1A. Stock Assessment of Aleutian Islands Region Pollock

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Executive Summary

Development of a detailed age-structured stock assessment for the Aleutian Islands Region pollock began in 2003 (Barbeaux et al. 2003) and has been further developed in 2004 and 2005 (Barbeaux et al. 2004, Barbeaux et al. 2005). In the initial study the near shore areas of the Aleutian chain island were isolated and identified as the Near, Rat, and Andreanof Island (NRA) sub-area. This sub-area was further refined to exclude the area east of 174°W to address data consistency issues. The Council supported this proposal and urged continuing development on an age-structured assessment model using data from the area west of 174°W (and omitting deep-water areas where survey data are unavailable).

Pollock fishery data collected near the eastern boundary of the Aleutian Islands region (between of 174°W and 170°W) highlight stock structure uncertainty between the Aleutian Islands region, the Aleutian Islands Basin, and the EBS. Consequently, they are excluded from all of the age-structured assessment models presented below. We do, however, recognize that fluctuations in biomass observed from the summer Aleutian Islands bottom trawl (AIBT) survey data from this area do not indicate clear cut patterns and that substantial uncertainty in the stock structure exists. We have included model configurations which include all of the AIBT survey data and one model that excludes data from the eastern NRA area (NRA area east of 174°W).

Spatial analyses of fishery, survey, and bycatch data using GIS methods reveal an important characteristic of pollock in the Aleutian Islands region: concentrations are highly variable and likely evolve quickly within seasons. These analyses underscore the challenge of evaluating stocks that: are highly mobile, spend variable time associated with the bottom, have patchy distributions, and are likely influenced by neighboring stocks.

Summary of major changes

The model configuration differs from the 2005 assessment in that natural mortality is estimated within the reference model. The data for this year's assessment differ from last year in that age data from the 2006 Aleutian Islands Cooperative Acoustic Survey Study was available as a proxy for fisheries data and biomass estimates from the 2006 Aleutian Islands bottom trawl survey were incorporated.

Changes in the assessment results

The estimate for natural mortality in the reference model was lower than that assumed in previous years, therefore biomass and F estimates are significantly lower than those from the 2005 assessment. The maximum permissible ABC for 2007 and 2008 under Tier 3a are 44,470 t and 33,090 t respectively and the maximum permissible ABC under Tier 5 for both years using the lower natural mortality is 16,800 t.

Response to SSC 2005 Comments

The SSC commented that they supported continued research of the Aleutians pollock stock. To that end we completed the 2006 Aleutian Islands cooperative acoustic survey study AICASS to ascertain whether it was possible to conduct acoustic surveys on pollock in the Central Aleutian Islands in the winter. This project was a success and has provided not only verification of the technique, but valuable data on the biology and health of the Aleutian Islands pollock stock. Some the biological data such as age and length composition have been used directly in this assessment, other data such as pollock tissue samples await funding for further analysis. We propose further research of this type for 2007 with an expanded AICASS.

Introduction

Walleye pollock (*Theragra chalcogramma*) are distributed throughout the Aleutian Islands with concentrations in areas and depths dependent on season. Generally, larger pollock occur in spawning aggregations during February – April. Three stocks of pollock inhabiting three regions in the Bering Sea – Aleutian Islands (BSAI) are identified in the U.S. portion of the BSAI for management purposes. These stocks are: the eastern Bering Sea pollock occupying the eastern Bering Sea shelf from Unimak Pass to the U.S.-Russia Convention line; the Aleutian Islands Region pollock encompassing the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and the Central Bering Sea—Bogoslof Island pollock. These three management stocks probably have some degree of exchange. The Central Bering Sea—Bogoslof stock is a group that forms a distinct spawning aggregation that has some connection with the deep water region of the Aleutian Basin. In the Russian Exclusive Economic Zone (EEZ), pollock are thought to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line. The northern stock is believed to be a mixture of eastern and western Bering Sea pollock with the former predominant. Bailey et al. (1999) present a thorough review of the population structure of pollock throughout the north Pacific region. Recent genetic studies using mitochondrial DNA methods have found the largest differences to be between pollock from the eastern and western sides of the north Pacific.

Previously, Ianelli et al. (1997) developed a model for Aleutian Islands pollock and concluded that the spatial overlap and the nature of the fisheries precluded a clearly defined "stock" since much of the catch was removed very close to the eastern edge of the region and appeared continuous with catch further to the east. In some years a large portion of the pollock removed in the Aleutian Islands Region was from deep-water regions and appeared to be most aptly assigned as "Basin" pollock. This problem was confirmed in the 2003 Aleutian Islands pollock stock assessment (Barbeaux et al. 2003).

Fishery

The nature of the pollock fishery in the Aleutian Islands Region has varied considerably since 1977 due to changes in the fleet makeup and in regulations. During the late 1970s through the 1980s the fishing fleet was primarily foreign. In 1989, the domestic fleet began operating in earnest and continued in the Aleutian Islands Region until 1999 when the North Pacific Fishery Management Council (NPFMC) recommended closing this region for directed pollock fishing due to concerns for Steller sea lion recovery. Table 1A.1 provides a history of ABC, OFL, and catch for Aleutian Islands pollock since 1991. In 2005 the fishery was reopened with a 19,000 t TAC. A directed pollock fishery was conducted in February 2005, but the vessels participating in the fishery failed to find commercially harvestable quantities outside of Steller sea lion critical habitat closure areas and removed less than 200 t of pollock. In addition, bycatch rates of Pacific Ocean perch were prohibitively high in areas where pollock aggregations were observed. The 2005 fishery is thought to have resulted in a net loss of revenue for participating vessels. Data on specific bycatch and discard rates for the 2005 fishery are not available due to issues of data confidentiality. In 2006 the Aleut Corporation, in partnership with the Alaska Fisheries Science Center, Adak Fisheries LLC and the owners and operators of the F/V Muir Milach, conducted the Aleutian Islands Cooperative Acoustic Survey Study (AICASS) to test the technical feasibility of conducting acoustic surveys of pollock in the Aleutian Islands using small (<32 m) commercial fishing vessels (Barbeaux, in press). This work was supported under an exempted fishing permit that allowed directed pollock fishing within Steller sea lion critical habitat. A total of 932 t of pollock were harvested during this study and biological data collected during this study are treated in the stock assessment as fishery data.

