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). Because age composition for the 1999 triennial trawl survey is not yet available, length composition data was used in the model. Length composition data show a mode of age-1 pollock and low abundance of fish in the 20-40 cm range (Fig 1.8). A mode at 45 cm probably represents the 1994 year class. The mode of age-1 fish progressively shifts to larger fish from west to east, possibly reflecting growth during the survey, which was conducted from west to east over the course of 2 ½ months. In the Southeastern area, there is an additional mode at 35 cm which was not found in any other area.

Shelikof Strait Echo Integration Trawl Survey

No EIT survey was conducted in Shelikof Strait during 1999. Delays in the scheduled shipyard work to complete repairs to the R/V *Miller Freeman* prevented the vessel from being fully operational in time for the survey. Thus, the most recent Shelikof Strait EIT survey was conducted during March 1998, and represented the latest in the series of surveys which have been conducted annually since 1981 (except 1983) to assess the spawning biomass of pollock in the Shelikof Strait area (Guttormsen and Wilson 1998).

The 1998 biomass estimate for pollock in Shelikof Strait was 489,900 t (Guttormsen and Wilson, 1998). This estimate was the seventh estimate made using the more sophisticated acoustic system. As in previous assessments, the biomass time series was adjusted to allow comparison with estimates from earlier surveys (1981-91) which were generated with an older acoustic system (Table 1.6). Earlier work demonstrated that similar biomass estimates were obtained between the present acoustic system and the older system when the volume backscattering (S_v) threshold of the new system was adjusted to -58.5 dB (Hollowed et al. 1992). Because of the newer system's lower noise level, abundance estimates since 1992 have been based on an S_v threshold of -69 dB. For the 1992 and 1993 surveys, a biomass estimate was produced for each S_v threshold. The average of the two biomass ratios (biomass adjusted to -58.5 dB/biomass adjusted to -69 dB) for these surveys was used to adjust current abundance estimates (-69 dB) to values comparable with the earlier estimates (Hollowed et al. 1994). The average ratio (0.79) has been used since 1994 to adjust the abundance estimates.

Echo Integrated Trawl Survey Length Frequency

Annual length frequency distributions from the 1989 to 1998 acoustic mid-water trawl surveys in Shelikof Strait show the progression of the strong 1988 year class through the population (Fig. 1.9). In recent years, a strong 1994 year class was evident. The 1998 Shelikof Strait EIT length frequency data show evidence of a weak 1995 and 1996 year classes and a moderate 1997 year class. Because age data were available for all survey years, length frequency data from the Shelikof EIT survey in 1990-98 were not included in the assessment model.

Echo Integrated Trawl Survey Age Composition

Estimates of numbers at age from the spring EIT survey in Shelikof Strait (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). In 1998, the 1994 year class dominated the age composition. The number of age-1 fish (the 1997 year class) in the Shelikof Strait survey was estimated as 390.1 million, placing it 5th in abundance out of 14 survey estimates of age-1 abundance.

Egg Production Estimates of Spawning Biomass

Estimates of spawning biomass in Shelikof Strait derived from egg production methods were included in this assessment. 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 1.6). 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 this assessment model.

Alaska Department of Fish and Game Surveys

The Alaska Department of Fish and Game (ADF&G) has conducted bottom trawl surveys of nearshore areas of the Gulf of Alaska since 1987 (Blackburn and Pengilly 1994). Although these surveys are designed to monitor population trends of Tanner crab and red king crab, walleye pollock and other fish are also sampled. Bottom trawls were first utilized to survey the crab populations in 1980 and completely replaced pot gear surveys in 1988 (Urban 1993). Standardized survey methods using a 400 mesh eastern trawl were employed from 1987 to the present. The survey is designed to sample 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.

Although there is considerable overlap between the AFSC triennial survey and the ADF&G survey, the ADF&G survey has a higher density of sampling stations in the nearshore areas. In addition, the ADF&G

survey samples some areas that are not assessed by the AFSC vessels. 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. 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 1.6).

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. 1.10). 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.

We evaluated the ADF&G survey data using an assessment model that treated the combined area ADF&G area-swept biomass time series as an index of abundance. Our interest in this survey time series is twofold. First, domed-shaped selectivity patterns are typically estimated for the AFSC triennial survey (Hollowed et al. 1998), raising the possibility of an overestimate of stock size if the older unsurveyed pollock are not present. The ADF&G survey, by concentrating in nearshore waters, provides a means of evaluating whether some fraction of the larger pollock are unassessed by the AFSC triennial survey. Second, if the survey provides a reliable index of stock size, inclusion in the assessment model would reduce uncertainty.

FOCI 1999 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 1999 Kodiak monthly precipitation, 2) wind mixing energy at [57N, 156W] estimated from 1999 sea-level pressure analyses, 3) advection of ocean water in the vicinity of Shelikof Strait inferred from drogued drifters deployed during the spring of 1999, 4) rough counts of pollock larvae from a survey conducted in May 1999, and 5) estimates of age 2 pollock abundance from this years assessment.

Analysis: Monthly total Kodiak precipitation for January through June 1999 was 122%, 48%, 66%, 93%, 73%, and 180%, respectively, of the 30-year (1962-1991) mean monthly averages. 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. This year, precipitation was quite low, except for January and June, and fresh-water runoff was likely lower than usual. Based on this information, the forecast element for Kodiak rainfall has a score of 1.85. This is "average" on the continuum from 1 (weak) to 3 (strong).

Monthly averaged wind mixing at the exit area of Shelikof Strait was lower than the monthly 30-year means during the entire January through June period, averaging 57%, 87%, 26%, 52%, 65%, and 59% of the 30-year mean for each month, respectively. Monthly averaged mixing has not been as high as the 30-year monthly mean since January 1997. Although lower-than-average wind mixing during the period when early-stage larvae are in the area (late April, May, early June) is considered beneficial to their survival, the lack of strong mixing during winter is thought to limit the supply of nutrients for later food production. Thus the lack of strong winter mixing keeps this year’s prediction from being "strong" The wind mixing score for this year is 2.26 which equates to "average to strong."

Wind stress has been show to be correlated with transport in Shelikof Strait. Based on analysis of regional wind stress for spring 1999, we assign a value of 2.0 (average) for the advection component of the prediction.

The larval index, based on late larval biological survey rough counts, was slightly lower than average this year compared to other years giving a prediction of weak-average with a numerical score of 1.7.

The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transitions. The data set consisted of estimates of age 2 abundance from 1964-99, representing the 1962-97 year classes (see Table 1.11). There were a total of 36 recruitment data points. The 33% and 66% percentile cutoff points were calculated from the full time series (33%=0.407 billion, 66%=0.764 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 1999 year class could be predicted from the size of the 1997 year class. The 1997 year class was estimated to be 0.182 billion and was classified as weak. The probabilities of other recruitment states following an weak year class for a lag of 2 years (n=34) are given below:

99YC		97YC	Probability	Count
Weak	follows	Weak	0.059	2
Average	follows	Weak	0.059	2
Strong	follows	Weak	0.176	6

The probability of a strong year class following a weak year class was higher than the combined probability of an average year class following a weak year class and a weak year class following a weak year class, so the prediction element from this data source was classified as strong and given a score of 2.7.

A rationale for weighting each data component is as follows. Rain and wind were weighted the same given that there were no missing data or any other unusual circumstances this year. The time series of recruitment was weighted equally with rain and wind. Advection was weighted lower than wind, rain, and time sequence of recruitment (because this estimate is more qualitative) but higher than the larval index. The larval index received the lowest weight because an average index really does not tell us much about recruitment.

Conclusion: Based on these five elements and the weights assigned in the table below, the FOCI forecast of the 1999 year class is average.

	Weights	Score	Total
Time Sequence of Recruitment	0.23	2.7	0.621
Rain	0.23	1.85	0.4255
Wind Mixing	0.23	2.26	0.5198
Advection	0.16	2.00	0.32
Larval Index-abundance	0.15	1.70	0.255
Total	1.00		2.1413 = Average

ANALYTIC APPROACH

Model Structure

Age-structured models for the period 1964 to 1999 (36 yrs) were used to assess Gulf of Alaska pollock. Population dynamics were modeled using standard formulations for exponential mortality and the Baranov 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 (1964-99)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-98)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-98)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-98)	Multinomial	Sample size = 60
Bottom trawl survey biomass (1975-99)	Log-normal	Survey-specific CV = 0.11 - 0.38
Bottom trawl survey age comp. (1973-96)	Multinomial	Survey-specific sample size = 38-74
Bottom trawl survey length comp. (1999)	Multinomial	Sample size = 60
Egg production biomass (1981-92)	Log-normal	Survey specific CV = 0.10-0.25
ADF&G trawl survey biomass (1989-99)	Log-normal	CV = 0.2
ADF&G survey length comp. (1989-99)	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, 1998-99)	Log-normal	CV =1.0

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. 1997). 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). The catchability coefficient for the egg production survey was estimated independently of the EIT survey of Shelikof Strait, unlike previous assessments where the two catchability coefficients were linked. Although both the EIT and the egg production surveys should measure the absolute biomass spawning in Shelikof Strait, both surveys are dependent on scaling factors (i.e., acoustic target strength) that may be incorrect without invalidating the survey as an index of abundance. The additional assumption that catchability is the same is not needed for both surveys to provide inferences on population trends.

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 model was fit to length frequency data from the POP fishery by converting predicted age distributions (as modified by age-specific selectivity) to predicted length distributions using an age-length transition matrix. The transition matrix for length data was defined from a von Bertalanffy growth function of the form:

$$L_a = L_\infty + (L_1 - L_\infty)\exp[-k(a-1)]$$

where L_∞ is the asymptotic length, L_1 is the size at age 1, and k is the growth parameter. Parameters for this equation were estimated from 1991 and 1992 EIT survey length at age data. The following length bin designations were used:

7 Bins (cm): 17 - 24, 25 - 31, 32 - 38, 39 - 45, 46 - 50, 51 - 55, 56 - 70.

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 1964-99 = 36	Estimated as log deviances from the log mean; recruitment in 1964-68, and in 1998 and 1999 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated
Fishing mortality	Years 1964-99 = 36	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) = 140	Estimated as deviations from mean selectivity and constrained by random walk process error
Survey catchability	No. of surveys = 4	AFSC bottom trawl survey catchability not estimated, other catchabilities estimated on a log scale
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	95 conventional parameters + 140 process error parameters + 2 fixed parameters = 237	

Parameters Estimated Independently

The life history of pollock is characterized by biological parameters estimated independently of the assessment model. These parameters are used to estimate spawning and population biomass, and obtain model predictions of fishery and survey biomass conditional on the parameters estimated in the model:

- Natural mortality (M)
- Proportion mature at age.
- Weight at age and year by fishery and by survey

Natural mortality was assumed to be 0.3 for all ages. 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. Hollowed et al. (1997) developed a model that accounted for predation mortality. This model suggested that age-2 natural mortality may be closer to 0.6.

We used the maturity at age from Hollowed et al (1991):

				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

Weight-at-age estimates used in the assessment model were derived from length-weight and length-age relationships estimated by Hollowed et al. (1995). Parameters for these relationships were derived using growth information from six strong cohorts of pollock (1972, 1975-1979). Estimates of mean weight at age were determined by a five-step process. First, length at age was estimated from fits to the von Bertalanffy growth equation for each of the six cohorts for each sex and area cell. Second, the estimates of length at age were averaged across years and area to produce an expected length at age for each sex. Third, parameters for a length-weight relationship were calculated for each year class, sex, and area using the equation:

$$W = a \; L^{b}$$

where L and W were the observed length and weight. Fourth, the length-weight parameters for each year class for each sex and area were applied to the estimate of mean length at age for the sex/area cell. These estimates were averaged over year class to obtain an estimate of weight at age for each of the sex/area cell. Finally, the estimates were averaged over sex and area to obtain a single estimate of weight at age. Growth parameters were also estimated from length at age data from the 1991 and 1992 Shelikof EIT survey.

Gulf pollock growth parameters are given below:

Growth parameter (males and females combined)	Strong cohorts (1972, 1975-1979)	1991 and 1992 Shelikof Strait EIT survey
L_1	12.7 cm	12.7 cm
L_∞	56.20 cm	59.7 cm
k	0.328	0.234
a	1.27 E-05	
b	2.885	

These growth parameters were used to develop the transition matrix used to incorporate length frequency data in the assessment model.

The nominal sample sizes for the multinomial age composition likelihoods were set equal to the approximate number of hauls sampled for ageing structures. Pennington and Vølstad (1994) found that even extensive resource surveys have a small effective sample size (< 100) due to intra-haul correlation. We assume that the number of hauls sampled may be more indicative of the effective sample size than the total number of otoliths sampled in a given year. The sample sizes in the multinomial likelihood for the fishery and the AFSC bottom trawl survey were set equal to the estimated number of hauls sampled for pollock otoliths (to a maximum of 400) (Table 1.8).

Model selection and evaluation

Comparison with the stock synthesis program

Moving to a new modeling environment affords an opportunity to check for errors in both the new and old assessment models and to compare optimization algorithms. A similar result with similar data and assumptions allows one to have higher confidence in both modeling approaches. For the comparison between ADModel Builder and stock synthesis we used identical data with all time series updated to 1999 except the triennial survey data. Our objective was to compare models with identical population dynamics and statistical assumptions using the final configuration in the last pollock assessment. This goal was not entirely achieved because stock synthesis has options for truncating age compositions at different ages in different years that we chose not implement in the new model. These differences, however, were very minor.

Figure 1.11 shows side by side comparisons of population biomass, recruitment, fits to survey biomass estimates and age composition, and selectivity patterns. Overall, the models produce similar results. Population biomass differed by less than 12% throughout the modeled time period, with less than a 5% difference for the final ten years. The average difference was close to zero, indicating that there were no consistent differences between models. Recruitment estimates were less similar, but differed by no more than 10% for the last 20 years of the model. The average difference in recruitment was also close to zero. The fits to the age and length composition data were similar, with stock synthesis obtaining a slightly better fit to the EIT survey length composition and the fishery age composition, while AD model builder obtained a better fit to the fishery length composition. These differences may be due to slight differences in how the length and ageing error transition matrices where implemented in stock synthesis and ADModel builder.

When the ADModel builder model was configured to mimic the Gulf pollock stock synthesis model, it was necessary to use a weaker convergence criteria for the maximum gradient, and the Hessian matrix was not invertible, indicating the parameters had not converged. Since convergence in stock synthesis is based on the change in the likelihood, not parameter gradients, it tends to be more forgiving of poorly estimated parameters than AD model builder. Stock synthesis also adaptively sets parameters to constant values when they approach their bounds. We considered these convergence problems as a diagnostic of the stock synthesis model. Parameters that were poorly estimated included the initial age composition parameters, recruitment parameters for the early part of the modeled time period, and several of the double-logistic selectivity parameters. These parameters had no affect on model results for the later part of the modeled time period. In the section on model selection below, we consider alternative parameterizations of selectivity.

We also imposed constraints 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, as in the stock synthesis implementation, 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 1964-99. We also used the same penalty for log deviations in recruitment for 1964-68, and in 1998 and 1999. These relatively weak constraints were sufficient to obtain converged parameter estimates.

Model selection

For the Gulf pollock fishery, potential causes of non-stationary selectivity include the changing composition of the fleet (Megrey 1989), change in pollock age composition as strong years pass through the populations (Hollowed and Megrey, 1989), and changes in how the fishery is regulated. Figure 1.12 compares a model where changing selectivity is modeled using random walk process error with the grouped-year approach used in previous assessments. Although the patterns are similar for both models, the random walk approach allows selectivity to change without having to make difficult choices about which years to group together. Although more parameters are needed with a process error approach, the effective degrees of freedom is much less than the number of parameters, and we considered this method an improvement over previous approaches.

We also evaluated alternative ways to model selectivity to the Shelikof Strait EIT survey and the AFSC bottom trawl survey. We began by estimating individual age-specific selectivity coefficients as in the CAGEAN model (Deriso et al. 1985). We then considered parametric functions which showed the same general pattern as the individual selectivity coefficients. A parametric function requires fewer parameters, and smooths the relationship between age and selectivity. Parametric functions evaluated included the double-logistic curve (see appendix), a single logistic curve, and an exponential-logistic curve (Thompson 1994) where age-specific selectivity is given by

$$s_j^{/} = \left(\frac{1}{1 + \exp[-\beta_1 (j - \alpha_1)]} \right) \exp\left[-\beta_2 (j - 2)\right] ,$$

$$s_j = s_j^{/} \ / \ \max_j \ (s_j^{/})$$

where α_1 = inflection age, β_1 = slope at the inflection age for the ascending logistic part of the equation, and β_2 = the slope for the descending exponential part. Note that exponential part of the curve is equal to one at age 2, so that the curve needs to be rescaled so that the maximum selectivity is one. We also tried the self-scaling parameterization of the exponential double logistic in Thompson (1994), but rejected it in favor of the above parameterization because the maximum selectivity occurred between two ages, so that the curve still needed to be rescaled.

For the Shelikof Strait EIT survey, the individual selectivity coefficients show maximum selectivity at ages two and three, then an irregular decline in selectivity with increasing age (Fig. 1.13). For a survey that is targeted primarily on spawning aggregations, this is a puzzling and unexpected result. We also estimated double-logistic and exponential-logistic curves where age-2 and age-3 selectivity were estimated as separate coefficients. There is an indication of lower selectivity for the age-4 and age-5 fish, supporting previous work using non-parametric selectivity curves that also show reduced selectivity for these ages (Hollowed et al. 1997). Examination of residual plots showed that modeling the Shelikof EIT with a two-parameter descending logistic curve provided an adequate description of age-specific selectivity for the strong year classes under the current set of model assumptions. In recent years, the residuals for the weaker year class in the Shelikof EIT survey have been consistently negative. One possible explanation for the flat selectivity pattern is that all immature fish that will eventually spawn in Shelikof Strait congregate Shelikof sea valley during the winter months as a rehearsal for spawning. Alternatively, and perhaps more plausibly, the natural mortality of younger fish may be higher than the model assumption. Models with higher juvenile mortality due to predation show a gradually ascending selectivity pattern for the Shelikof EIT survey (Hollowed et al. in press). We intend to explore models with higher juvenile mortality in future assessments, however, it is important to note that estimates of mature and exploitable biomass should not strongly depend on assumptions concerning the mortality of age-2 and age-3 fish.

Previous assessments have estimated a dome-shaped selectivity pattern for the bottom trawl survey (Hollowed et al. 1998). This result is plausible given the nearshore distribution of large pollock. Individual selectivity coefficients for the bottom trawl survey show reduced selectivity for the age 7, 8, and 10 fish, but high selectivity for the age-9 fish (Fig 1.13). Double-logistic and exponential-logistic curves show a similar dome-shaped pattern of increasing selectivity to age-7 and decreasing selectivity for the older fish. We concluded that the double-logistic curve used in previous assessments provides an adequate description of age-specific selectivity.