Data

Catch estimates

Estimates of pollock catch in the Aleutian Islands Region are derived from a variety of data sources (Table 1A.2). During the early period, the foreign-reported database (held at AFSC) is the main source of information and was used to derive the official catch statistics until about 1980 when the observer data were introduced to provide more reliable estimates. The foreign and joint-venture (JV) blend data takes into account observer data and reported catches and forms the basis of the official catch statistics until 1990. The NMFS Observer data are the raw observed catch estimates and provide an indication of the amount of catch observed relative to the current estimates from the blend data. Estimates of pollock discard levels have been available since 1990. During the years when directed fishing was allowed pollock discards represented a small fraction of the total catch (Table 1A.3).

For the period 1977-1984, the foreign reported catch database was used to partition catches while for 1985-2003, observer data were used. These proportions were then expanded to match the total catch (Table 1A.4; Fig. 1A.1).

The distribution of observed catch differed between the JV years (1977-1989) and the domestic fishery (1989-2002; Fig. 1A.2). In the early period, the JV fishery operated in the deep basin area extending westward to Bowers Ridge and in the eastern most portions of the Aleutian Islands. Some operations took place out to the west but observer coverage was limited. In the recent period (1989-1998, since the Aleutian Islands Region has been closed to directed pollock fishing since 1999) the fishery was more dispersed along the Aleutian Islands chain with no observed catches along Bowers Ridge and fewer operations in the deep basin area. Considering the spatial distribution of these fisheries, we recommended that the Aleutian Islands Region be broken into areas where apparent breaks existed (Fig. 1A.3). These breaks separate the northern “basin” area from the Aleutian Islands chain and split the eastern-most portion of the Aleutian Islands Region from the Aleutian Islands. Two regional partitions were developed, one called NRA (for Near, Rat, and Andreanof Island groups) extending to 170°E, and another that excludes the eastern portion between 174°W and 170°W. The time series of catch estimates for these two groups is shown in Table 1A.5. In the NRA area west of 174°W the fishery tended to concentrate in two distinct locations one on the north side of Atka Island around 174°W and the other near 177°W northwest of Adak Island. While the overall catch level was relatively low, the fishery moved far to the west in 1998 (Fig. 1A.4).

Fishery length frequency

The number of hauls and length samples in the NRA region west of 174°W are quite small compared with the eastern and northern (basin) areas (Table 1A.6). The differences in the length frequencies appear to be substantial between regions (Barbeaux et al. 2004). During the early period, the region west of 174°W longitude was composed of smaller fish. This region also tended to have a broader range of lengths. The Basin region was similar to the eastern most region and the Bogoslof region (during the years when a fishery was allowed there). In the 2005 stock assessment we investigated whether the changes in length frequency distributions for the NRA region west of 174°W could be attributed to different seasonal concentrations of fishing. These investigations showed that before 1990, the fishery tended to be more concentrated later in the year, but inter-annually the fishery was consistent in the time between the eastern and western NRA (Barbeaux et al. 2005). We therefore concluded that differences in length distributions observed between these two regions could not be attributed to differences in the time of year in which the fishery was conducted. Intra-annual differences may show a trend that could be consistent with seasonality differences. The occurrence of larger fish later in the time series is likely due to the fishery targeting on spawning pollock. Pollock average weights-at-age from the early period are lower than the recent period (Table 1A.7). As shown in the 2005 assessment the observed proportion of females in the catch appeared to show a slight decline over this period (Barbeaux et al. 2005).

Fishery age composition

Catch-at-age composition estimates are made following Kimura (1989) and modified by Dorn (1992). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The number of age samples and length samples was highly variable over this time period (Table 1A.8). This problem is exacerbated for samples collected from different areas and gears (Table 1A.9). The estimates for catch-age composition are shown in Table 1A.10. The age composition data collected in the 2006 AICASS was used as fishery data.

Survey data

Bottom trawl survey effort in the Aleutian Islands region has not been as extensive as in the eastern Bering Sea. The National Marine Fisheries Service in conjunction with the Fisheries Agency of Japan completed bottom trawl surveys for the Aleutian Islands region (from ~165°W to ~170°E) in 1980, 1983, and 1986. The Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division (RACE) conducted bottom trawl surveys in this region in 1991, 1994, 1997, 2000, 2002, 2004 and 2006. Biomass estimates from the surveys conducted in the 1980s ranged between 309 and 779 thousand tons (mean 546). Biomass estimates from the five most recent RACE surveys ranged between 112 and 366 thousand tons (mean 225; Table 1A.11). The biomass estimates from the early surveys are not comparable with the biomass estimates obtained from the RACE trawl surveys because of differences in the net, fishing power of the vessels, and sampling design. In the early surveys, biomass estimates were computed using relative fishing power coefficients (RFPC) and were based on the most efficient trawl during each survey. Such methods will result in pollock biomass estimates that are higher than those obtained using standard methods employed in the RACE surveys. Plotted on a simple catch-per-tow basis, the relative distribution of pollock appears to be variable between years and areas (Fig. 1A.5).

RACE Aleutian Islands bottom trawl (AIBT) surveys prior to 2004 indicate that most of the pollock biomass has been located in the Eastern Aleutian Islands Area (Area 541) and along the north side of Unalaska-Umnak Islands in the eastern Bering Sea region (~165°W and 170°W). The 2004 Aleutian Islands trawl survey showed the greatest density and estimated biomass in the Unalaska-Umnak area in the eastern Bering Sea region, but only low densities of pollock were observed in the Unalaska-Umnak Islands area in the 2006 survey. If we ignore the biomass estimates from the Unalaska-Umnak area the 2004 and 2006 AIBT surveys are very similar and show a very different pattern of biomass abundance than the 2002 survey (Fig. 1A.5). Within the Aleutian Islands Region (Areas 541, 542, and 543) the 2002 AIBT survey indicated the highest densities and biomass were in the Central Aleutian Islands Area (Area 542) followed by the Eastern (Area 541) and Western areas (Area 543). In the 1991-2000 AIBT surveys the highest biomasses for the NRA Areas were estimated in Area 541 followed by Area 542 and Area 543. The earlier RACE AIBT surveys indicated a decline in pollock biomass in the portion of Area 541 east of 174°W longitude from a high of 53,865 t in 1991 to a low of 28,985 t in the 2000 survey. This trend was reversed in the 2002 survey with an estimate of 53,368 t, in 2004 with an estimate of 111,250 t, and 117,000 t in 2006 (Table 1A.11). In the 1991-2002 surveys a number of large to medium sized tows were encountered throughout the Aleutians indicative of a fairly well distributed population. This is very different from the 2004 and 2006 survey estimates which indicated a low level of pollock abundance in both Area 542 and Area 543, and a much higher pollock density in Area 541. The 2004 survey revealed very few pollock throughout the NRA, except for a single large tow in Seguam pass. The distribution of pollock in the 2006 survey revealed a similar pattern to that of the 2004 survey with high CPUE in the

Seguam pass area. The 2006 survey found a higher concentration of pollock in the Delerof Islands that was not observed in 2004, but is consistent with aggregations observed in 2002. Like the 2004 survey there were very few pollock observed west of 180° longitude. Since there has not been a substantial fishery in the Aleutians not has there been a substantial change in survey methodology or design, the continued decrease in pollock must be attributed to either a change in catchability due to vertical migration of pollock out of the reach of the bottom trawl, increased emigration of pollock out of the surveyed area, decreased recruitment, increased natural mortality exceeding recruitment, or some combination of these factors. Since the AIBT is limited to within the 500 m isobath the survey biomass estimates do not include mid-water pollock, nor do they include pollock located offshore of the 500 m isobath. These biomass estimates therefore represent an unknown portion of the total biomass. The biomass in this area may be greater if the on-bottom/off-bottom distribution is similar to that of the eastern Bering Sea (Ianelli et al. 2005). In addition, climatic and year class variation may cause a difference in the proportion of pollock available to the bottom trawl survey.

This year we looked at distribution patterns of pollock in relation to temperature and depth. We found that in comparison with pollock distribution observed in the 2004 Bering Sea and 2005 Gulf of Alaska bottom trawl surveys (BSBTS and GOABTS respectively), the distribution observed in the 2004 and 2006 Aleutian Islands bottom trawl surveys (AIBTS) was in a more limited temperature range and generally deeper (Fig. 1A.6). Overall the bottom temperature in the AIBTS was much less variable than in either the BSBTS or GOABTS at depth and ranged between the other surveys with the BSBTS generally cooler at depth and GOABTS warmer at depth. In the AIBTS the highest concentrations of pollock are encountered between 140 m and 300 m, while in the BSBTS the highest concentrations of pollock were above 100 m and above 150 m in the GOABTS. The 2006 AIBTS was colder at shallower depths than in 2004 and pollock concentrations appeared to shift towards deeper water (Fig. 1A.7). The shift of pollock distribution to deeper waters with colder bottom temperatures is consistent with a shift observed in the Bering Sea between 1999, a cold year, and 2004, a warm year (Fig. 1A.8).

Survey Length Frequencies

There are apparent differences in pollock length-at-age between the Aleutian Island, Bering Sea, and Gulf of Alaska between ages 2 and 9, with the Aleutian Islands pollock being largest, GOA next, then Bering Sea pollock the smallest at age (Fig. 1A.9). The pollock length frequency collection from the 2006 AIBTS showed the primary mode between 56 and 66 cm similar to previous years and is thought to be primarily composed of 2000 and/or 1999 year-class fish (Fig. 1A.10). There was a small mode between 15 and 25 cm that would be consistent with 1 or 2 year old fish, but much fewer than observed in 2004. The 2004 AIBT survey found a large proportion of small fish (between 10 and 25 cm, indicative of 1 or 2 year old fish) in the NRA area west of 174°W, but very few small fish east of 174°W. The 2002 AIBT survey did not find very many small fish anywhere in the Aleutians. There were a large number of small fish observed in the 1994 and 2000 surveys throughout the NRA . The large numbers of 1 or 2 year old size pollock observed in the these surveys were assumed to have entered the fishable population in 1996 and 2002, respectively, and should have stabilized or increased pollock biomass in the Aleutian Islands in recent years.

Other Surveys

In addition to the bottom trawl survey there has been one echo integration-trawl survey in a portion of the NRA. The R/V Kaiyo Maru conducted a survey between 170°W and 178°W longitude in the winter of 2002 after completing a survey of the Bogoslof region (Nishimura et al 2002; Fig. 1A.11). Due to difficulties in operating their large mid-water trawl on the steep slope area they determined that their catches in this area were insufficient for accurate species identification and biomass estimation. They did however come up with some preliminary biomass estimations. For the entire area from 170°W and 178°W longitudes they estimated a biomass of 93,000 t of spawning pollock biomass with between 61,000 t estimated in the NRA east of 173°W and 32,000 t in the remainder of the survey area to 178°W longitude (Table 1A.12). The largest aggregations in the NRA area were observed at 174°W longitude north of Atka Island. Most of the pollock echo sign was observed along the slope of the Aleutian Islands relatively near shore.

In 2006 the Aleut corporation in conjunction with the Alaska Fisheries Science Center, Adak Fisheries LLC, and the F/V Muir Milach conducted the Aleutian Islands Cooperative Acoustic Survey Study (AICASS) to test the technical feasibility of conducting acoustic surveys of pollock in the Aleutian Islands using small commercial fishing vessels (<32 m) (Barbeaux, in press). The study resulted in three surveys of a 180 nm^2 area north of Atka Island between 174.5°W and 175.5°W longitude (Fig. 1A.12), two surveys of a 72 nm^2 area within the larger area, and a 9 nm^2 area within this area over a three week period. Since this survey was conducted in conjunction with a commercial fishery the catch-at-age data (Fig. 1A.13) from this survey was used as the Fishery catch at age data within the stock assessment model. Age structure and length frequency data collected during this study reveal that the 2000 and 1999 year classes were dominant in the studied population with strong 1992 and 1996 showing up as well. These year classes are also prevalent in the summer AIBTS and in the Eastern Bering Sea. The biomass within the large area started at 8,810 t for the first survey, was at 7,980 t for the second large survey (a statistically insignificant change), then dropped significantly to 3,639 t for the final survey (Table 1A.13, Fig. 1A.14, and Fig. 1A.15). From the first to last survey there was a 59% decline in pollock abundance even though the fishery only had an 11% harvest rate (Fig. 1A.16). The reason for this decline, although undoubtedly in part due to fishing, is confounded with possible effects of spawning emigration from the survey area. Although, a trend in the maturity data showed that pollock began showing signs of active spawning only at the end of the study (Fig. 1A.17).

Analytic Approach

The 2006 Aleutian Islands walleye pollock stock assessment uses the same modeling approach as last year's model; through the Assessment Model for Alaska (here referred to as AMAK). AMAK is a variation of the "Stock Assessment Toolbox" model presented to the plan team in the 2002 Atka mackerel stock assessment, with some small adjustments to the model and a user-friendly graphic interface.