Evaluation of ADF&G survey

To evaluate the consistency of the ADF&G survey with other information on Gulf pollock population trends, components were added to the likelihood for the survey biomass index (log-normal) and length composition (multinomial). Initially, these components were given low emphasis (survey biomass index CV = 10, sample size for length composition =10). Survey catchability was estimated as a free parameter. To fit the length composition data, an empirical age-length transition matrix was estimated using second and third trimester fishery age and length data during the years covered by the survey (1989-98). Unbiased length distributions at age were estimated for each year using age-length keys, then averaged across years. The following length bin designations were used: 6 Bins (cm): 25 - 34, 35 - 41, 42 - 45, 46 - 50, 51 - 55, 56 - 70, 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.

Despite the low emphasis on the survey index, the trend in the survey index closely follows the population trend (Fig 1.14). Length-composition residuals indicate an adequate fit, except for the 1994 length composition. Length-frequency data for the ADF&G survey in 1994 show an abundance of fish in the 25-35 cm range that were not present in any other year (Fig. 1.10). The individual age-specific selectivity coefficients for ADF&G coastal survey are quite irregular when no additional constraints are placed on them, reflecting the difficulty of estimating age-specific selectivity using coarsely binned length data (Fig. 1.13). When a first difference constraint is placed on the individual selectivity coefficients, selectivity increases steadily to age 10. This result is in accord with previous observations that the ADF&G survey captures mostly older fish (Hollowed et al. 1998). A two-parameter ascending logistic curve matches this pattern closely. A significant correlation between a survey index and predicted values from a model with low emphasis on the index helps to validate the survey as an index of abundance (Ralston and Ianelli 1998). For the model predictions and survey observations in Fig. 1.14, the correlation is highly significant (p=0.003). Including the ADF&G survey time series results in a slightly lower biomass trajectory during the 1990s, but does not significantly degrade model fit to other data sources (Fig. 1.15). Based on this evaluation of the ADF&G survey, we include the ADF&G survey in the base-run model, however alternate harvest projections for 2000 were also made using a model without the ADF&G survey.

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 1.16 and 1.17 show residuals of the fit to the fishery, the Shelikof Strait EIT survey, and the AFSC trawl survey age compositions. 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 fairly clear tendency of negative residuals for the age-4 and age-5 fish. This is a result of the decision to use a descending logistic curve to model survey selectivity.

The model fits to survey biomass estimates are similar to previous assessments (Hollowed et al. 1998) (Fig. 1.18). The model is still unable to the fit high biomass estimates in early 1980’s from the Shelikof Strait EIT survey. 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 1.9. Table 1.10 gives the estimated population numbers at age for the years 1964-99. Table 1.11 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1964-99 (see also Fig. 1.19). Stock size in peaked in early 1980s at approximately twice the average unfished stock size, and is currently close to 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 1993-98 is shown in Figure 1.20. The current estimated trend in spawning biomass for 1964-99 is consistent with previous estimates. All time series show a similar pattern of increasing spawning biomass to the early 1980's, an abrupt decline, and then a gradual decreasing trend since 1985. The current assessment estimates higher spawning biomass prior to the increase in the 1980's, but the confidence intervals on population biomass prior to 1970 are very wide (Fig 1.19). The estimated 1998 age composition from the current assessment is also highly consistent with the 1998 estimate, with the exception of a increase in the strength of the 1995 year class at age 3 (Fig. 1.21). This change is due the relatively strong appearance of the age-3 fish in the 1998 fishery age composition.

PROJECTIONS AND HARVEST ALTERNATIVES

Reference Fishing Mortality and Yields

Estimates of F30%, F35%, and F40% were obtained using the life history characteristics of Gulf pollock (Table 1.12). Weight-at-age vectors were the same as in previous assessments (Hollowed et al. 1998). An evaluation of seasonal and interannual trends in Gulf pollock weight at age is a priority for future assessments. Equilibrium estimates of biomass and catch were based on mean 1979-98 recruitment (875 million). The recruitment estimate for 1999 was not used because of its low precision (CV = 0.6). Spawning was assumed to occur on March 15th , and female spawning biomass was calculated using a weight at age appropriate for that time of the year. The SPR at F=0 was estimated as 0.707 kg/recruit.

FSPR rates depend the selectivity pattern of the fishery. Selectivity in the Gulf 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 pollock have been managed with time and area restrictions, and selectivity has been fairly stable since 1992 (Fig 1.12). For SPR calculations, we used a selectivity pattern based on an average of the selectivity pattern during 1992-99. There is evidence of lower selectivity for the younger fish during 1995-97. This may be due to avoidance of smaller fish, or because fewer small fish are retained as a result of greater use of square mesh codends in the fishery. Studies indicate that many of the fish that escape through square mesh codends will eventually die (Erickson et al. 1999). Selectivity of the younger fish increased in 1998, possibly reflecting increased targeting on the 1994 year class by the fishing fleet. For this reason we did not implement the approach used in previous assessments (Hollowed et al. 1998), where different selectivity patterns were used to calculate the FSPR rate and to make short-term projections. In addition, longer term projections (10-12 year) based on average selectivity are required for MSFCMA status determination. Alternative stock projections using the short-term selectivity pattern in Hollowed et al. (1998) indicated that the 2000 ABC would be reduced by approximately 10%.

Gulf of Alaska pollock FSPR harvest rates are given below:

FSPR rate	Fishing mortality	Equilibrium under average 1979-98 recruitment				
		Avg. Recr. (Million)	Total 3+ biom. (1000 t)	Female spawning biom. (1000 t)	Catch (1000 t)	Harvest rate
F100%	0.000	875	1720	619	0	0.0%
F45%	0.325	875	999	278	161	16.2%
F40%	0.391	875	930	247	174	18.7%
F35%	0.475	875	860	216	186	21.7%
F30%	0.585	875	787	186	198	25.1%

The B40% estimate of 247,000 t is similar to the estimate of 240,000 t in the 1998 assessment based on average recruitment for all years (1964-98) (Hollowed et al. 1998). The proxy for BMSY under tier 3 is B35% (216,000 t). The F40% equilibrium harvest rate (catch/age 3+ biomass) of 19% is comparable to the F40% harvest rate of 19-21% for Eastern Bering Sea pollock (Ianelli et al. 1998). Gulf of Alaska pollock show faster growth, but delayed maturity compared to Eastern Bering Sea pollock. These factors would compensate each other in the estimate of the FSPR harvest rate.

Information on recent year class strength

Survey information on recent year class strength is generally consistent with FOCI predictions for 1997 and 1998 year classes, and suggests that the strength of these year classes will be in the middle third of the recruitment distribution. Consequently, stock projections for 2000 were made with the assumption of average recruitment in 2000. Model estimates of recruitment abundance for the 1996 and 1997 year classes (70 and 182 million respectively) indicate that they are weak year classes (in the lower third of the distribution). Because of poor to average recruitment since the 1994 year class, Gulf pollock biomass is expected to decline over the next three years.

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

Year of recruitment	1999	2000	2001
Year class	1997	1998	1999
FOCI prediction	Average	Average	Average
Survey information	1998 Shelikof EIT survey age-1 estimate is 390 million: (5th in abundance out of 14 surveys)	1999 bottom trawl age-1 (<23 cm) estimate is 154 million. (3rd in abundance out of 7 surveys)	

Harvest and Abundance in 2000

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 2000 is projected to be 214,900 t, which is below B40% (247,000 t), thereby placing Gulf pollock in sub-tier "b" of Tier 3. Estimates of OFL and several ABC alternatives in 2000 are provided for two models: the base-run model, which incorporates the ADF&G survey time series, and, since this is the first year that the ADF&G survey time series has been used, a model without the ADF&G survey data:

	Base-run model		Without the ADF&G survey	
Harvest policy	2000 fishing mortality rate	2000 catch	2000 fishing mortality rate	2000 catch
F45% adjusted	0.28	94,962 t	0.31	113,523 t
F40% adjusted (Maximum permissible)	0.34	111,306 t	0.37	132,857 t
F35% adjusted (OFL)	0.40	130,758 t	0.44	155,784 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 comparison, the age 3+ biomass in 2000 is projected to be 588,000 t for the base-run model and 651,000 t for the model without the ADF&G survey data. These estimates are similar to biomass projections made last year, which ranged from 581,500 t to 674,500 t (Hollowed et al. 1998).

ABC recommendation

By including the ADF&G survey time series, the base-run model provides a degree of precaution in setting the ABC in light of a 1999 triennial survey biomass estimate that indicates relatively little change in stock size since 1996, but is more uncertain than previous triennial surveys for several reasons. For this reason, we recommend a 2000 ABC of 111,306 t based on a F40% adjusted harvest policy. This represents an increase of 28% from the projected 2000 ABC in the 1998 assessment (Hollowed et al. 1998) for the Central and Western Gulf (80,139 t).

The higher projected 2000 ABC is caused by several factors:
1. A larger assessment area including Prince William Sound and all of West Yakutat.
2. Increased abundance of the 1995 year class based on 1998 fishery age composition data (492 million at age 2 as compared to 181 million in the 1998 assessment). This represents increase in relative abundance of the 1995 year class from 21% to 56% of mean 1979-98 recruitment.
3. The use of average fishery selectivity for 1992-99 both to calculate SPR rates and to project harvests. Last year's assessment used the 1985-98 average selectivity to calculate SPR rates, and 1994-98 average selectivity to project yields.
4. The correction of a minor error in the calculation of SPR rates in last year's assessment.

An appendix evaluates various approaches to apportioning the ABC, and recommends a regional allocation based on a 4-survey average of triennial surveys (41.0% Shumagin, 24.4% Chirikof, 32.1% Kodiak, 2.5% West Yakutat). 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

This year 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 1999 numbers at age estimated by the assessment. This vector is projected forward to the beginning of 2000 using natural mortality (0.3), mean 1992-99 selectivity, and the anticipated catch in 1999 (set equal to the 1999 TAC for Gulf pollock west of 140° W long.). 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 1979-98 estimated in the assessment. An alternative projection model using bootstrapped recruitment for 1979-98 gave nearly identical mean values, indicating that the assumption of an inverse Gaussian distribution for recruitment is not critical to the results. Spawning biomass is computed in each year based on the time of peak spawning (March 15) using the maturity and weight schedules in Table 1.12. 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 2000, 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 2000 recommended in the assessment to the *max* F_{ABC} for 2000. (The recommended F_{ABC} is equal to *max* F_{ABC},, so this scenario is redundant for Gulf pollock.)

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 1994-1998 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 2000 and 2001, 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 1.13. Under all harvest policies except F = 0, spawning biomass is projected to decline over the next three years. Under an F40% adjusted harvest policy (the maximum permissible under Tier 3), spawning biomass is projected to be 27% of unfished in 2002. Because spawning biomass will be below B40%, catch is strongly dependent on spawning biomass. Projected catches in 2001 and 2002 are 70% of the ABC in 2000.

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

Spawning biomass is projected to be 212,700 t in 2000 under an FOFL harvest policy, less than B35% (216,000 t), but greater than ½ of B35%. Under scenario 6, the projected mean spawning biomass in 2010 is 239,100 t, 111% of B35%. Therefore, Gulf pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2002 is 166,600 t, less than B35%, but greater than ½ of B35%. Projected mean spawning biomass in 2012 is 236,300 t, 109% of B35%. Therefore, Gulf pollock is not approaching overfished condition.

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Table 1.1--Walleye pollock catches (1000 t) in the Gulf of Alaska, 1964-98. The TAC reported for 1999 applies to waters west of 140° W long. only. Research catches for 1977-98 are also reported.

Year	Foreign	Joint Venture	Domestic	Fishery total	Combined gulf-wide TAC	Research catch
1964	1.126			1.126	---	
1965	2.749			2.749	---	
1966	8.932			8.932	---	
1967	6.276			6.276	---	
1968	6.164			6.164	---	
1969	17.553			17.553	---	
1970	9.343			9.343	---	
1971	9.458			9.458	---	
1972	34.081			34.081	---	
1973	36.836			36.836	---	
1974	61.880			61.880	---	
1975	59.512			59.512	---	
1976	86.527			86.527	---	
1977	117.834		0.522	118.356	150.000	0.089
1978	96.392	0.034	0.509	96.935	168.800	0.100
1979	103.187	0.566	1.995	105.748	168.800	0.052
1980	112.997	1.136	0.489	114.622	168.800	0.229
1981	130.324	16.857	0.563	147.744	196.930	0.433
1982	92.612	73.917	2.211	168.740	168.800	0.110
1983	81.358	134.131	0.119	215.608	256.600	0.213
1984	99.260	207.104	1.037	307.401	416.600	0.311
1985	31.587	237.860	15.379	284.826	305.000	0.167
1986	0.114	62.591	25.103	87.809	116.000	1.202
1987		22.823	46.928	69.751	84.000	0.227
1988		0.152	65.587	65.739	93.000	0.019
1989			78.392	78.392	72.200	0.073
1990			90.744	90.744	73.400	0.158
1991			107.542	107.542	103.400	0.016
1992			90.857	90.857	87.400	0.040
1993			108.908	108.908	114.400	0.116
1994			107.335	107.335	109.300	0.070
1995			72.618	72.618	65.360	0.044
1996			51.263	51.263	54.810	0.147
1997			90.130	90.130	79.980	0.048
1998			125.407	125.407	124.730	0.064
1999					94.590	
Average (1977-98)				123.022	144.469	0.179

Sources: 1964-85--Megrey (1988); 1986-90--Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission. Domestic catches in 1986-90 were adjusted for discard as described in Hollowed et al. (1991). 1991-98--NMFS Alaska Regional Office.

Table 1.2--Annual catches of walleye pollock (t) by statistical area in the Gulf of Alaska (1991-98). Catches (including discards) compiled from blend data provided by the NMFS Alaska Regional Office.

Year	Shumagin 610	Chirikof 620	Kodiak 630	West Yakutat 640	Prince William Sound 649 (state waters)	Southeast and East Yakutat 650 & 680	Southeastern 659 (state waters)	Gulf-wide total
1991	43,190	8,405	50,232	5,684	0	30	0	107,542
1992	19,490	17,237	53,876	233	1	20	1	90,857
1993	21,204	23,788	63,253	648	8	4	3	108,908
1994	17,266	22,239	60,963	6,862	2	2	0	107,335
1995	30,378	13,080	25,768	533	2,813	47	0	72,618
1996	24,200	12,293	13,361	613	794	2	0	51,263
1997	26,262	32,916	25,062	3,968	1,826	92	4	90,130
1998	29,308	49,043	39,035	6,357	1,657	1	7	125,407
Average 1991-98	26,412	22,375	41,444	3,112	888	25	2	94,258

Table 1.3--Number of fishing days by season, area and year in 1994-99.

		Statistical Area		
Season	Year	610	620	630
Winter	1994	15	20	29
(January-February)	1995	13	6	4
	1996	8	9	7
	1997	6	18	15
	1998	6	13	18
	1999	11	28	7
Summer	1994	2	18	35
(June & July)	1995	2	9	8
	1996	0.5	0.5	0.5
	1997	1	7	8
	1998	11	30	11
	1999	6	10	9
Fall	1994	3	9	9
(September-October)	1995	0.5	1	3
	1996	17	26	2
	1997	6	20	11
	1998	7	44	15.5
	1999	6.75	25.5	6.5

Table 1.4--Gulf of Alaska pollock catch at age (millions of fish).

							Age								
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1964	0.00	0.35	0.27	1.08	0.74	0.01	0.01	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.00	2.52
1965	0.04	0.38	1.25	1.09	0.55	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.42
1966	0.00	0.59	1.84	4.66	5.26	0.85	1.90	0.45	0.73	0.12	0.14	0.03	0.00	0.00	0.00	16.56
1967	0.00	0.00	0.42	3.99	1.36	0.58	1.21	0.86	0.78	0.37	0.32	0.16	0.06	0.00	0.16	10.27
1968	0.00	0.04	0.00	5.04	3.61	0.39	0.61	0.44	0.37	0.29	0.15	0.09	0.02	0.00	0.01	11.06
1969	0.00	0.66	0.74	9.31	19.51	0.53	0.75	0.44	0.76	0.08	0.13	0.00	0.06	0.00	0.00	32.97
1970	0.00	0.26	2.92	6.26	0.52	0.69	0.02	0.04	0.05	0.00	0.01	0.00	0.00	0.00	0.00	10.76
1971	0.00	4.18	6.59	1.77	1.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.10
1972	0.00	0.11	0.68	2.31	7.03	5.81	9.39	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.68
1973	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1974	0.00	0.00	3.37	32.93	56.79	14.14	6.26	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	114.48
1975	0.00	0.00	19.16	12.02	20.00	1.34	2.16	2.24	1.32	0.00	0.08	0.00	0.00	0.00	0.00	58.31
1976	0.00	1.91	24.21	108.69	39.08	16.37	3.52	2.25	1.91	0.31	0.00	0.00	0.00	0.00	0.00	198.25
1977	0.01	2.76	7.06	23.83	89.68	30.35	8.33	2.13	1.79	0.67	0.44	0.10	0.02	0.00	0.00	167.17
1978	0.08	12.11	48.32	18.26	26.39	51.86	12.83	4.18	1.36	1.04	0.32	0.04	0.01	0.00	0.00	176.80
1979	0.00	2.53	48.83	76.37	14.15	10.13	16.70	5.02	1.27	0.60	0.16	0.04	0.00	0.00	0.00	175.81
1980	0.25	19.01	26.50	58.31	36.63	11.31	8.61	8.00	3.89	1.11	0.50	0.21	0.08	0.03	0.00	174.42
1981	0.14	2.59	31.55	73.91	47.97	20.29	4.87	4.83	2.73	0.26	0.03	0.02	0.00	0.00	0.00	189.19
1982	0.01	10.67	55.55	100.77	71.73	54.25	10.46	1.33	0.93	0.55	0.03	0.02	0.02	0.00	0.00	306.31
1983	0.00	3.64	20.64	110.03	137.31	67.41	42.01	7.38	1.24	0.06	0.28	0.07	0.00	0.00	0.00	390.07
1984	0.34	2.37	33.00	38.80	120.80	170.72	62.55	19.31	5.42	0.10	0.07	0.03	0.03	0.00	0.00	453.54
1985	0.04	12.74	5.53	33.22	42.22	86.02	128.95	41.19	10.84	2.20	0.70	0.00	0.00	0.00	0.00	363.64
1986	0.66	8.63	20.34	10.12	19.13	7.32	8.70	9.78	2.13	0.80	0.00	0.00	0.00	0.00	0.00	87.59
1987	0.00	8.83	14.03	8.00	6.89	6.44	7.18	4.19	9.95	1.94	0.00	0.00	0.00	0.00	0.00	67.44
1988	0.17	3.05	20.80	26.95	11.94	5.10	3.45	1.62	0.34	3.21	0.00	0.00	0.00	0.00	0.00	76.62
1989	1.08	0.27	1.47	19.39	28.89	16.96	8.09	4.76	1.69	1.10	3.62	0.43	0.01	0.00	0.00	87.77
1990	0.00	2.77	2.40	2.99	9.49	40.39	13.06	4.90	1.08	0.41	0.01	0.56	0.01	0.07	0.06	78.20
1991	0.00	0.59	9.68	5.45	2.85	5.33	26.67	3.12	16.10	0.87	5.65	0.42	2.19	0.21	0.77	79.90
1992	0.05	3.25	5.57	50.61	14.13	4.02	8.77	19.55	1.02	1.49	0.20	0.73	0.00	0.00	0.00	109.41
1993	0.02	1.97	9.43	21.83	47.46	15.72	6.55	6.29	8.52	1.81	2.07	0.49	0.72	0.13	0.24	123.25
1994	0.06	1.26	4.49	9.63	35.92	31.32	12.20	4.84	4.60	6.15	1.44	1.02	0.29	0.09	0.08	113.37
1995	0.00	0.06	1.01	5.11	11.52	25.83	12.09	2.99	1.52	2.00	1.82	0.19	0.28	0.03	0.15	64.61
1996	0.00	1.27	1.37	1.12	3.50	5.11	12.87	10.60	3.14	1.53	0.80	1.43	0.35	0.23	0.16	43.48
1997	0.00	1.07	6.72	3.77	3.28	6.60	10.09	16.52	12.24	5.06	2.06	0.79	0.54	0.17	0.02	68.92
1998	0.31	0.27	26.44	36.44	15.06	6.65	7.50	11.36	14.96	10.76	3.75	0.75	0.38	0.21	0.11	134.95

Table 1.5--Number of survey hauls, number of hauls with walleye pollock, mean CPUE, biomass, coefficient of variation and mean weight based on the 1999 Gulf of Alaska triennial bottom trawl survey, by INPFC area.