The abundance, mortality, recruitment, and selectivity of the Aleutian Islands pollock were assessed with a stock assessment model constructed with AMAK as implemented using the ADMB software. The ADMB is a C++ software language extension and automatic differentiation library. It allows for estimation of large numbers of parameters in non-linear models using automatic differentiation software developed into C++ libraries (Fournier 1998). The optimizer in ADMB 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 1×10^{-7}). A feature of ADMB and AMAK is that it includes post-convergence routines to calculate standard errors (or likelihood profiles) for quantities of interest.

Model structure

The AMAK model models catch-at-age with the standard Baranov catch equation. The population dynamics follows numbers-at-age over the period of catch history with natural and age-specific fishing mortality occurring throughout the 14-age-groups that are modeled (ages 2-15+). Age-2 recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve. Deviations between the observations and the expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. This overall log-likelihood (L) is the weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances. Barbeaux et al. 2005, Appendix Tables 1 –3 provide a description of the variables used, and the basic equations describing the population dynamics of Aleutian Islands pollock and likelihood equations. The model was modified from that of Barbeaux et al. (2003). These modifications include a feature that allows a user-specified age-range for which to apply the survey (or other abundance index) catchability. For example, specifying the age-range of 6-10 (as was done for Aleutian Islands pollock) means that the average age-specific catchability of the survey is set to the parametric value (either specified as fixed, as in this assessment, or estimated). Also, in the 2003 assessment age-1 pollock were explicitly modeled whereas in the work presented here, they were dropped from consideration because observations of age-1 pollock are irregular, and in trials where they were included, they were found to limit the flexibility to incorporate alternative model specifications such as parametric forms of selectivity functions. The quasi[1] likelihood components and the distribution assumption of the error structure are given below:

Likelihood Component	**Distribution Assumption**
Catch biomass	Lognormal
Catch age composition	Multinomial
Survey catch biomass	Lognormal
Survey catch age composition	Multinomial
Recruitment deviations	Lognormal
Stock recruitment curve	Lognormal
Selectivity smoothness (in age-coefficients, survey and fishery)	Lognormal
Selectivity change over time (fishery only)	Lognormal
Priors (where applicable)	Lognormal

The age-composition components are heavily influenced by the sample size assumptions specified for the multinomial likelihood. Since sample variances of our catch-at-age estimates are available (Dorn 1992), “effective sample sizes” ($\dot{N}_{i,j}$) can be derived as follows (where *i* indexes year, and *j* indexes age):

$$\dot{N}_{i,j} = \frac{p_{i,j}\left(1-p_{i,j}\right)}{\mathrm{var}\left(p_{i,j}\right)}$$

where $p_{i,j}$ is the proportion of pollock in age group *j* in year *i* plus an added constant of 0.01 to provide some robustness. The variance of $p_{i,j}$ was obtained from the estimates of variance in catch-at-age. Thompson et al., (2003, p. 137) and Thompson (pers. comm.) show that the above is a random variable that has its own distribution. They show that the harmonic mean of this distribution is equal to the true sample size in the multinomial distribution. This property was used to obtain sample size estimates for the surveys and fishery numbers-at-age estimates:

Fishery data	Year	1978	1979	1980	1981	1982	1983	1984	1985	1987
	$\dot{N}_{i,\bullet}$	246	170	119	215	553	81	296	225	150
	Year	1990	1992	1993	1994	1995	1996	1997	1998	2006
	$\dot{N}_{i,\bullet}$	199	238	172	327	211	228	30	302	300
Survey data										
	Year	1991	1994	1997	2000	2002	2004			
	$\dot{N}_{i,\bullet}$	1*	740	690	831	1124	774			

*The 1991 value was down-weighted by a factor of 1,000 because the samples collected in that year were not representative of the region considered.

[1] The likelihood is *quasi* because model penalties (e.g., non-parametric smoothers) are included.

Parameters

Parameters estimated independently

Natural Mortality

For two base models (Model 1 and Model 2A) a natural mortality value of 0.3 was used for comparison with last year's assessment. We started with a value of M based on the studies of Wespestad and Terry (1984) for the Bering Sea. Wespestad and Terry (1984) provide estimates of $M = 0.3$ for ages 3+ (Table 1A.14). Currently, the assessment model does not allow for age-specific natural mortality rates. It should be noted that in general, a higher natural mortality rate for age 2 pollock may be more appropriate (e.g., Ianelli et al. 2003) and that this model differs from the Eastern Bering Sea model in this manner. In the future, we will be investigating methods to improve AMAK to include age varying natural mortality.

Length and Weight at Age

We estimated length and weight-at-age separately for the survey and for the fishery. We obtained survey estimates from AIBT surveys and computed fishery estimates from observer data and the 2006 AICASS. For the time period between 1978 and 1990 the von Bertalanffy growth curve parameters and length weight regression parameters for length and weight at age estimates for surveys were estimated for the 1980, 1983, and 1986 AIBT surveys (Table 1A.15). For the time period between 1990 and 2006 we calculated the average length at age by weighted averages by age and calculated the length-weight relationships using linear regression analysis. Data for these analyses were retrieved from the Resource Assessment and Conservation Engineering Division's (RACE) survey database. Length and weight-at-age data were available for the 1991, 1994, 1997, 2000, 2002, and 2004 AIBT surveys. For years without survey length and weight-at-age data we used the mean values at age for the two nearest surveys (Table 1A.16). Fishery data east of 174°W longitude were excluded from the data set for calculating length and weight-at-age. For the fishery, we used year (when available) and age-specific estimates of average weights-at-age as computed from the fishery age and length sampling programs from data collected west of 174°W. These values (Table 1A.17) are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight).

Maturity at Age

The maturity at age schedule is based on the studies of Wespestad and Terry (1984; Table 1A.18). An updated analysis on maturity-at-age using more recent data was presented in the 2005 Bering Sea pollock stock assessment. However, the EBS data collected in 2002 and 2003 are in agreement with that observed by Westpestad and Terry (1984), and a change in model configuration is not warranted at this time.

Parameters estimated conditionally

Deviations between the observations and the expected values are quantified with a specified error structure. Lognormal error is assumed for estimates of survey and fishery catch, and a multinomial error structure is assumed for analysis of the survey and fishery age compositions. These error structures are used to estimate the following parameters conditionally within the model.