INPFC area	Depth (m)	Number of Trawl hauls	Hauls with catch	CPUE (kg/km^2)	Biomass (t)	CV	Mean weight (kg)
Shumigan	1 - 100	90	84	10,153	417,823	0.55	1.027
	101 - 200	32	25	629	9,238	0.27	0.428
	201 - 300	8	8	1,128	3,146	0.40	0.736
	301 - 500	12	10	202	512	0.20	0.824
	501 - 700	5	5	81	162	0.32	0.727
	701 - 1000	1	0	---	---	---	---
	All depths	148	132	6,620	430,880	0.53	0.994
Chirkof	1 - 100	59	40	1,474	38,386	0.34	0.813
	101 - 200	52	48	426	10,159	0.23	0.646
	201 - 300	35	35	239	2,754	0.16	0.339
	301 - 500	8	5	51	82	0.65	0.673
	501 - 700	6	0	---	---	---	---
	701 - 1000	8	1	6	17	1.00	1.090
	All depths	168	129	755	51,398	0.26	0.722
Kodiak	1 - 100	86	55	1,733	66,733	0.26	0.553
	101 - 200	94	66	871	37,747	0.43	0.491
	201 - 300	36	32	433	4,976	0.16	0.220
	301 - 500	14	7	66	192	0.42	0.700
	501 - 700	5	1	7	13	1.00	0.776
	701 - 1000	10	4	35	122	0.54	0.822
	All depths	245	165	1,082	109,782	0.22	0.498
Yakutat	1 - 100	38	26	301	5,011	0.39	0.108
	101 - 200	63	54	159	4,662	0.23	0.162
	201 - 300	14	14	370	1,913	0.46	0.422
	301 - 500	12	5	40	105	0.52	0.846
	501 - 700	0	0	---	---	---	---
	701 - 1000	0	0	---	---	---	---
	All depths	135	99	204	11,690	0.21	0.146
Southeastern	1 - 100	10	5	2,194	14,363	0.80	0.233
	101 - 200	24	18	487	5,397	0.40	0.524
	201 - 300	16	15	1,816	9,177	0.52	0.725
	301 - 500	14	3	24	76	0.60	0.932
	501 - 700	2	0	---	---	---	---
	701 - 1000	2	0	---	---	---	---
	All depths	68	41	1,035	29,013	0.44	0.342
Total	All Depths	764	566	---	632,763	0.37	---

Table 1.6--Walleye pollock biomass estimates (metric tons) from AFSC echo integration trawl surveys of Shelikof Strait, AFSC bottom trawl surveys, egg production surveys of Shelikof Strait, and ADFG coastal trawl surveys. An adjustment of +1.05% was made to the AFSC bottom trawl biomass to account for unsurveyed biomass in Prince William Sound.

Year	EIT Shelikof Strait survey	EIT Shelikof Strait survey (unadjusted)	AFSC bottom trawl west of 140° W long.	Shelikof St. egg production	Coastal ADF&G trawl survey
1975			850,336*		
1976					
1977					
1978					
1979					
1980					
1981	2,785,755			1,788,908	
1982					
1983	2,278,172				
1984	1,757,168		752,825		
1985	1,175,823			768,419	
1986	585,755			375,907	
1987			872,943	484,455	
1988	301,709			504,418	
1989	290,461			433,894	214,434
1990	374,731		839,813	381,475	114,451
1991	380,331			370,000	
1992	580,000	681,400		616,000	127,359
1993	295,785	408,200	781,178		132,849
1994	366,800	467,300			103,420
1995	572,900	725,200			
1996	588,800	745,400	663,254		122,477
1997	450,260	570,100			93,728
1998	386,904	489,900			81,215
1999			606,295		53,587

* Expanded from an area-swept biomass estimate of the Chirikof area using a 400 mesh eastern trawl (Hughes and Hirschhorn, 1979)

Table 1.7--Estimated pollock numbers at age (million) from AFSC echo integration-trawl surveys of Shelikof Strait during late winter/early spring, and from AFSC bottom trawl surveys. For the acoustic survey in 1987, and the bottom trawl survey in 1973, the percent at age is given. Bottom trawl survey estimates are for statistical areas 610-630 only.

AFSC Acoustic survey																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1981	77.650	3481.177	1510.767	769.162	2785.905	1051.917	209.926	128.520	79.426	25.190	1.727	0.000	0.000	0.000	0.000	10121.368
1983	1.212	901.770	380.191	1296.788	1170.808	698.131	598.780	131.536	14.478	11.610	3.925	1.708	0.000	0.000	0.000	5210.934
1984	61.654	58.252	324.491	141.659	635.042	988.206	449.622	224.347	41.031	2.744	0.000	1.023	0.000	0.000	0.000	2928.071
1985	2091.742	544.435	122.688	314.774	180.531	347.171	439.312	166.677	42.721	5.556	1.768	1.294	0.000	0.000	0.000	4258.670
1986	575.363	2114.833	183.618	45.629	75.358	49.340	86.149	149.361	60.221	10.618	1.291	0.000	0.000	0.000	0.000	3351.781
1987	7.5%	25.5%	55.8%	2.9%	1.7%	1.2%	1.6%	1.2%	2.1%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	100.0%
1988	17.436	109.926	694.323	322.113	77.571	16.994	5.697	5.603	3.979	8.961	1.776	1.835	0.196	0.000	0.000	1266.409
1989	399.476	89.517	90.013	222.048	248.691	39.407	11.750	3.831	1.885	0.551	10.661	1.420	0.000	0.000	0.000	1119.250
1990	49.140	1210.171	71.694	63.374	115.919	180.055	46.326	22.445	8.197	8.211	0.931	3.084	1.509	0.789	0.237	1782.081
1991	21.979	173.652	549.896	48.111	64.868	69.597	116.316	23.648	29.433	2.231	4.287	0.920	4.381	0.000	0.000	1109.318
1994	155.712	30.327	42.967	29.310	146.265	79.069	40.466	25.983	42.661	46.463	14.215	6.402	1.080	2.252	0.547	663.719
1995	10000.003	467.545	71.970	71.718	98.512	235.251	116.744	51.357	15.960	10.303	13.977	5.574	2.041	0.418	0.000	11161.373
1996	51.496	3193.329	110.730	23.754	51.716	68.318	193.464	114.140	38.397	12.532	10.929	5.132	2.423	0.024	0.367	3876.751
1997	66.417	179.049	1230.483	77.535	17.691	42.985	50.476	95.268	51.520	13.957	2.336	2.970	0.908	0.449	0.000	1832.045
1998	390.123	85.492	123.981	467.344	133.518	13.643	30.444	34.549	70.482	24.643	13.634	6.556	0.260	0.537	0.536	1395.742

AFSC bottom trawl survey																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1973	3.2%	7.3%	38.2%	8.3%	11.2%	21.3%	2.5%	2.8%	2.8%	1.6%	0.8%	0.1%	0.0%	0.0%	0.0%	100.0%
1984	0.932	10.022	67.812	155.775	261.165	474.568	145.100	24.796	16.592	1.663	0.213	1.317	0.000	0.000	0.000	1159.955
1987	25.450	363.015	172.988	138.967	91.125	168.274	78.142	43.988	175.390	22.405	7.808	3.508	1.819	0.000	0.000	1292.879
1989	208.875	63.488	47.555	243.152	301.093	104.428	54.472	28.392	26.141	5.975	10.656	0.000	0.000	0.000	0.000	1094.227
1990	64.044	251.213	48.336	46.675	209.772	240.820	74.408	110.406	26.126	34.226	5.033	27.727	5.702	1.071	1.627	1147.186
1993	139.313	71.146	50.935	182.956	267.121	91.511	33.120	68.978	76.619	26.358	11.847	6.293	3.818	1.819	4.411	1036.245
1996	194.225	128.786	17.301	26.133	50.043	63.175	174.405	87.622	52.370	27.734	12.102	18.463	7.163	9.677	19.704	888.903

Table 1.8--Estimated number of hauls that were sampled for pollock otoliths (1975 - 1998) based commercial fishery and AFSC bottom trawl survey data. Commercial fishery data was obtained from observer and port sampling records. For the years 1988 - 1996, the estimated number of hauls was based on an average of 3 hauls per delivery. In 1987, otoliths were collected from observer and port sample collections.

Year	Hauls	Port deliveries	AFSC bottom trawl survey
1975	7		
1976	143		
1977	185		
1978	313		
1979	234		
1980	274		
1981	296		
1982	550		
1983	717		
1984	201		73
1985	287		
1986	84		
1987	12 (obs), 18 (port)	6	42
1988	18	6	
1989	171	57	
1990	528	176	38
1991	594	198	
1992	624	208	
1993	672	224	71
1994	870	290	
1995	426	142	
1996	222	74	74
1997	576	157	
1998	1320	324	

Table 1.9--Selectivity at age for Gulf pollock fisheries and surveys for base-run model. The fisheries and surveys were modeled using double logistic selectivity functions, with random walk process error for the fisheries. The fishery selectivity coefficients reported below are the average of the annual selectivity for the indicated time period, rescaled so that the maximum is one.

Age	POP fishery (1964-71)	Foreign (1972-84)	Early domestic (1985-91)	Recent domestic (1992-99)	EIT survey	Bottom trawl survey	Egg production survey	ADF&G bottom trawl
2	0.001	0.039	0.041	0.037	1.000	0.176	0.034	0.069
3	0.026	0.257	0.156	0.123	1.000	0.306	0.116	0.117
4	0.523	0.763	0.422	0.344	1.000	0.501	0.325	0.192
5	1.000	1.000	0.734	0.658	1.000	0.744	0.639	0.302
6	0.951	0.941	0.944	0.878	0.998	0.950	0.867	0.445
7	0.699	0.702	1.000	0.970	0.983	1.000	0.960	0.609
8	0.301	0.338	0.845	1.000	0.882	0.854	0.989	0.768
9	0.078	0.109	0.457	0.975	0.492	0.606	0.997	0.902
10	0.017	0.030	0.153	0.391	0.111	0.376	1.000	1.000

Table 1.10--Gulf pollock numbers at age (millions of fish) estimated by the base-run model, 1964-1999.

	Age								
	2	3	4	5	6	7	8	9	10
1964	179	762	481	467	101	77	84	79	58
1965	479	133	564	355	345	75	57	62	102
1966	195	355	98	417	262	254	55	42	122
1967	497	144	263	72	303	191	186	41	121
1968	493	368	107	193	53	221	140	137	120
1969	769	365	272	78	140	38	161	103	190
1970	257	570	270	194	54	96	27	117	216
1971	632	190	421	196	138	38	69	20	246
1972	1156	468	141	307	140	99	28	51	197
1973	763	857	346	100	209	96	69	20	183
1974	3051	565	633	245	67	141	67	50	150
1975	615	2260	418	444	155	43	96	48	148
1976	405	456	1651	289	304	107	30	69	145
1977	1949	299	328	1134	198	209	75	22	158
1978	2696	1442	217	224	763	134	145	54	132
1979	2463	1991	1034	149	152	522	94	104	137
1980	3506	1820	1440	712	101	105	365	67	177
1981	1776	2588	1319	1007	492	70	73	261	180
1982	420	1313	1882	919	690	337	49	52	323
1983	498	308	934	1305	634	478	237	35	277
1984	194	365	218	630	867	423	328	171	231
1985	493	141	251	136	376	518	266	229	296
1986	1643	359	97	153	75	201	285	169	383
1987	561	1200	252	64	95	46	126	196	407
1988	153	412	866	174	42	62	30	83	441
1989	364	113	299	607	117	28	40	20	384
1990	1645	269	83	214	412	76	17	25	294
1991	1043	1216	197	60	146	263	46	11	233
1992	409	771	892	142	41	96	169	30	159
1993	248	302	561	626	95	27	62	109	136
1994	105	183	219	394	419	62	17	40	169
1995	264	77	133	154	265	276	40	11	144
1996	1153	195	56	95	106	179	185	27	110
1997	492	853	144	41	67	73	123	126	96
1998	70	364	625	103	28	43	45	75	143
1999	182	51	257	417	63	16	24	25	134

Table 1.11--Estimated time series of Gulf pollock biomass, recruitment, and harvest for 1969-99 for the base-run assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

Year	2+ total biomass (1,000 t)	3+ total biomass (1,000 t)	Female spawn. biom. (1,000 t)	Age 2 recruits (million)	Catch (t)	Harvest rate	1998 Assessment results 2+ total biomass	Female spawn. biom.	Age 2 recruits	Harvest rate
1969	1,165	1,095	415	769	17,553	2%	700	277	640	3%
1970	1,131	1,108	389	257	9,343	1%	668	226	445	1%
1971	1,126	1,069	384	632	9,458	1%	714	211	605	1%
1972	1,173	1,069	385	1,156	34,081	3%	834	224	1,113	4%
1973	1,248	1,179	381	763	36,836	3%	969	252	670	4%
1974	1,547	1,272	401	3,051	61,880	5%	1,272	297	2,639	5%
1975	1,825	1,770	456	615	59,512	3%	1,547	370	522	4%
1976	2,023	1,986	560	405	86,527	4%	1,719	474	323	5%
1977	2,081	1,905	660	1,949	118,356	6%	1,754	558	1,639	6%
1978	2,249	2,007	686	2,696	96,935	5%	1,876	579	2,084	5%
1979	2,620	2,399	711	2,463	105,748	4%	2,150	591	2,010	5%
1980	3,151	2,835	810	3,506	114,622	4%	2,552	662	2,862	4%
1981	3,596	3,437	971	1,776	147,744	4%	2,917	784	1,649	5%
1982	3,749	3,711	1,142	420	168,740	5%	3,041	916	342	6%
1983	3,525	3,481	1,247	498	215,608	6%	2,851	995	474	8%
1984	3,001	2,984	1,180	194	307,401	10%	2,409	939	170	13%
1985	2,334	2,290	950	493	284,826	12%	1,839	739	530	15%
1986	1,845	1,697	716	1,643	87,809	5%	1,471	535	1,849	6%
1987	1,706	1,655	592	561	69,751	4%	1,450	451	631	5%
1988	1,613	1,599	540	153	65,739	4%	1,454	441	144	5%
1989	1,457	1,425	527	364	78,392	6%	1,362	472	308	6%
1990	1,384	1,236	489	1,645	90,744	7%	1,325	463	1,645	7%
1991	1,416	1,322	432	1,043	107,542	8%	1,368	420	940	8%
1992	1,462	1,425	415	409	90,857	6%	1,407	405	364	7%
1993	1,428	1,406	451	248	108,908	8%	1,362	438	238	8%
1994	1,268	1,258	462	105	107,335	9%	1,202	444	86	9%
1995	1,071	1,047	423	264	72,618	7%	1,000	401	249	7%
1996	990	886	366	1,153	51,263	6%	950	343	1,401	5%
1997	992	948	313	492	90,130	10%	964	298	181	8%
1998	958	951	281	70	125,407	13%	933	278	90	13%
1999	824	808	273	182	---	---	---	---	---	---
Average										
1969-98	1,838	1,748	591	993	100,722	6%	1,535	483	895	6%
1979-98	1,978	1,900	651	875	124,559	7%	1,700	551	808	6%

Table 1.12--Gulf pollock life history and fishery schedules used to estimate spawning biomass per recruit (FSPR) harvest rates. For comparison, fishery selectivity patterns used to calculate FSPR rates and to make short-term projections in 1998 assessment (Hollowed et al. 1998) are also shown. Mid-year weights at age are based on a multi-year average of fishery weight at age for the second trimester (Hollowed et al. 1998). Weight at age at the begining of the year and at spawning are obtained by linear interpolation from the mid-year weight at age. Yield per recruit is calculated using the mid-year weight at age.

			Weight at age				Previous assessment	
Age	Natural mortality	Fishery selectivity (Avg. 1992-99)	Beginning of year	At spawning (March 15)	Mid-year (July 1)	Proportion mature females	Fishery selectivity for SPR rates	Short-term projection selectivity
2	0.3	0.037	0.115	0.150	0.186	0.034	0.022	0.016
3	0.3	0.123	0.283	0.324	0.380	0.116	0.105	0.077
4	0.3	0.344	0.480	0.519	0.579	0.325	0.337	0.247
5	0.3	0.658	0.670	0.704	0.760	0.639	0.644	0.476
6	0.3	0.878	0.836	0.864	0.911	0.867	0.882	0.678
7	0.3	0.970	0.972	0.995	1.033	0.960	1.000	0.865
8	0.3	1.000	1.081	1.099	1.129	0.989	0.922	1.000
9	0.3	0.975	1.167	1.180	1.204	0.997	0.611	0.843
10+	0.3	0.391	1.233	1.243	1.261	1.000	0.288	0.371

Table 1.13--Projections of Gulf pollock spawning biomass, full recruitment fishing mortality, and catch for 2000-2004 under different harvest policies. All projections begin with estimated age compositon in 1999 for the base-run model, which includes the ADF&G survey time series. Coefficients of variation are given in parentheses, and reflect only variability in recruitment in 2000-2004. The F40% adjusted harvest rate policy corresponds to both the maximum permissible and the FABC recommendation.