Fishing Mortality

Fishing mortality in all models was parameterized to be separable with both an age component (selectivity) and a year component. In all models selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a penalty was imposed on sharp shifts in selectivity between ages using the sum of squared second differences. In addition, the age component parameters are assumed constant for the last 4 age groups (ages 12-15). Finally, selectivity was allowed to vary over time. The model was set with controls selecting the degree to which selectivity is allowed to change between ages and over time.

Survey Catchability

For the bottom trawl survey, survey catchability-at-age follows the parameterization similar to the fishery selectivity-at-age presented above. The catchability-at-age relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change and curvature specified by the user). To provide regularity in the age component, a penalty was imposed on sharp shifts in catchability-at-age between ages using the sum of squared second differences. In addition, the age component parameters are assumed constant for the last 4 age groups (ages 12-15). As noted above, the model allows specification of the age-range over which the catchability parameter is applied. For Aleutian Islands pollock, ages 6-10 were selected to have the average catchability (factoring selectivity components) equal to the catchability parameter value.

In the 2004 Aleutian Islands pollock stock assessment, the focus of our analysis was to evaluate a key model assumption: the extent to which the NMFS summer bottom trawl survey catchability should be estimated by the available data (resulting in very high stock sizes) or constrained to be close to a value of 1.0 (implying that the area-swept survey method during the summer months reasonably applies to a fishery that will likely occur during the winter). We provided evidence that suggests that fixing the value of survey catchability to 1.0 is unreasonable. However, recognizing that no other information is available to “anchor” the assessment model to an absolute biomass level, the authors were reluctant to proceed with specifying influential prior distributions on catchability values. The effects of the fishery on the pollock population dynamics appear to be poorly determined given the available data. This could be due to a number of factors including: characteristics of Aleutian Islands pollock relative to adjacent regions, poor quality data, and the possibility that the fishing effects are minor relative to other factors. The latter point is likely to be true at least for the recent period where the fishery removals have been minor since 1999. We have therefore selected a fixed catchability value of 1.00 for our 2006 preferred alternative models.

Recruitment

A reparameterized form of the Beverton-Holt stock recruitment relationship based on Francis (1992) was used. Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the “steepness” (h) of the stock-recruit relationship. The “steepness” parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). As an example, a value of $h = 0.8$ implies that at 20% of the unfished spawning stock size will result in an expected value of 80% of the unfished recruitment level. The steepness parameter (h) was estimated with a prior of 0.7 and CV of 0.2, and sigma r was set at 0.6 for all model runs.

Natural Mortality

For Model 2B natural mortality (M) was estimated within the model using an uninformative prior starting with a value of 0.3 with a CV of 0.2. The addition of the 2006 catch-at-age data from the 2006 AICASS allowed for improved model stability while estimating natural mortality.

Model evaluation

Three models were evaluated for this year’s stock assessment (Model 1, Model 2A, and Model 2B). All three models are configured with a survey catchability of 1.0, a stock recruitment steepness parameter centered on 0.7 with a CV of 0.2 as a (normal) prior distribution and sigma r of 0.6. The data configuration for the three models differ in that Model 1 contains only survey data from the NRA area west of 174º W longitude and Model 2A and Model 2B contain survey data from the entire NRA region. Model 2A and Model 2B differ in that natural mortality is set at 3.0 in Model 2A, but is estimated within Model 2B with a prior of 0.3 and CV of 0.2. Models 1 and 2A have the same parameterization as Models 1 and 2 in the 2005 Aleutian Islands pollock stock assessment with the addition of the 2006 survey biomass estimate and the 2006 AICASS catch-at-age estimates.

Relative differences in model fits are shown in Table 1A.19 and key results are presented in Table 1A.20. By including the survey biomass from the area east of 174°W Model 2A and 2B show a marked improvement in fit from Model 1 based on lowest quasi-likelihood. This is primarily due to a better fit to the survey index, but Models 2A and 2B provide a better fit to all of the data components. A better fit to the survey index by Models 2A and 2B can be attributed to the lower intra-annual variability in the NRA-wide biomass estimate with a much smoother trend which allows for a better fit to the model. The results from the 2004 and 2006 summer bottom trawl surveys are not consistent with the assumed stock delineation proposed in Model 1, and more analyses need to be conducted to determine a tenable stock delineation. Including an internal estimate of natural mortality in Model 2B improves the model fit over Model 2A. In particular Model 2B provides an improved fit to the age composition data for both the survey and fishery.

For all three models the fit to the survey data is relatively poor, but not surprisingly so, given the estimates of variance for the individual survey point estimates and the high intra-annual variability of the estimates. For all models the fit to the survey age composition data was excellent, except for the 1991 data which, for sampling reasons, was given less weight than for the other years. Results of fits to the fishery age-composition data were much poorer, the high variability in the age data probably reflects the diversity in sampling locations for the fishery in different years. The time-varying selectivity patterns estimated by the models show only slight changes for the survey, but a relatively large shift (to older fish) after 1990 for the fishery data coinciding with the change from a foreign fishery to a domestic fishery targeting spawning aggregations. The estimated total biomass trends for the three models diverge considerably (Fig. 1A.18). Differences between Model 1 and Model 2A are due to differences in the survey estimates for the two areas, differences between Model 2A and Model 2B are due to the lower estimated natural mortality in Model 2B. Model 2B MCMC results show that the natural mortality (M) estimate is stable with a mean of 0.235 and CV = 0.10 (Table 1A.21, Fig. 1A.19, and Fig. 1A.20). A lower estimate for natural mortality than that estimated for the Bering Sea pollock is supported by estimates M for Bogoslof area pollock conducted by Ianelli et al. (2005) resulting in an estimate of M of 0.26 and by Westpestad and Terry (1984) estimate of M = 0.2 for Aleutian Basin pollock.

Because of the improved fit (lowest negative quasi-likelihood) to the available data and stable estimate for M, Model 2B was chosen as the reference model. Fits to the survey index, survey age composition, fishery age composition, and selectivity trend are show in Fig. 1A.21, Fig. 1A.22, Fig. 1A.23, and Fig. 1A.24 respectively. As stated above the Model 2B fit to the bottom trawl survey index is better than Model 1, but remains relatively poor, the model has difficulty fitting the low 1994 survey index in light of the high level of catch observed in 1995 and the increase in the survey index in 1996. The model predicts a decline in abundance that corresponds with the high fishing mortality observed in the mid- to late-1990s. Model 2B fits to the survey and fishery age composition data are for the most part very good.

Results

Abundance and exploitation trends

As indicated in the 2004 stock assessment analysis (Barbeaux et al, 2004), the abundance trend is highly conditioned on the assumptions made about the area-swept survey trawl assumptions on catchability. Even with catchability fixed at 1.0, the uncertainty in the trend and level is very high. Bearing in mind the high degree of uncertainty, the total biomass trend (Table 1A.22 and Fig. 1A.25) appears to have increased from 1999 to 2003 after cessation of directed fishing in the area, but from 2003 to 2006 was stable to decreasing. In this assessment total biomass is pollock at age 2 and above.

Spawning biomass appears to have been greatly influence by the high exploitation in the late 1990s (Fig. 1A.26). The highest fishing mortality occurred in 1995 (F = 0.71 and Catch/biomass = 0.20) when the fishery harvested more than 75% of the 1994 survey biomass estimate (Table 1A.23). The reference model shows continued higher than average exploitation in 1997 and 1998 with F = 0.67 for both years. The spawning biomass has been increasing since 2000.

Recruitment

Estimates of recruitment (at age 2) are estimated with high variance (Table 1A.24 and Table 1A.25 , Fig. 1A.27). The 1978 year-class is the largest (308 million age 2 recruits). The 1989 year class is the second largest (137 million age 2 recruits), and the 2000 the third (107 million age 2 recruits). Whether AI pollock recruitment is synchronous with other areas is an open question (e.g., the 1978, 1989, and 2000 year classes are also strong in the EBS region, Ianelli et al. 2005). An alternative explanation is that movement between other areas may affect year-class abundance. The extent to which adjacent stocks interact is an active area of research.

Projections and harvest alternatives

For projection purposes we use the yield projections estimated for reference Model 2B. Because a directed fishery on pollock was banned between 1999 and 2004, and because the 2005 and 2006 fisheries were greatly limited, we do not believe the 2006 AI pollock selectivity-at-age assumed in these models would be relevant to a fully utilized directed fishery. For projections we used the selectivity-at-age derived from the 2005 EBS pollock assessment (Ianelli, et al 2005), because a current estimate for selectivity-at-age for a directed pollock fishery in the Aleutians is not available (Table 1A.26). The selectivity-at-age for the EBS pollock would be applicable if an Aleutian Islands Pollock fishery was prosecuted by EBS pollock fishing vessels. Catchability within the reference model (Model 2B) is fixed at 1.0. The reference model excludes fishery data from east of 174°W longitude, but includes all AIBTS data from west of 170°W longitude.

Reference fishing mortality rates and yields

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than or equal to this maximum permissible level. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawner biomasses that would be expected under average estimated recruitment from 1983-2006 for Model 2B would be 67.49 million age 2 fish and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. We chose to exclude the 1978 extreme recruitment event, treating it as an anomalous event therefore allowing a more conservative estimate of future recruitment. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for NRA pollock for Tier 3 of Amendment 56. For our analyses, we estimated the following values from Model 2B:

Female spawning biomass	Model 2B
$B_{100\%}$	100,945 t
$B_{40\%}$	40,378 t
$B_{35\%}$	35,331 t
B_{07}	82,210 t

Specification of OFL and Maximum Permissible ABC

For Model 2B, the projected year 2007 female spawning biomass (SB_{07}) is estimated to be 82,210 t, above the $B_{40\%}$ value of 40,378 t placing NRA pollock in Tier 3a. The maximum permissible ABC and OFL values under Tier 3a are:

Model 2B Tier 3a:

Harvest Strategy	FSPR%	Fishing Mortality Rate	2007 Projected yield (t)
max F_{ABC}	$F_{40\%}$	0.29	44,470 t
F_{OFL}	$F_{35\%}$	0.38	54,540 t

Under Tier 5 with new model estimated natural mortality of 0.235 the 2007 ABC would be 16,800 t (94,992 t x 0.75 x 0.235 = 2 t) and under Tier 5 with an assumed natural mortality of 0.3 the 2007 ABC would be 21,370 t.

ABC Considerations and Recommendation

ABC Considerations

There remains considerable uncertainty in the Aleutian Islands pollock assessment. We've noted some concerns below:

1) The amount of interaction between the Aleutian stock and the Eastern Bering Sea stock is unknown. It is evident that some interaction does occur and that the abundance and composition of the eastern portion of the Aleutian Islands stock is highly confounded with that of the Eastern Bering Sea stock. Overestimation of the Aleutian Islands pollock stock productivity due to an influx of Eastern Bering Sea stock is a significant risk.

2) As assessed in the 2004 AI pollock stock assessment (Barbeaux et al. 2004), AIBT survey catchability is probably less than 1.0, but we have no data to concretely anchor the value at anywhere less than 1.0. We therefore employed a default value for catchability of 1.00 (a conservative estimate). This provides a conservative total biomass estimate.

3) AIBT survey estimates of biomass are uncertain with an average CV of 0.36. The 2002, 2004, and 2006 estimates are especially uncertain with CVs of 0.38, 0.78, and 0.48 respectively. This results in considerable uncertainty in the projections.

ABC Recommendations

The pollock spawning stock biomass in the NRA appears to be increasing, even in light of the latest low values for the AIBT survey and the total biomass appears to be stable. The estimated female spawning biomass projected for 2007 is expected to be 82,210 t. The total age 3+ biomass for 2007 is expected to be 167,581 t. The year 2007 maximum permissible ABC based on $F_{40\%}$, is 44,470 t (F=0.29).

Standard Harvest Scenarios and Projection Methodology

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

For each scenario, the projections begin with the vector of 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2006. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2007, are as follows (a "*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 2007 recommended in the assessment to the *max* F_{ABC} for 2007. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

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

Scenario 4: In all future years, *F* is set equal to the 2002-2006 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 FOFL. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2007 or 2) above ½ of its MSY level in 2008 and above its MSY level in 2007 under this scenario, then the stock is not overfished.)

Scenario 7: In 2007 and 2008, *F* is set equal to *max* F_{ABC}, and in all subsequent years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2019 under this scenario, then the stock is not approaching an overfished condition.)

The author included one more scenario in order to take into consideration of the Exempted fishing permit studies currently being carried out.