Harvest rate policy	Year	Spawning Biomass (1,000 t)		Full-recruitment fishing mortality		Catch (t)	
FOFL	2000	212.7	(0.01)	0.40	(0.01)	130,758	(0.03)
F35% adjusted	2001	167.7	(0.08)	0.31	(0.08)	84,100	(0.22)
	2002	158.3	(0.27)	0.29	(0.23)	84,087	(0.65)
	2003	181.8	(0.45)	0.32	(0.30)	115,214	(0.81)
	2004	209.3	(0.50)	0.35	(0.28)	143,751	(0.78)
FABC	2000	214.9	(0.01)	0.34	(0.01)	111,306	(0.03)
F40% adjusted	2001	176.0	(0.08)	0.27	(0.08)	77,168	(0.21)
	2002	167.8	(0.26)	0.25	(0.21)	77,535	(0.60)
	2003	192.3	(0.45)	0.27	(0.27)	104,414	(0.77)
	2004	222.7	(0.51)	0.30	(0.26)	129,974	(0.76)
F45% adjusted	2000	216.6	(0.01)	0.28	(0.01)	94,962	(0.03)
	2001	183.2	(0.07)	0.24	(0.07)	70,078	(0.20)
	2002	176.4	(0.26)	0.22	(0.19)	70,975	(0.56)
	2003	202.1	(0.44)	0.24	(0.25)	94,225	(0.74)
	2004	235.4	(0.51)	0.26	(0.24)	116,864	(0.75)
50% of FABC	2000	220.2	(0.01)	0.17	(0.01)	58,979	(0.03)
	2001	199.5	(0.07)	0.15	(0.07)	49,935	(0.18)
	2002	197.6	(0.24)	0.15	(0.16)	52,367	(0.49)
	2003	227.3	(0.43)	0.15	(0.21)	67,908	(0.67)
	2004	267.7	(0.51)	0.17	(0.20)	83,335	(0.71)
Average F	2000	220.5	(0.01)	0.16	(0.00)	55,549	(0.02)
(1994-1998)	2001	200.6	(0.07)	0.16	(0.00)	51,978	(0.10)
	2002	197.7	(0.25)	0.16	(0.00)	54,354	(0.31)
	2003	226.8	(0.45)	0.16	(0.00)	64,710	(0.51)
	2004	269.1	(0.54)	0.16	(0.00)	75,000	(0.61)
F = 0	2000	225.7	(0.01)	0.00	---	0	---
	2001	227.8	(0.07)	0.00	---	0	---
	2002	241.6	(0.21)	0.00	---	0	---
	2003	285.3	(0.39)	0.00	---	0	---
	2004	345.1	(0.49)	0.00	---	0	---

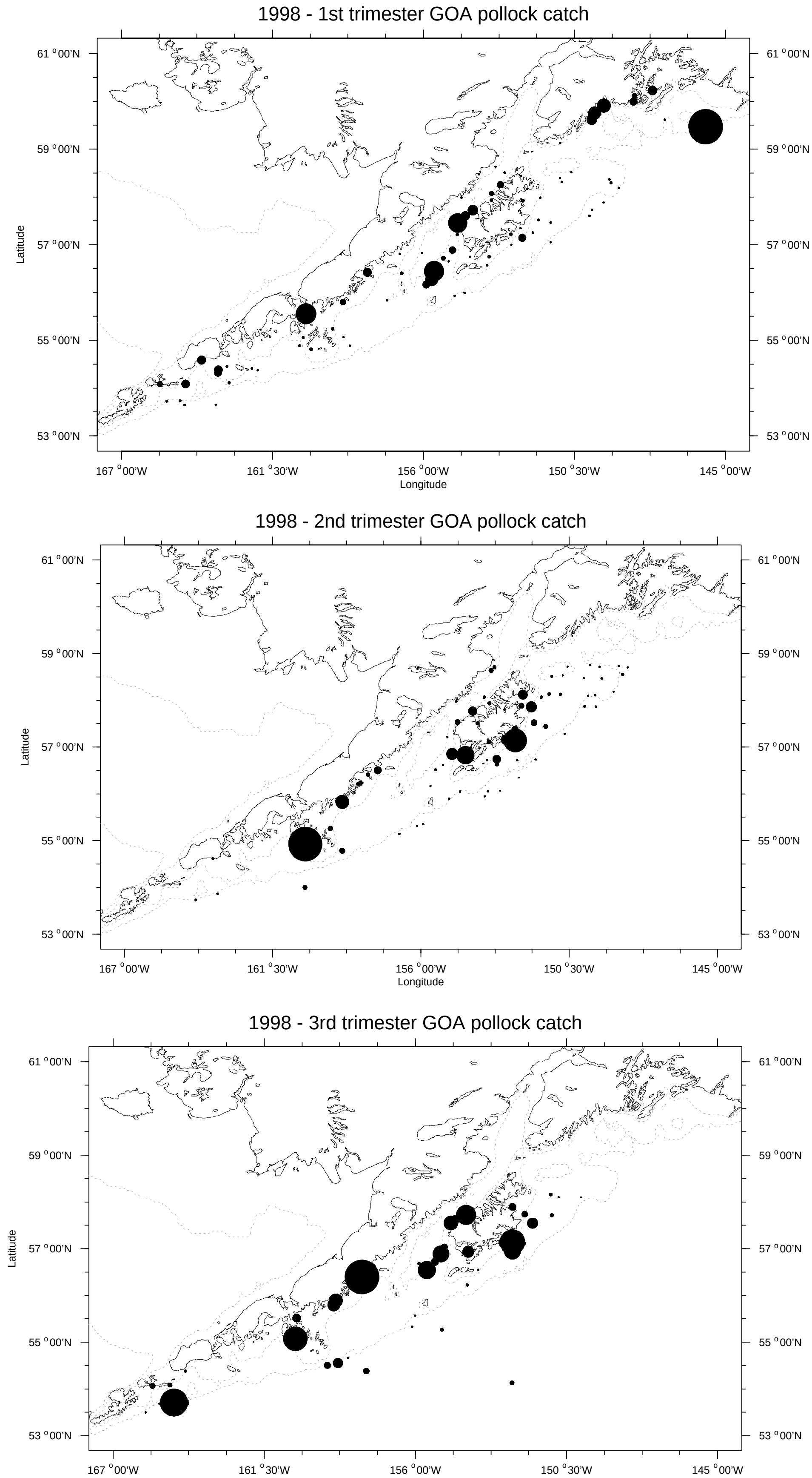


Figure 1.1--Pollock catch by 20 sq. nmi. blocks by trimester in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. The area of the circle is proportional to the catch.

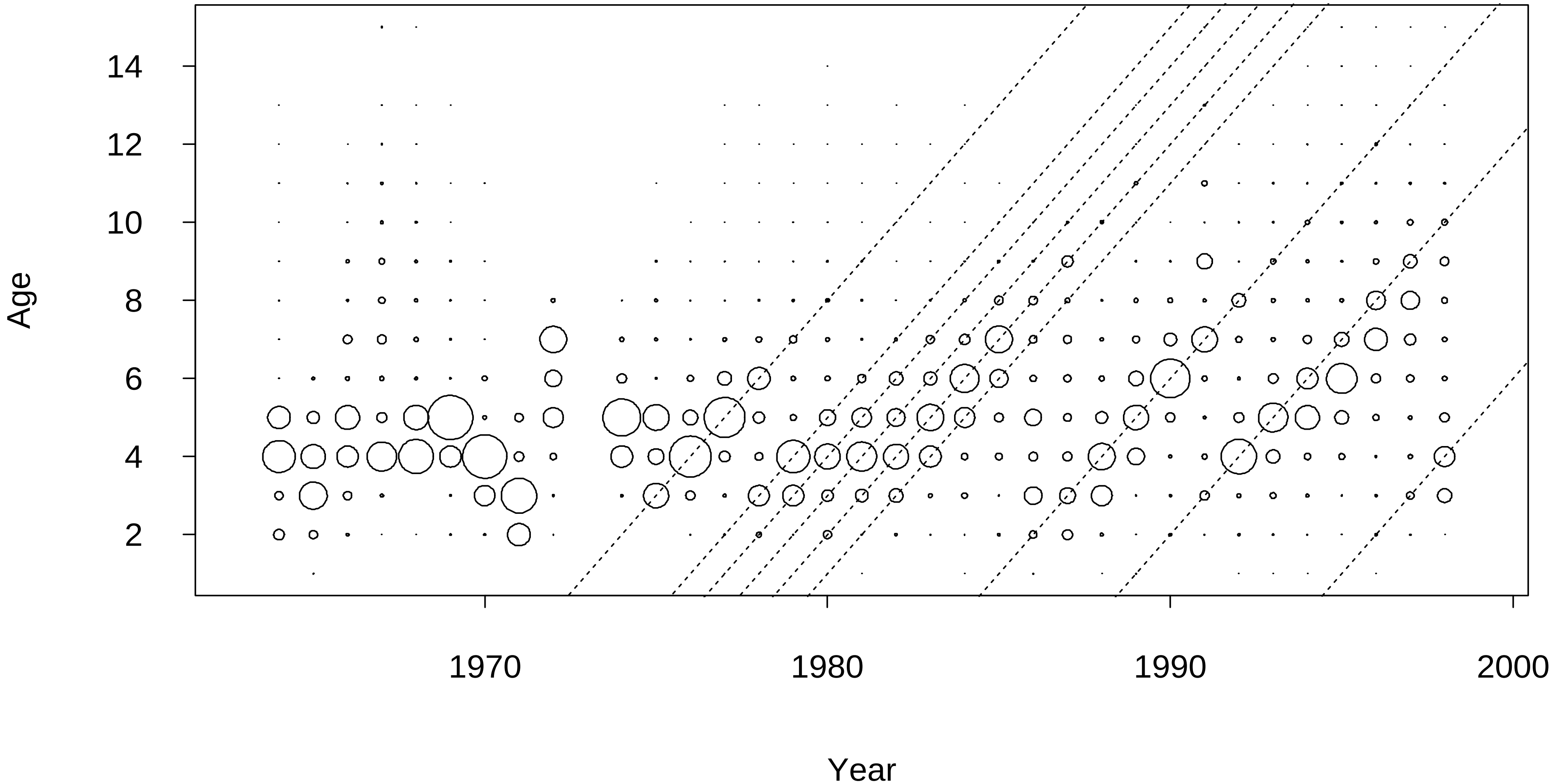


Figure 1.2--Gulf of Alaska pollock catch proportions at age (1964-98). The diameter of the circle is proportional to the catch. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994)

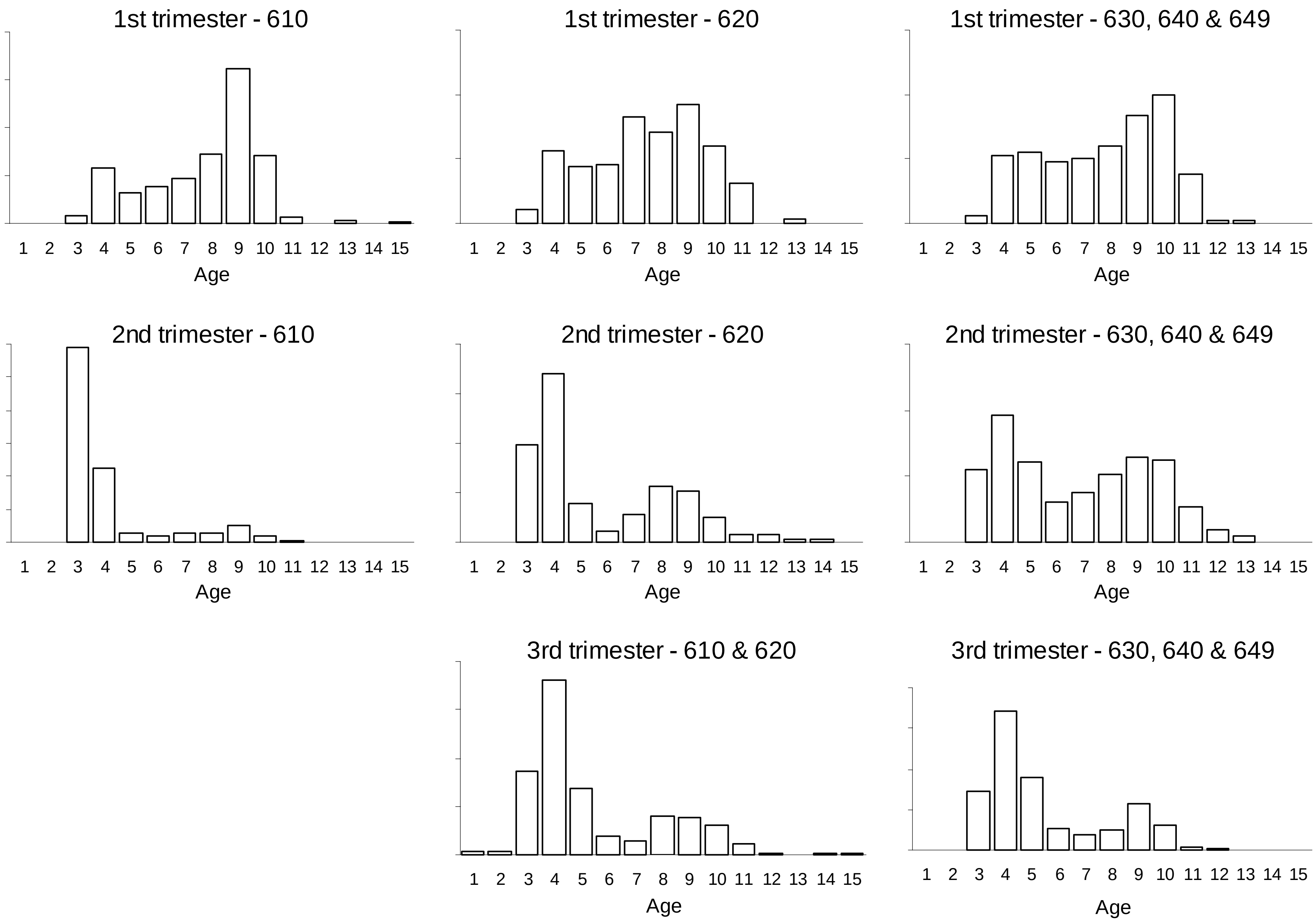


Figure 1.3--1998 catch proportions at age by trimester and statistical area. Areas 610 and 620 were combined for the 3rd trimester because the ageing sample was small.

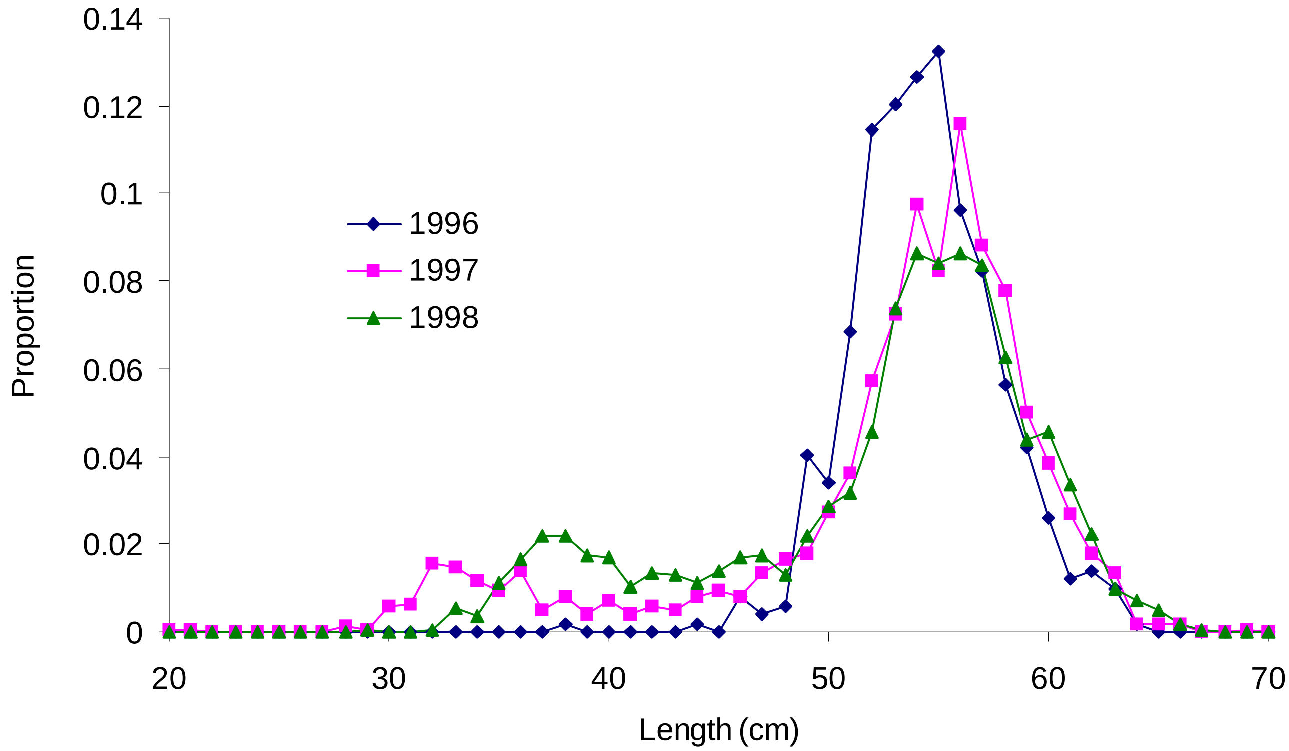


Figure 1.4--Pollock length frequency from fishery and survey samples of winter spawning aggregations in Prince William Sound (1996-1998).

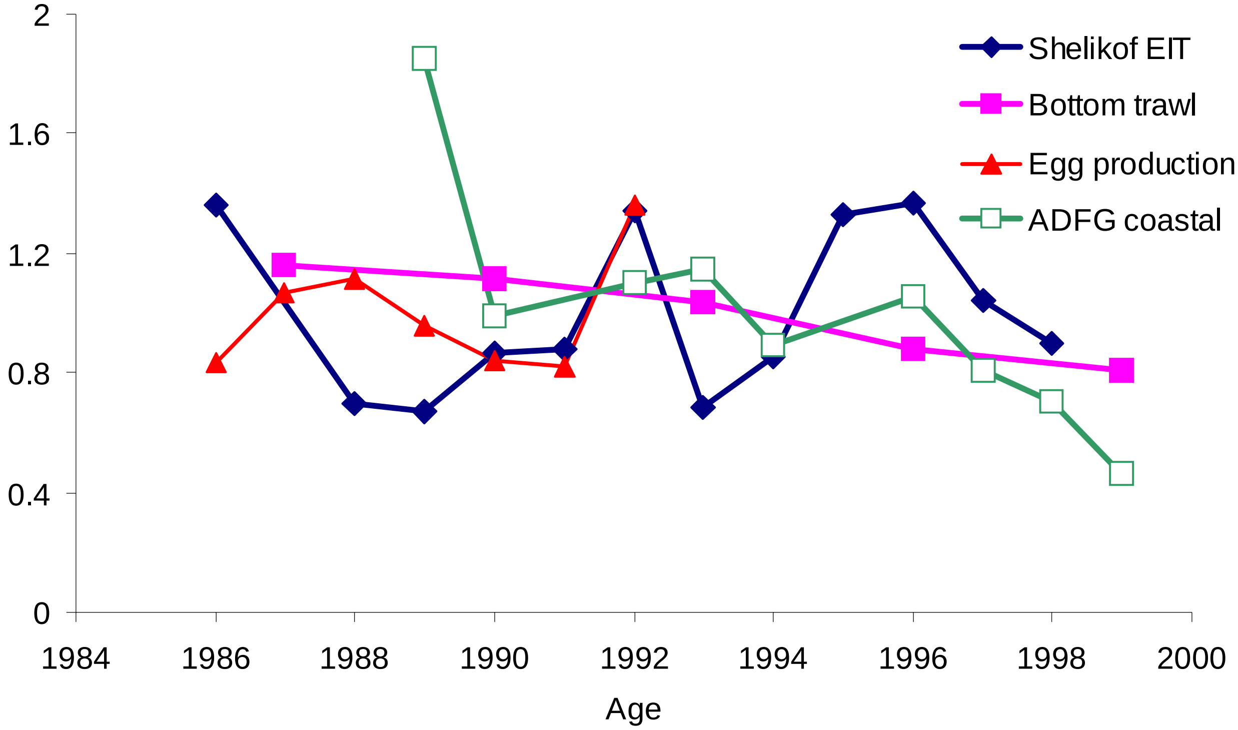


Figure 1.5--Trends in Gulf pollock biomass since 1986 for the Shelikof Strait EIT survey, the triennial bottom trawl survey, the egg production survey, and the ADF&G coastal trawl survey. Each survey biomass estimate is divided by the average for the survey since 1986.

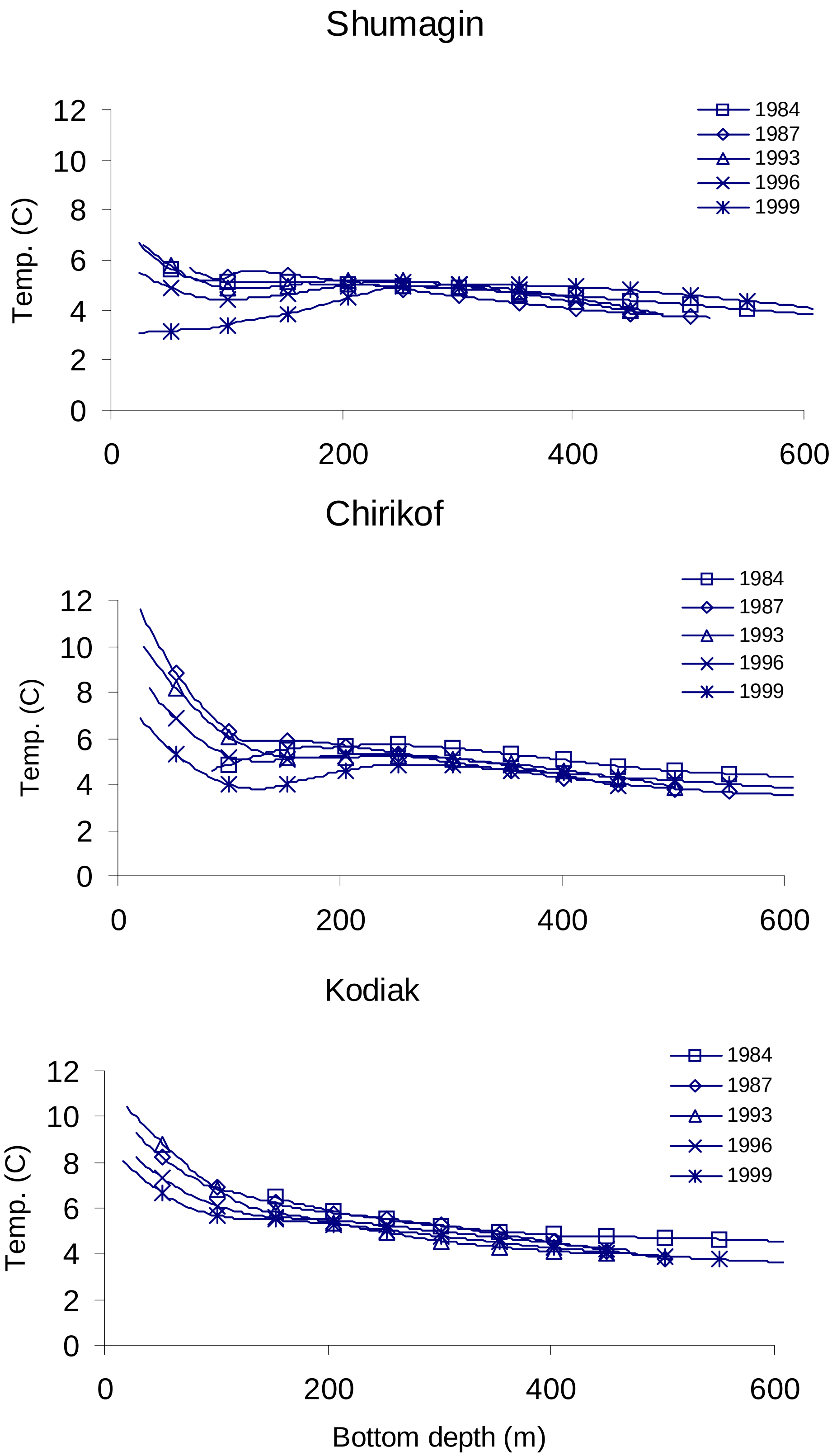


Figure 1.6--Bottom temperature as a function of bottom depth by INPFC area in the Gulf of Alaska during triennial bottom trawl surveys in 1984, 1987, 1993, 1996, and 1999. Temperature data were smoothed using the SPLUS function *loess*.

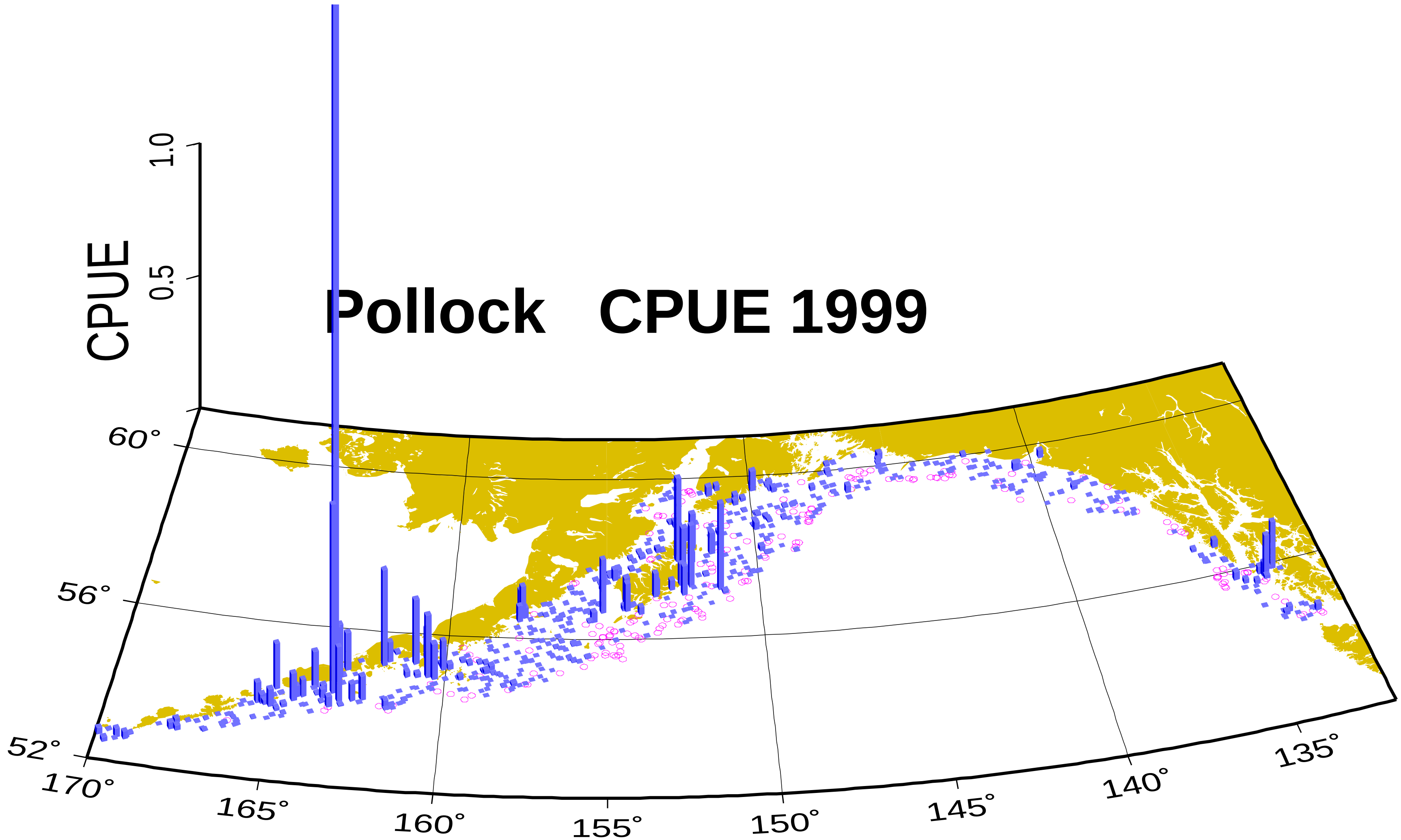


Figure 1.7--Gulf pollock CPUE from the 1999 triennial bottom trawl survey.

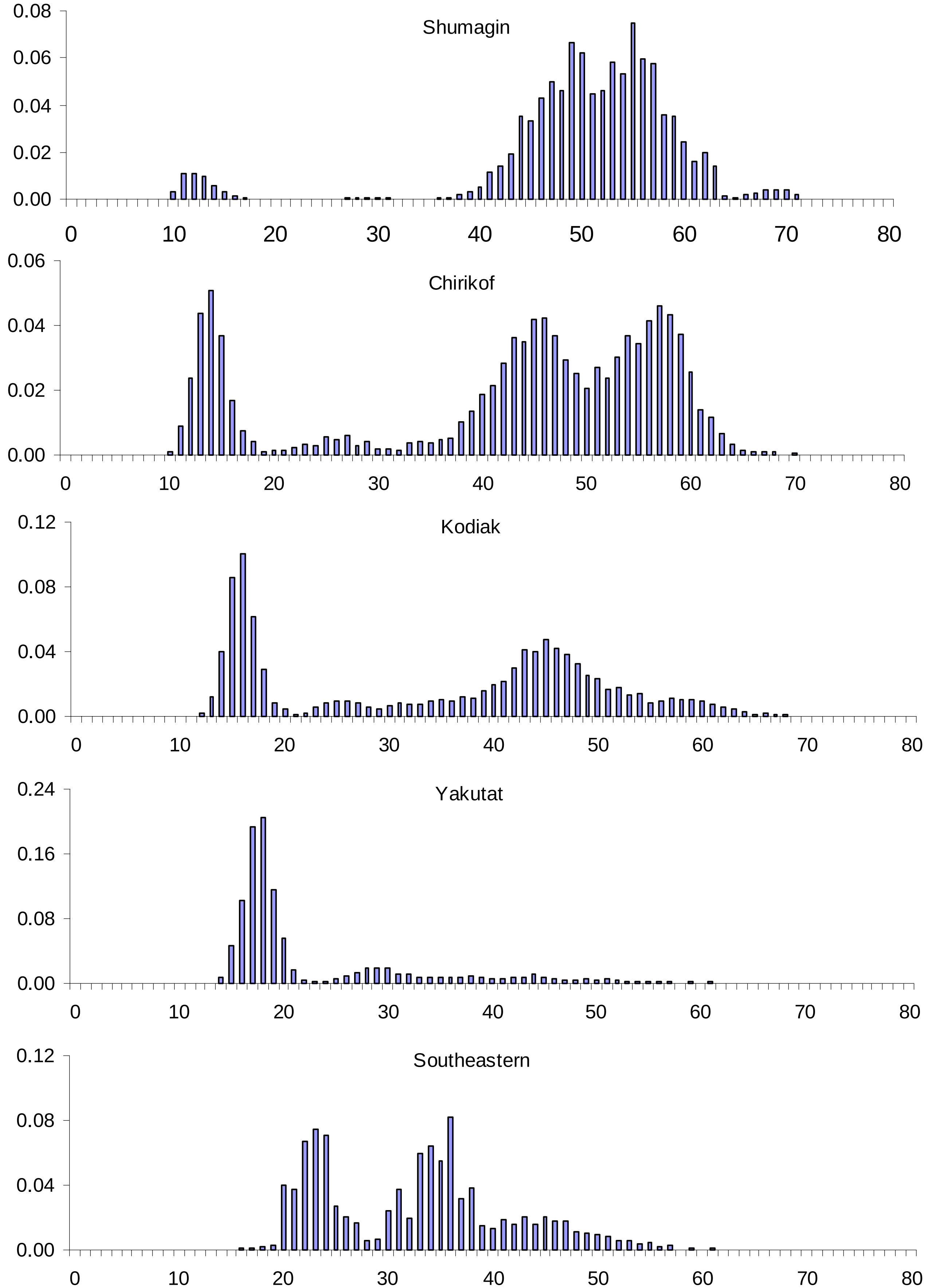


Figure 1.8--Pollock length distribution by INPFC area for the 1999 triennial bottom trawl survey.

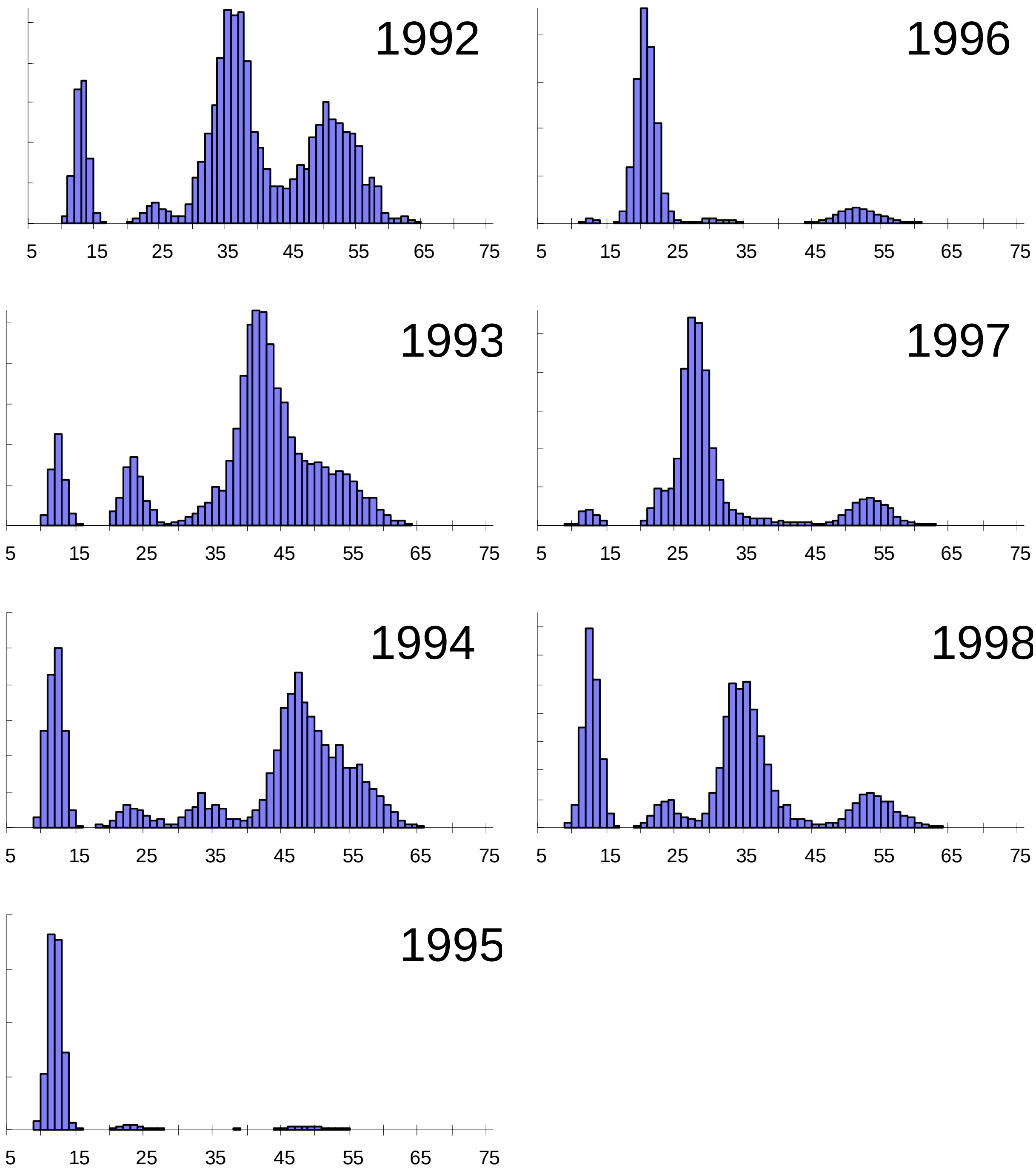


Figure 1.9--1992-98 Shelikof Strait EIT survey pollock length frequency.

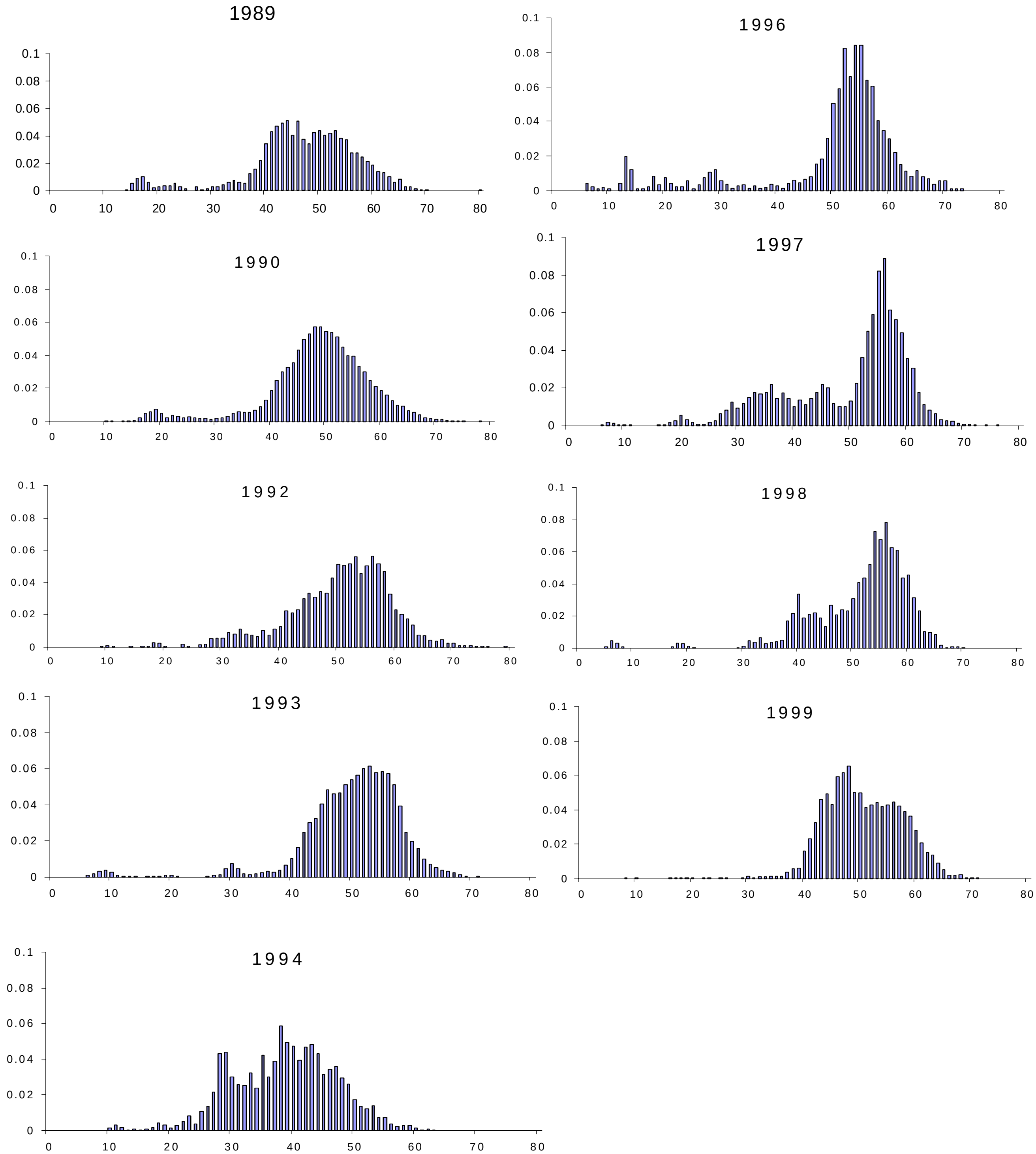


Figure 1.10--Length frequency of pollock for ADF&G bottom trawl surveys in 1989-99.