Scenario 8: In 2007 the TAC is set at 4,000 t, increased to 7,600 t for 2008 and 2009 then increased to 19,000 t from 2010 through 2019. (Rationale: This scenario seems like a plausible outcome given the current proposal for conducting the Aleutian Islands Cooperative Acoustic Survey Study under an exempted fishing permit, 7,600 t is 40% of the 19,000 cap which is the A-season allocation, and 19,000 is the AI pollock cap by law).

Projections and status determination

The projected yields, female spawning biomass, and the associated fishing mortality rates for the seven harvest strategies for the reference model are shown in Table 1A.27. Under a harvest strategy of $F_{40\%}$ (Scenario 1), female spawning biomass is projected to be above $B_{40\%}$ for all 13 years of the projection Fig. 1A.28 and Fig. 1A.29. Female spawning biomass is projected to fall below $B_{40\%}$ when fishing at F_{OFL} (Scenarios 6 & 7, Table 1A.27) in 2009 and remain below for the remainder of the projection. Please note again that the fishing mortality rates are prescribed on the basis of the harvest scenario and the spawning biomass in each year. Thus, fishing mortality rates may not be constant within the projection if spawning biomass drops below $B_{40\%}$ in any run.

The associated long-term average female spawner biomass that would be expected under average estimated recruitment from 1978-2003 (67.49 million age 2 fish) and $F = F_{35\%}$, denoted $B_{35\%}$ is estimated to be 35,331 t. This value ($B_{35\%}$), is used in the status determination criteria. Female spawning biomass for 2007 (82,210 t) is projected to be above $B_{35\%}$ thus, the NRA pollock stock would be determined to be *above* its minimum stock size threshold (MSST) and is *not overfished*. Female spawning biomass for 2009 is projected to be above $B_{35\%}$ in scenario 7, thus the NRA pollock stock is *not* expected to fall below its MSST in two years and is *not approaching an overfished condition*.

Scenario 8 (Fig. 1A.28, Fig. 1A.29, and Table 1A.27) shows that a harvest of 4,000 t for 2007 an increase to 7,600t for 2008 and 2009, and an increase to 19,000 t through 2019 would be a conservative harvest strategy under Model 2B, resulting in $F_{07} = 0.002$ and a slowly declining female spawning stock biomass trajectory approaching B_{40} by 2019.

Ecosystem Considerations

Pollock is a commercially important species which is also important as prey to other fish, birds, and marine mammals, and has been the focus of substantial research in Alaskan ecosystems, especially in the Gulf of Alaska (GOA; e.g. Hollowed et al 2000). To determine the ecosystem relationships of juvenile and adult pollock in the Aleutian Islands (AI), we first examine the diet data collected for pollock. Diet data are collected aboard NMFS bottom trawl surveys in the AI ecosytem during the summer (May – August). In the AI, a total of 1458 pollock stomachs were collected between the 1991 and 1994 bottom trawl surveys (n=688 and 770, respectively) and used in this analysis. The diet compositions reported here reflect the size and spatial distribution of pollock in each survey (see Appendix A, “Diet calculations” for detailed methods). Juvenile pollock were defined as fish less than 20 cm in length, which roughly corresponds to 0 and 1 year old fish in the stock assessment, and adult pollock were defined as fish 20 cm in length or greater, roughly corresponding to age 2+ fish.

In the AI, pollock diet data reflects a closer connection with open oceanic environments than in either the Eastern Bering Sea (EBS) or the GOA. Similar to the other ecosystems, euphausiids and copepods together make up the largest proportion of AI adult pollock diet (29% and 19%, respectively); however, it is only in the AI that adult pollock rely on mesopelagic forage fish in the family Myctophidae for 24% of their diet, and AI juvenile pollock have a lower proportion of euphausiids and a higher proportion of gelatinous filter feeders than in the GOA or EBS (Fig. 1A.30, left panels). We can take this diet composition information and convert it to broad ranges of tons consumed annually by pollock in the AI using the Sense routine (Aydin et al. in review), which incorporates information on pollock consumption derived from the stock assessment (see Appendix A, “ration calculations” for detailed methods), as well as uncertainty in all other food web model parameters. As estimated by the Sense routine, AI adult pollock consumed between 100 and 900 thousand metric tons of euphausiids annually during the early 1990s, with similar ranges of myctophid and copepod consumption. Juvenile AI pollock consumed an additional estimated 100 to 900 thousand tons of copepods per year (Fig. 1A.30, right panels).

Using diet data for all predators of pollock and consumption estimates for those predators, as well as fishery catch data, we next estimate the sources of pollock mortality in the AI (see detailed methods in Appendix A). Sources of mortality are compared against the total production of pollock as estimated in the AI pollock stock assessment model. In the AI, integration of this single species information with predation within the food web model suggests that most adult pollock mortality was caused by the pollock trawl fishery during the early 1990s (48%; Fig. 1A.31, left panels). (Fishery catch of pollock in the AI has subsequently declined to less than half the early 1990s catch by the late 1990s, and the directed fishery was closed in 1999 (Ianelli et al 2005). Therefore, AI pollock likely now experience predation mortality exceeding fishing mortality as in the EBS and GOA ecosystems.) The major predators of AI adult pollock are Pacific cod, Steller sea lions, pollock themselves, halibut, and skates. In the AI, juvenile pollock have a very different set of predators from adult pollock; Atka mackerel cause most juvenile pollock mortality (71%). Estimates of the tonnage of adult pollock consumed by predators from the Sense routines (Aydin et al in review) ranged from 8 to 27 thousand tons consumed by cod annually during the early 1990s, while Atka mackerel were estimated to consume between 75 and 410 thousand tons of juvenile pollock annually in the AI ecosystem (Fig. 1A.31, right panels).

After reviewing the diet compositions and mortality sources of pollock in the AI, we shift focus slightly to view pollock and the pollock fishery within the context of the larger AI food web. When viewed within the AI food web, the pollock trawl fishery (in red; Fig. 1A.32) is a relatively high trophic level (TL) predator which interacts mostly with adult pollock, but also with many other species (in green; Fig. 1A.32). The diverse pollock fishery bycatch ranges from high TL predators such as salmon sharks, sleeper sharks, and arrowtooth flounder, to mid TL pelagic forage fish and squid, to low TL benthic invertebrates such as crabs and shrimp, but all of these catches represent extremely small flows. Because the pollock trawl fishery contributes significant fishery offal and discards back into each ecosystem, these flows to fishery detritus groups are represented as the only "predator consumption" flows from the fishery; the biomass of retained catch represents a permanent removal from the system.