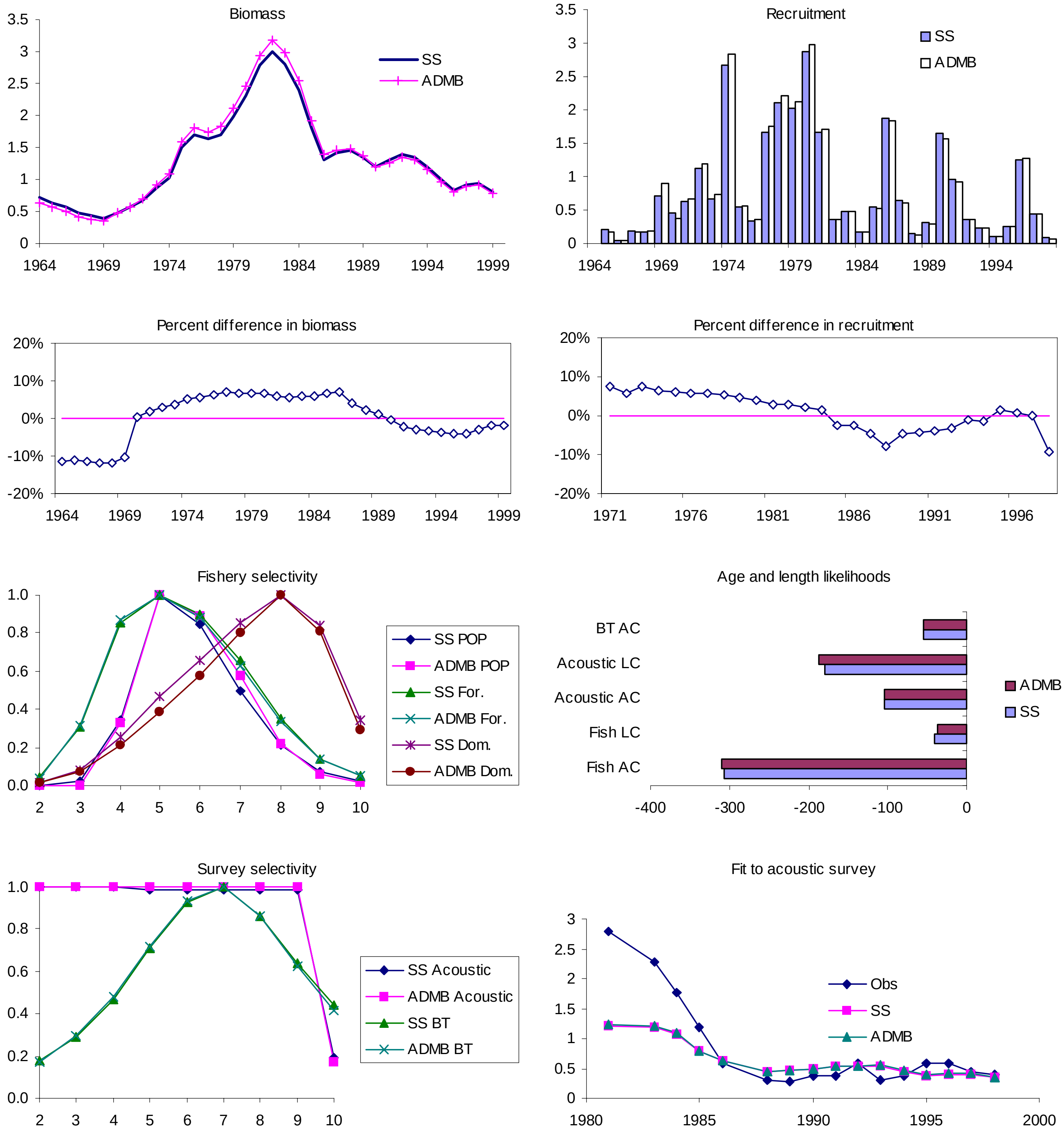
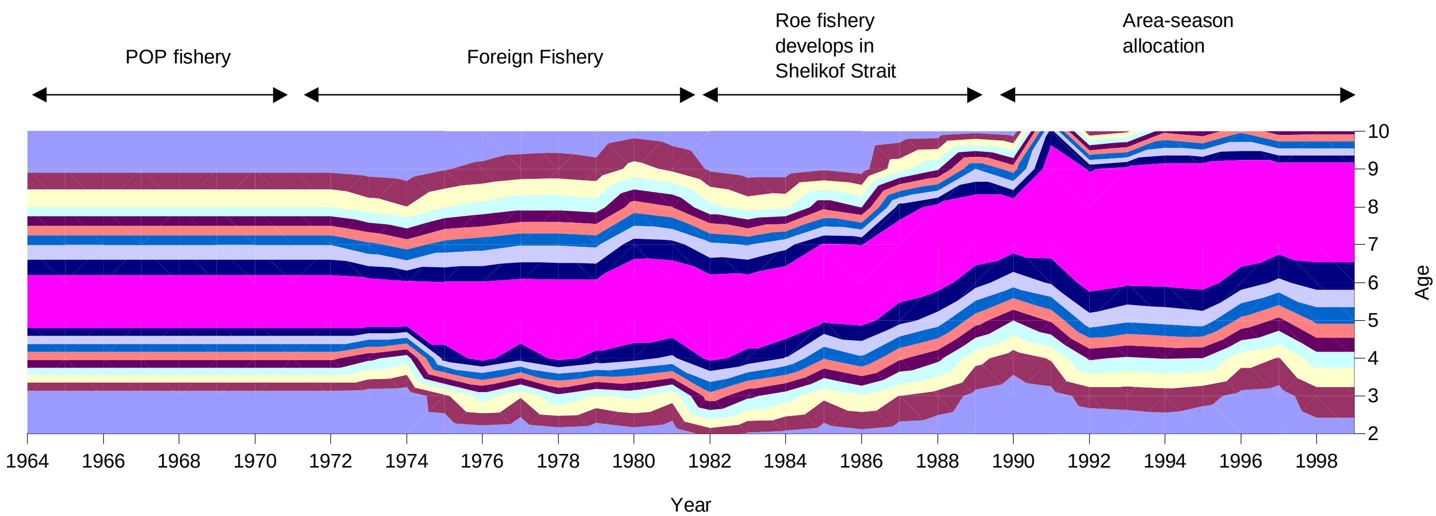


Figure 1.11--Comparison of model results for stock synthesis and AD model builder.



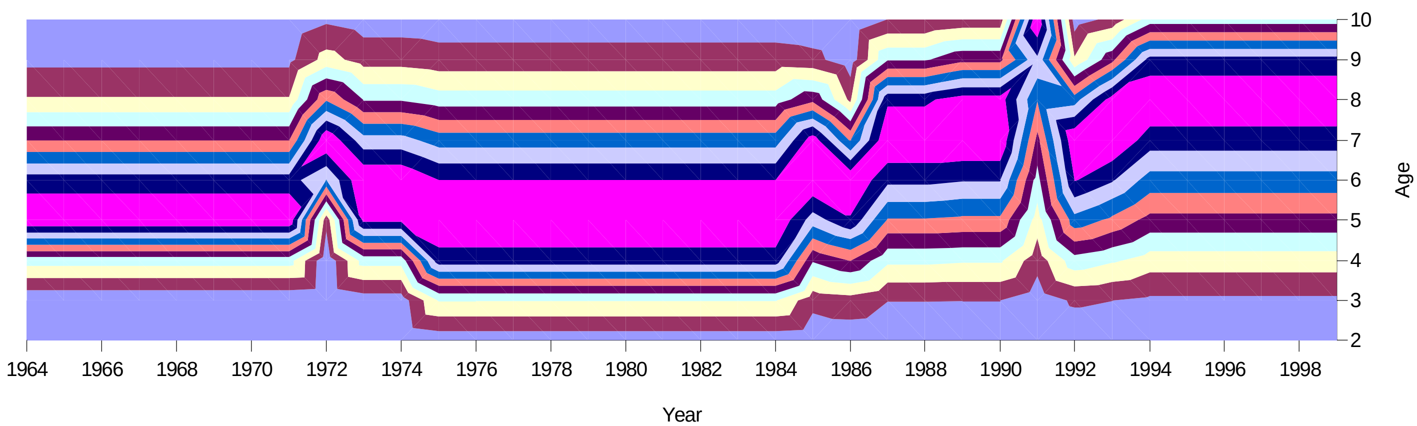


Figure 1.12--Comparison of time-varying fishery selectivity for random walk process error (top panel), and the grouped year approach implemented in the stock synthesis model (lower panel).

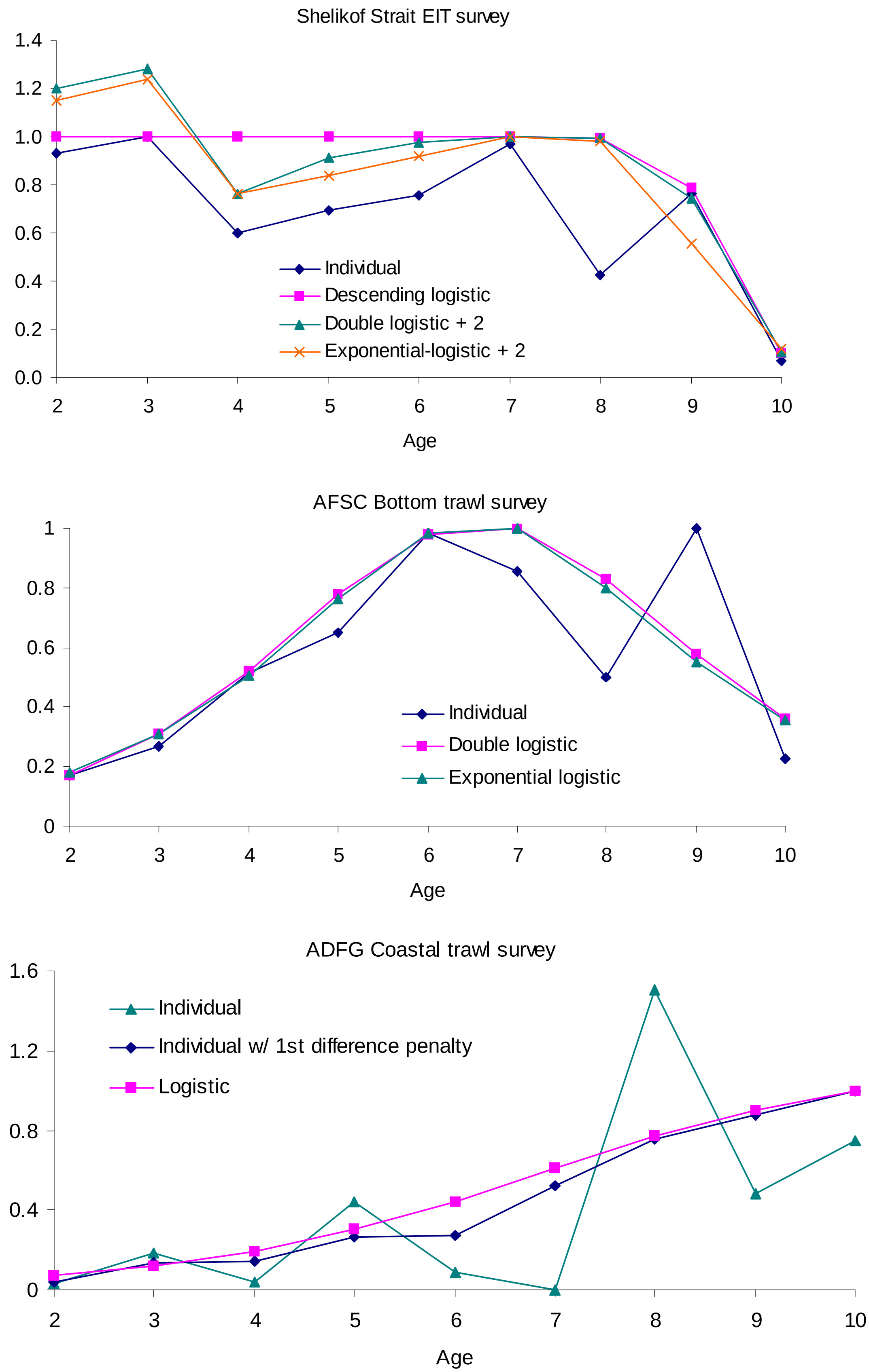
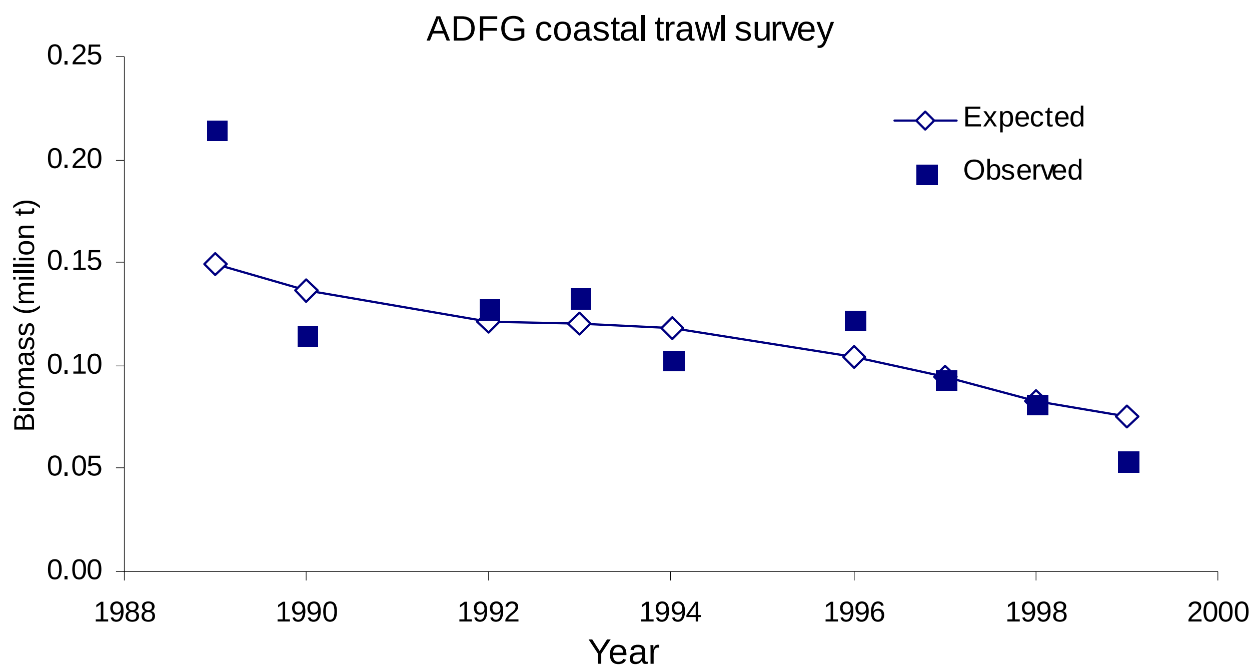


Figure 1.13--Comparison of alternative selectivity curves for the Shelikof Strait EIT survey (top panel), triennial bottom trawl survey (middle panel), and the ADFG coastal trawl survey (bottom panel).



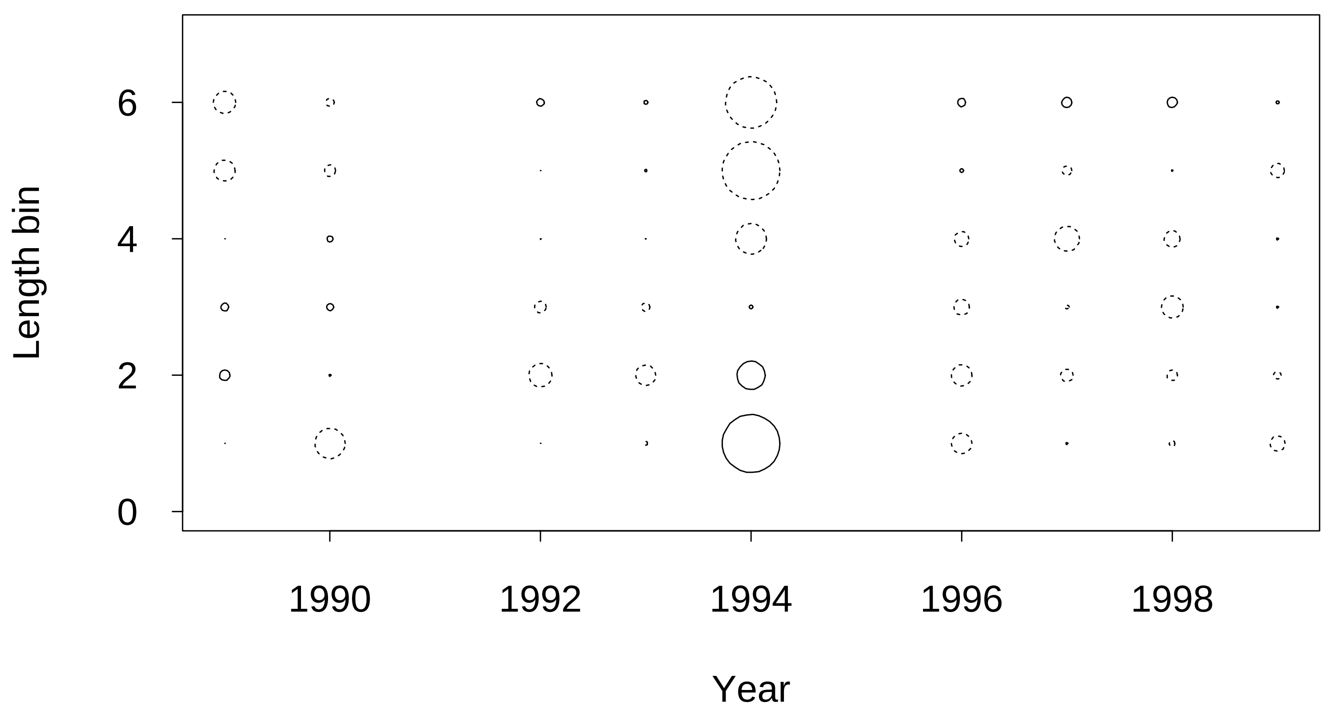
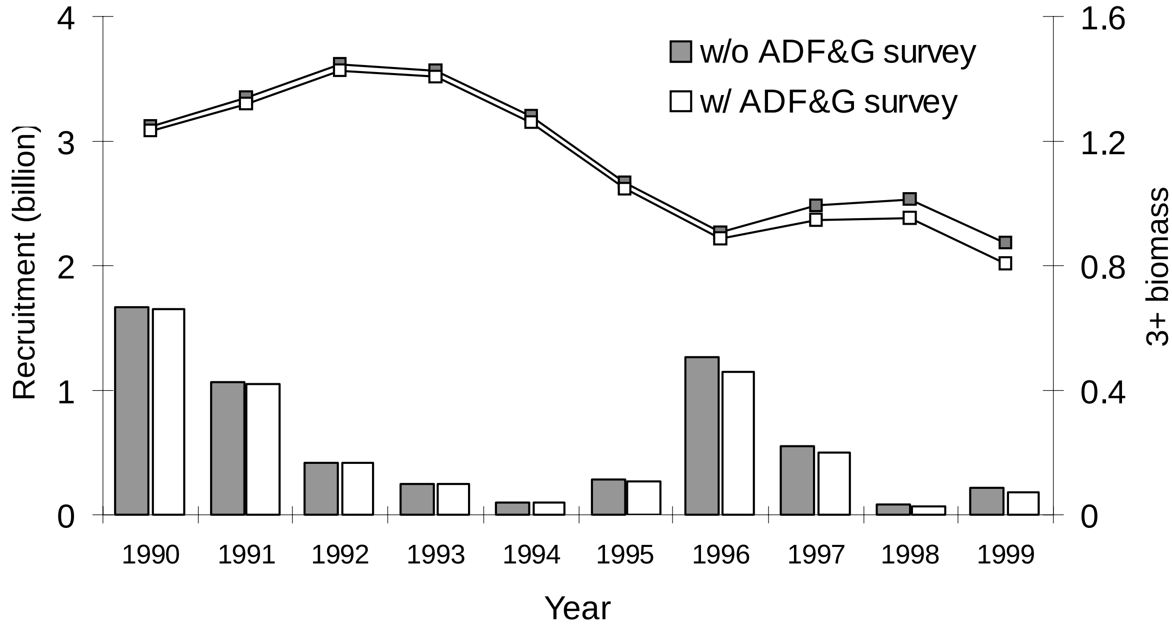


Figure 1.14--Evaluation of a model where data from the ADFG coastal trawl survey is included with low emphasis (survey biomass index CV = 10, sample size for age composition = 10). The top panel shows the fit to the biomass index; the bottom panel shows the residuals from binned survey length-frequency data.



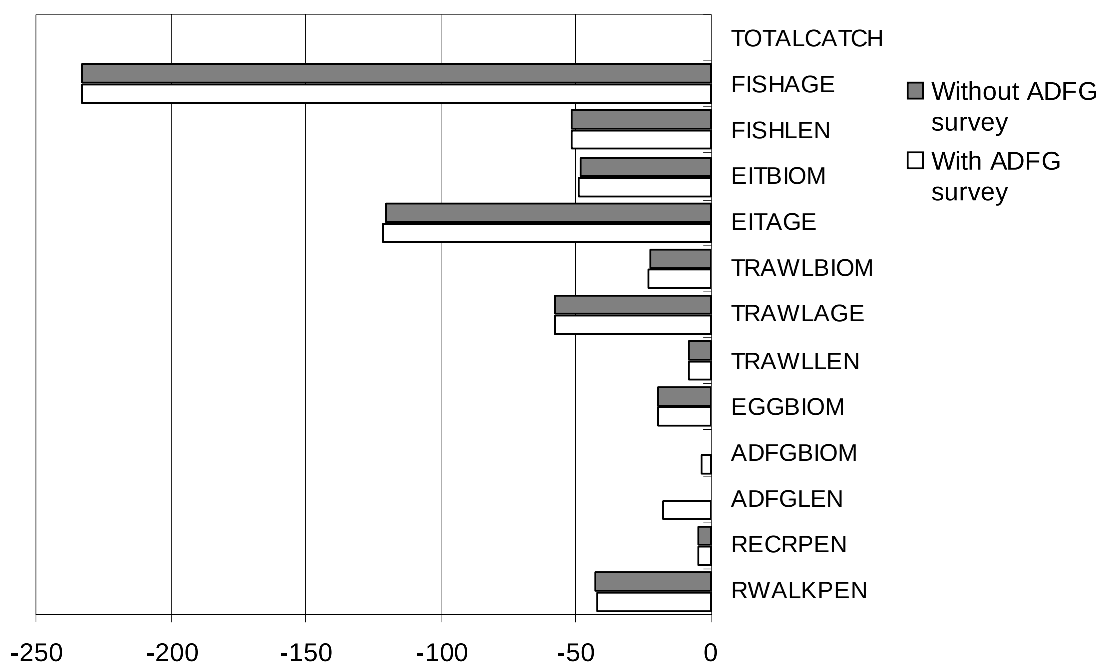


Figure 1.15--Effect of including the ADF&G survey in the assessment model: recruitment and biomass during 1990-99 (top panel), model fit as measured by log likelihood (bottom panel).

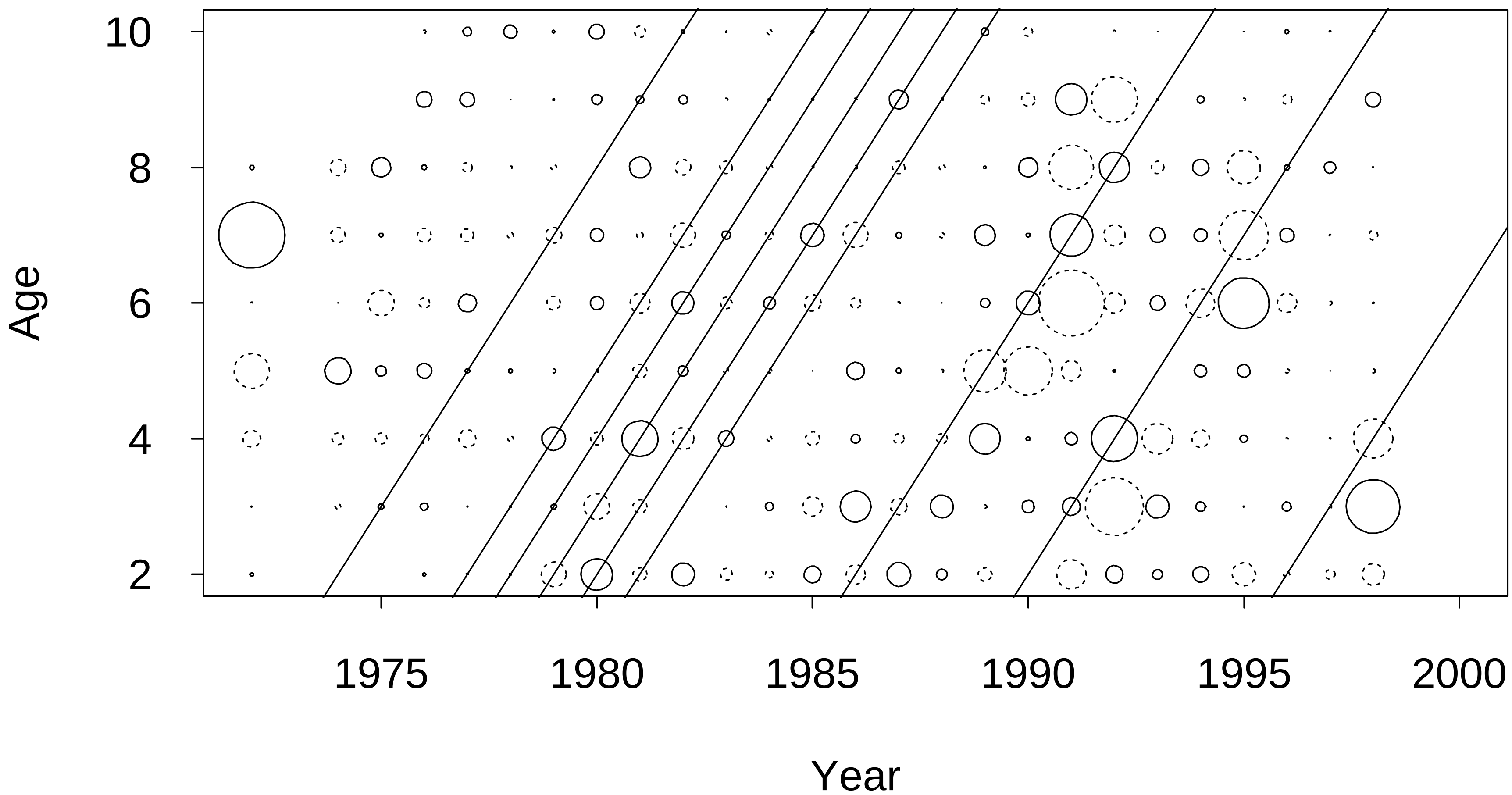


Figure 1.16--Residuals from base-run assessment model for fishery age composition (1972-98). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

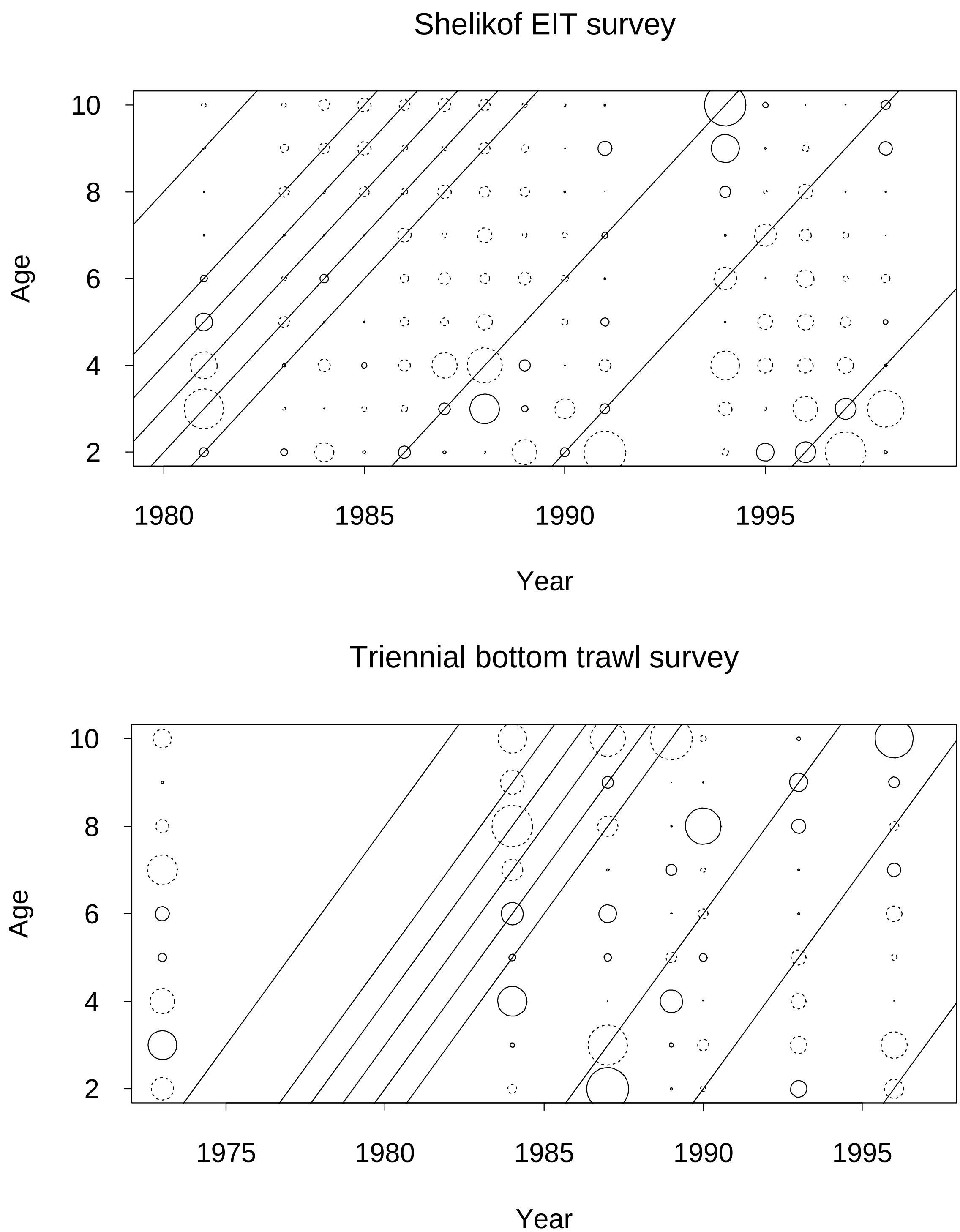


Figure 1.17--Residuals from base-run assessment model for the Shelikof Strait EIT age composition (top panel) and triennial bottom trawl age composition (bottom panel). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

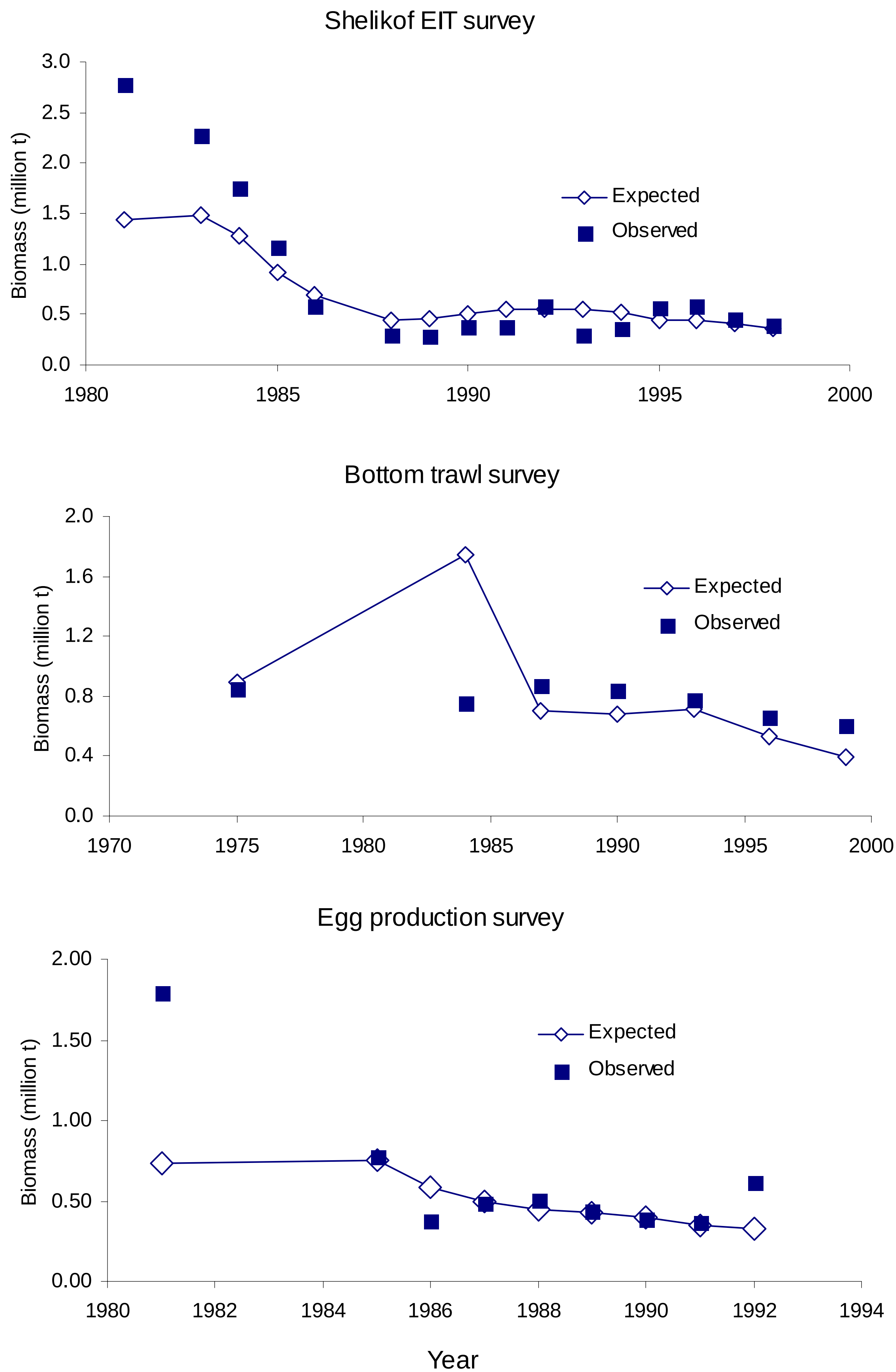


Figure 1.18--Observed and predicted Shelikof Strait EIT survey biomass (top panel), AFSC trawl survey biomass (middle panel), and egg production survey biomass (bottom panel) for the base-run model.

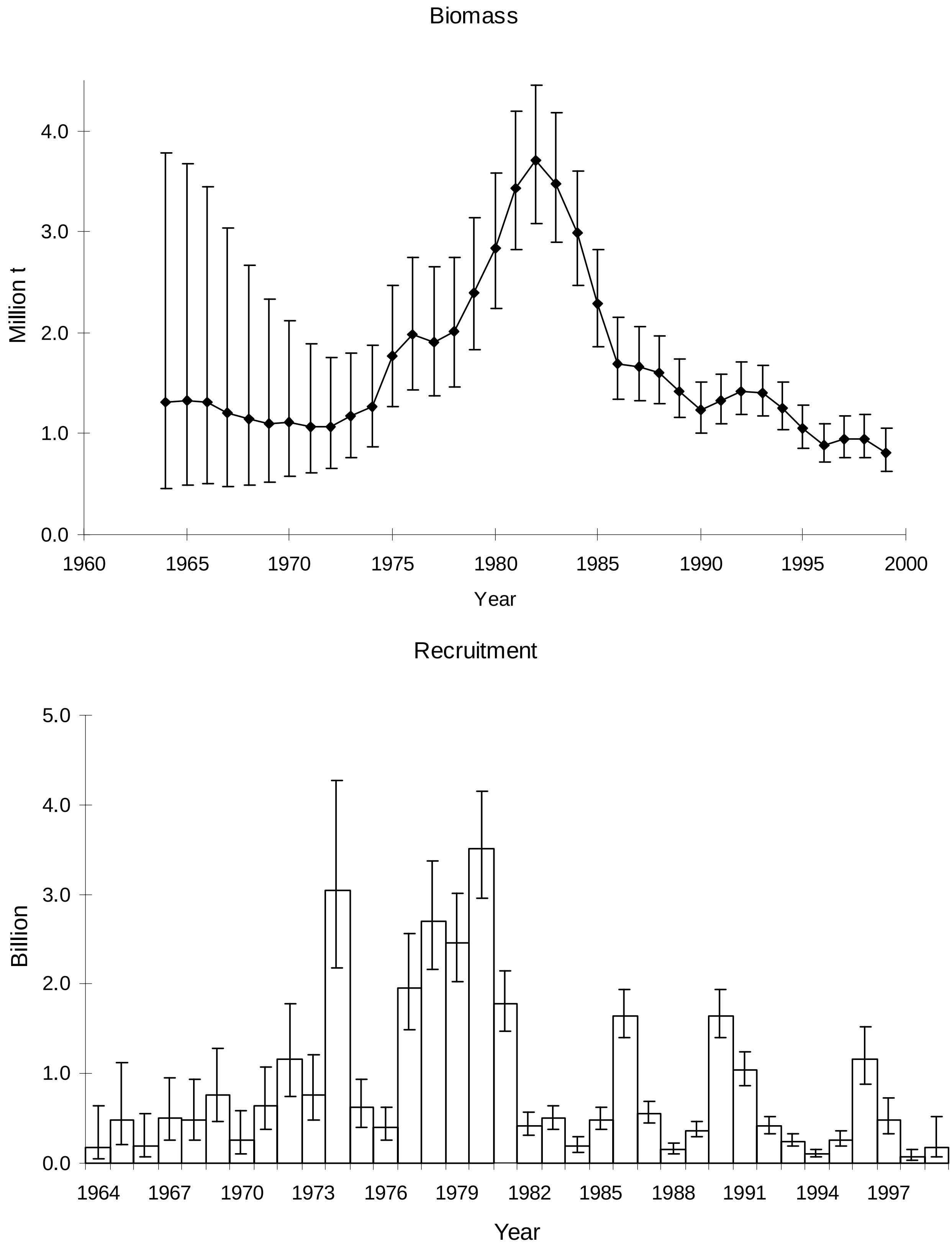


Figure 1.19--Estimated time series of Gulf pollock age 3+ biomass (million t) and age-2 recruitment (billions of fish) during 1972-98. Vertical bars represent two standard deviations.

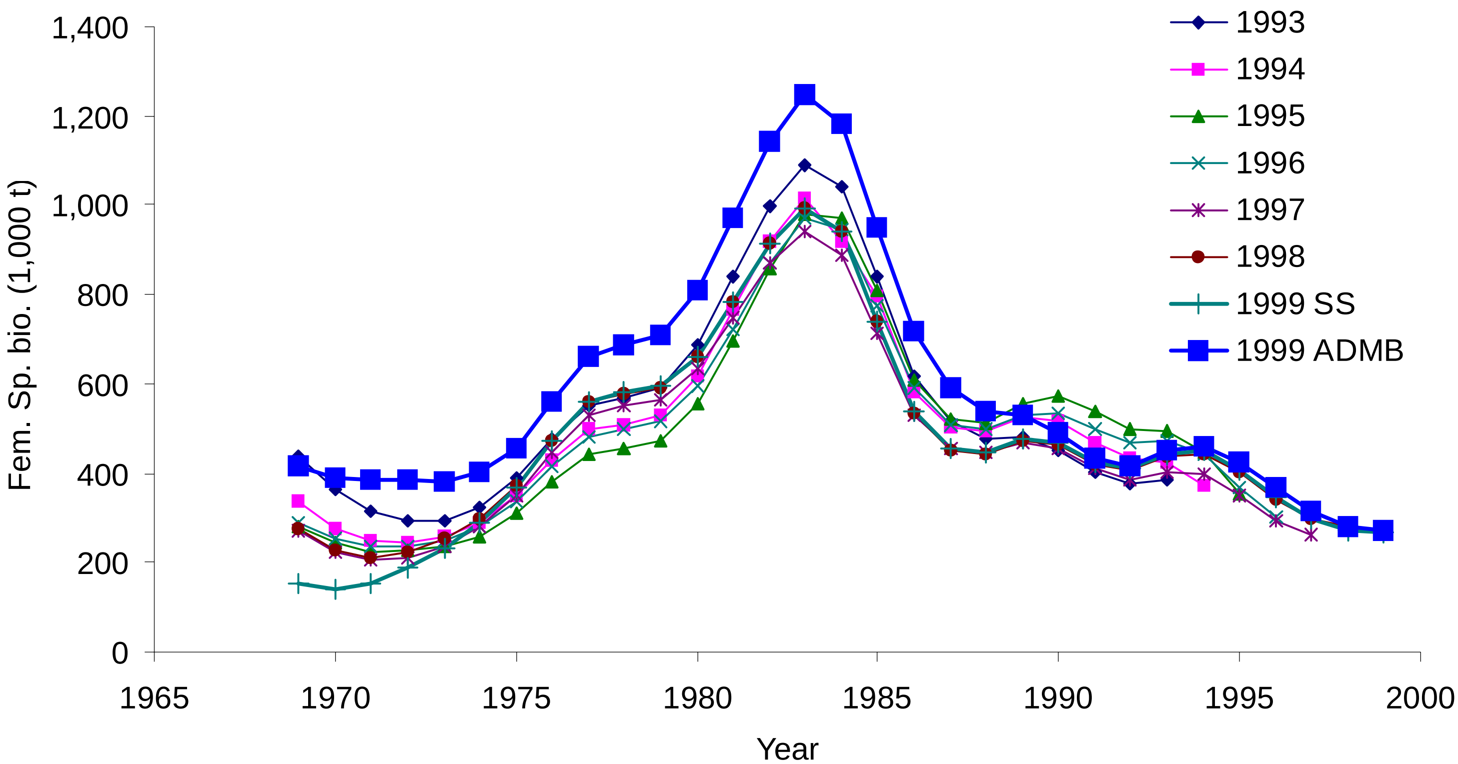


Figure 1.20--Retrospective plot of the estimated Gulf pollock female spawning biomass for stock assessments in the years 1993-99.

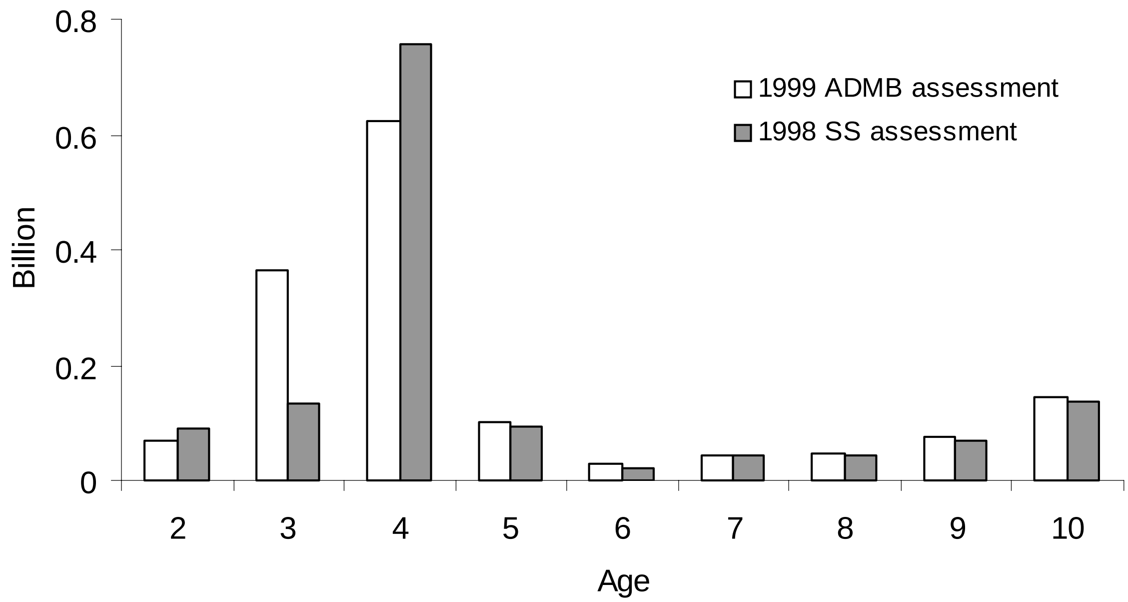


Figure 1.21--Comparison of 1998 estimated age composition for the current assessment and the 1998 Gulf pollock assessment (Hollowed et al. 1988).

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 30-50,000 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.

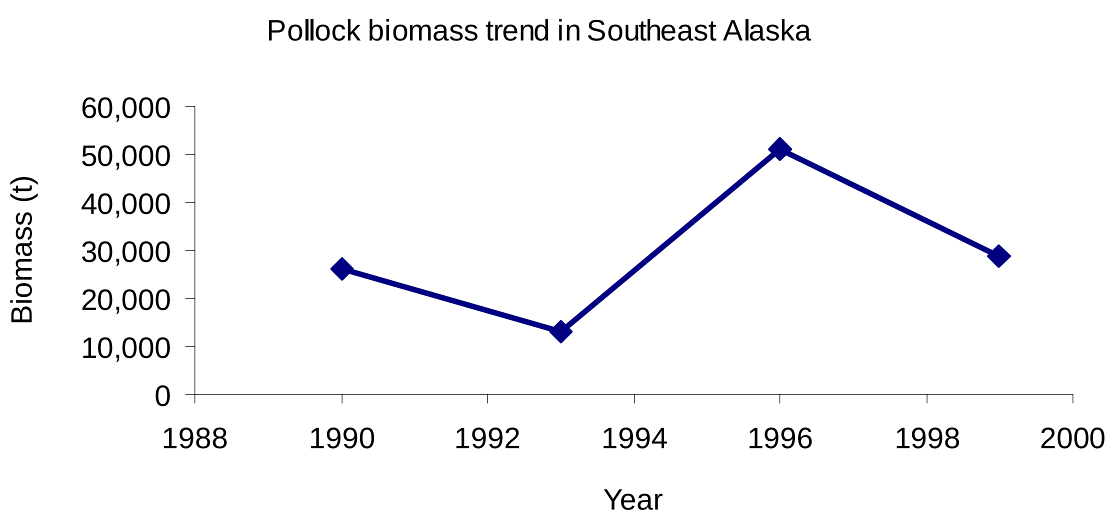


Figure 1.22. Pollock biomass trend in southeast Alaska from triennial surveys in 1990-1999.

Appendix B. Apportioning the Gulf pollock ABC

Since 1994, the Gulf pollock ABC has been apportioned between areas 610, 620 and 630 based on the most recent trawl survey biomass. Because the assessment boundary has been shifted east to include all of area 640, it should be included when apportioning the 2000 ABC. Both single species and ecosystem considerations provide the rationale for ABC apportioning. From an ecosystem perspective, apportioning the ABC will spatially distribute the effects of fishing on other pollock consumers (i.e., sea lions), thus reducing the overall intensity of adverse interactions..

The triennial trawl survey occurs every three years in the summer months, and thus provides a "snapshot" of a highly dynamic stock. For example, ABC apportionment in 1999 was based on a survey three years earlier. It is important to consider how to make best use of limited information on biomass distribution from the trawl survey when apportioning the ABC. The spatial distribution of pollock biomass will have the following properties:

- Observation error: Biomass estimates will be larger or smaller than the true biomass because of sampling variability.

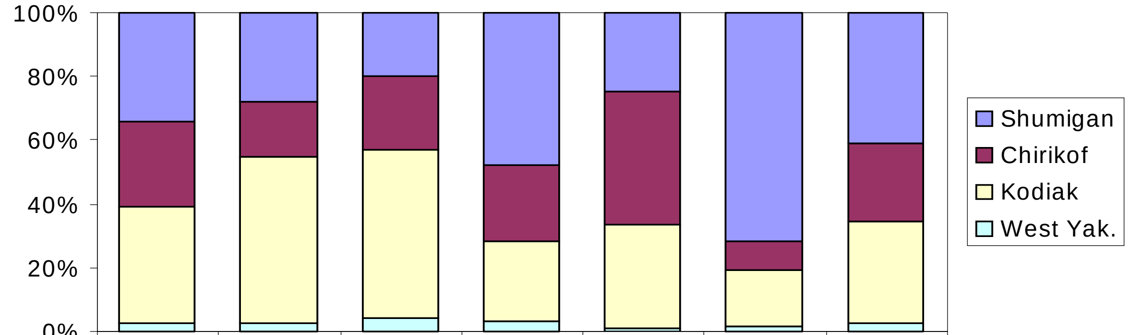
- Autocorrelation: The predictable tendency for the true biomass distribution to be similar from one year to the next.

- Process error: The random variability of the true biomass distribution from one year to the next.

- Projection: Because the surveys occur infrequently, there is a lag (one to three years) between the most recent survey and year when the ABC is apportioned. If process error is large, the projected biomass distribution will become increasingly uncertain as more time elapses.

The above description identifies the components of a proposed state space model for biomass distribution (Harvey 1990). A similar approach was introduced in an appendix to the Gulf of Alaska Other Species Assessment (Gaichas and Ianelli 1999). The qualitative characteristics of projections using a state space model include 1) a tendency to down weight more recent observations in favor a value closer to the long-term average state, especially if the recent observations are highly uncertain, 2) projected values asymptotically approach the long-term average state in the absence of new observations. Simpler *ad hoc* alternatives are 1) using only the most recent survey, 2) using a long-term average of the surveys, 3) intermediate approaches, e.g., using a weighted average with emphasis on the most recent surveys. The relative merits of each *ad hoc* approach depend on the ratio of process error to observation error, and on the strength of autocorrelation.

Two time series of biomass distribution for Gulf pollock are available: the triennial survey time series, and the annual ADF&G survey (Figs. 1.23-1.24). Although the surveys are designed with different strata, the Shumagin area closely corresponds to the ADF&G South Peninsula area. Both time series indicate that pollock biomass distribution in the 1990s has been highly variable, however the annual ADF&G survey does suggest that pollock biomass distribution is autocorrelated at lags of several years. Focusing on the Shumagin/South Peninsula area only, the ADF&G survey suggests that triennial surveys during the 1990s have tended to occur during the extremes of the biomass distribution, i.e., when the biomass in the Shumagin area was higher than average, or lower than average. With a three-year survey cycle, apportioning the ABC based on the most recent survey could induce a "wobble" in the population dynamics. Areas with higher than usual biomass in one survey could be subjected to higher harvest rates for a three year period, producing lower than usual biomass in the following survey.



	1984	1987	1990	1993	1996	1999	4 survey average
Shumigan	33.9%	27.6%	20.0%	47.6%	24.7%	71.8%	41.0%
Chirikof	26.7%	17.4%	23.1%	24.0%	41.7%	8.6%	24.4%
Kodiak	37.0%	52.5%	52.8%	25.1%	32.3%	18.3%	32.1%
West Yak.	2.5%	2.5%	4.1%	3.3%	1.2%	1.3%	2.5%

Figure 1.23. Percent distribution of Gulf pollock biomass west of 140° W long as measured by triennial trawl surveys in 1984-99. The percent in West Yakutat in 1984 and 1987 was set equal to the mean percent in 1990-99.

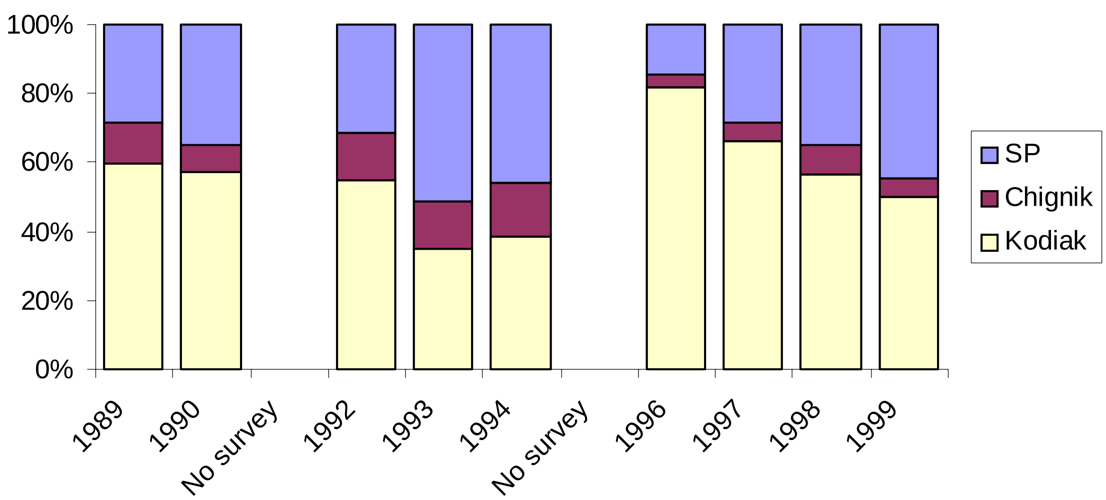


Figure 1.24. Percent distribution of Gulf pollock biomass by strata in the ADF&G coastal survey during 1989-99.

The percent of the biomass in the South Peninsula area is correlated with the fraction of older fish (age 4+) in the population (Fig. 1.25), suggesting that ontogenetic shifts in summer foraging habitat can account for some of the variability in biomass distribution. Without quantitative modeling, the objective should be to apportion the 2000 ABC in a way that is risk averse to potential overharvest within any area. The apparent mobility of Gulf pollock shown in the annual ADF&G survey and poor track record of the most recent trawl survey in predicting future biomass distributions would argue that a multi-year average would be more appropriate than the current method. The sensitivity of the 1999 biomass distribution to an extremely large tow in the Shumagin area is also a concern (i.e., large observation error). A four-survey average (1990-99) would capture any changes in average biomass distribution during the 1990s while reducing the potential for overharvest within any area.

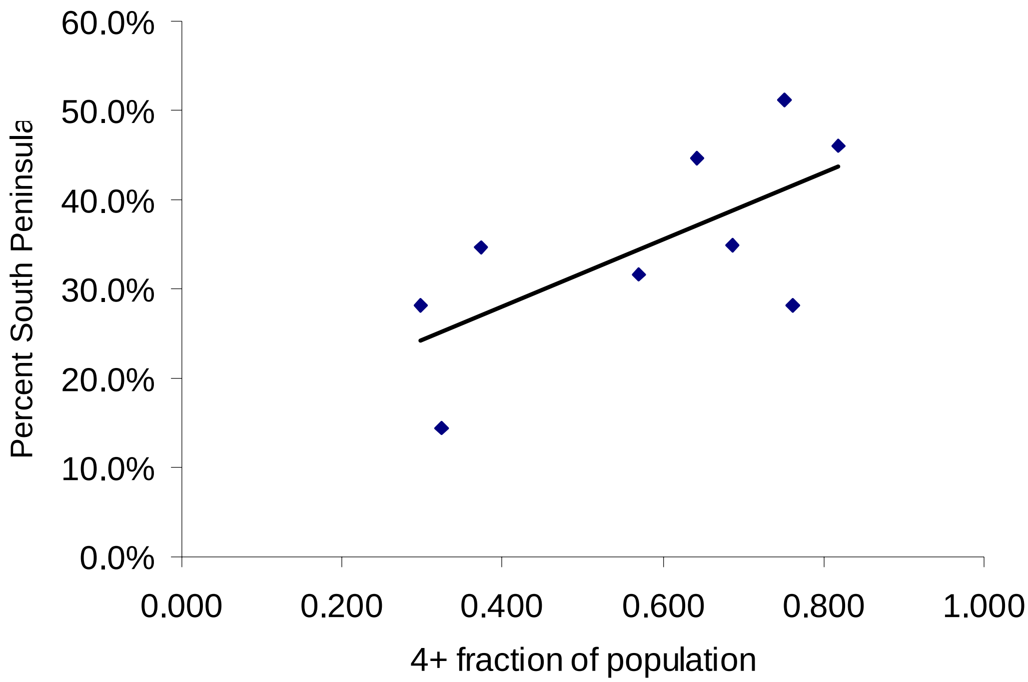


Figure 1.25. Percent of biomass in South Peninsula area in the ADFG survey as a function of the fraction of age 4 and older fish of the total population.

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

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

$$s_j = s_j^{/} \ / \max_j \ (s_j^{/})$$

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 *i*th 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,

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