In the AI food web model, we included detailed information on bycatch for each fishery. This data was collected in the early 1990s when the AI pollock fishery was much larger than it is at present. During the early 1990's, the pollock trawl fishery was extremely species-specific in the AI ecosystem, with pollock representing over 90% of its total catch by weight (Fig. 1A.33). No single bycatch species accounted for more than 1% of the catch. Although these catches are small in terms of percentage, the high volume pollock fisheries still account for the majority of bycatch of pelagic species in the BSAI management areas, including smelts, salmon sharks, and squids (Gaichas et al 2004).

The intended target of the pollock trawl fishery is also a very important prey species in the wider AI food web. When both adult and juvenile pollock food web relationships are included, over two thirds of all species groups turn out to be directly linked to pollock either as predators or prey in the food web model (Fig. 1A.34). In the AI, the significant predators of pollock (blue boxes joined by blue lines) include halibut, cod, Alaska skates, Steller sea lions, and the pollock trawl fishery. Significant prey of pollock (green boxes joined by green lines) are myctophids, euphausiids, copepods, benthic shrimps, and amphipods, with juveniles preying on the euphausiids and copepods.

We can investigate whether these differences in pollock diet, mortality, and relationships between the EBS and AI might suggest different ecosystem roles for pollock in these areas. We use the diet and mortality results integrated with information on uncertainty in the food web using the Sense routines (Aydin et al in review) and a perturbation analysis with each model food web to explore the ecosystem relationships of pollock further. Two questions are important in determining the ecosystem role of pollock: which species groups are pollock important to, and which species groups are important to pollock?

First, the importance of pollock to other groups within the AI ecosystem was assessed using a model simulation analysis where pollock survival was decreased (mortality was increased) by a small amount, 10%, over 30 years to determine the potential effects on other living groups. This analysis also incorporated the uncertainty in model parameters using the Sense routines, resulting in ranges of possible outcomes which are portrayed as 50% confidence intervals (boxes in Fig. 1A.35) and 95% confidence intervals (error bars in Figure 1A. 6). Species showing the largest median changes from baseline conditions are presented in descending order from left to right. Therefore, the largest change resulting from a 10% decrease in pollock survival in both ecosystems is a decrease in adult pollock biomass, as might have been expected from such a perturbation. However, the decrease in pollock biomass resulting from the 10% survival reduction is uncertain in AI: the 50% intervals range from a 5-37% decrease in the AI (Fig. 1A.35, upper panel). Along with the decrease in pollock biomass predicted in this simulation is a decrease in pollock fishery catch. The next largest median effect is on juvenile pollock, which are predicted to decrease in 50% of feasible ecosystems, but he 95% interval includes zero, suggesting that the decrease is uncertain. The simulation further suggests the possibility that herring, Atka mackerel, and other miscellaneous deepwater fish might increase slightly as a result of a decrease in pollock survival; however, for all of these species groups the 95% intervals cross zero, so the direction of change is uncertain. Therefore, this analysis suggests that in the AI ecosystem during the early 1990's, pollock were most important to themselves, and to the pollock fishery.

To determine which groups were most important to pollock in each ecosystem, we conducted the inverse of the analysis presented above. In this simulation, each species group in the ecosystem had survival reduced by 10% and the system was allowed to adjust over 30 years. The strongest median effects on AI adult pollock are presented in Fig. 1A.35 (lower panel). The largest effect on adult pollock was the reduction in biomass resulting from the reduced survival of juvenile pollock, although the 95% intervals include zero change, indicating considerable uncertainty in this result. (The same caution applies to the interpretation of all of the results of this simulation as all of the 95% intervals contain zero). It is interesting, however, that reduced survival of juvenile Atka mackerel had a larger median effect on adult pollock biomass than the direct effect of reduced adult pollock survival itself (Fig. 1A.35, lower panel), and that the effect is positive. Adult Atka mackerel show the same pattern, which is likely explained by the amount of mortality caused by Atka mackerel on juvenile pollock in the AI food web model (see Fig. 1A.31, lower panels). Reduced survival of Atka mackerel adults or juveniles apparently relieves considerable mortality on juvenile pollock in this model, accounting for the increases in pollock biomass predicted (which is similar in magnitude to the increase predicted from reducing the pollock fishery catch by 10%). Although this result is uncertain, it does indicate an important interaction between two commercially important species in the AI ecosystem which might be further investigated.

Ecosystem effects on Aleutian Islands Walleye Pollock

The following ecosystem considerations are summarized in Table 1A.28.

Prey availability/abundance trends

Adult walleye pollock in the Aleutian Islands consume a variety of prey, primarily large zooplankton, copepods, and myctophids. Figure 36 highlights the trophic level of pollock in relation to its prey and predators. No time series of information is available on Aleutian Islands for large zooplankton, copepod, or myctophid abundance.

Predator population trends

The abundance trend of Aleutian Islands Pacific cod is decreasing, and the trend for Aleutian Islands arrowtooth flounder is relatively stable. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases. Declining trends in predator abundance could lead to possible decreases in walleye pollock mortality. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could affect young-of-the-year mortality.

Changes in habitat quality

The 2006 Aleutian Islands summer bottom temperatures indicated that water temperatures were slightly cooler at shallower depths than 2004, but was otherwise an average year. Bottom temperatures could possibly affect fish distribution, but there have been no directed studies, and there is no time series of data which demonstrates the effects on Aleutian Islands walleye pollock.

AI pollock fishery effects on the ecosystem

AI pollock fishery contribution to bycatch

The 2006 AI pollock fishery was conducted in conjunction with the 2006 AICASS, Pacific Ocean perch (POP) was the most substantial bycatch species and made up 3% of the catch. The AI pollock fishery opening in 2005 was limited to only four hauls, within these four hauls the bycatch level of POP was very high (~50%). Besides the lack of commercially harvestable levels of pollock, the high levels of POP bycatch convinced fishers to discontinue the fishery in 2005. Prior to 1998, levels of bycatch in the pollock fishery of prohibited species, forage, HAPC biota, marine mammals and birds, and other sensitive non-target species was very low compared to other fisheries in the region.

Concentration of AI pollock catches in time and space

Since the AI pollock fishery is expected to be conducted in conjunction with the 2007 AICASS, catch is expected to be limited to 3,000 t and distributed evenly between 173°W and 179°W longitude. The impacts of this fishery due to temporal and spatial concentration are not expected be substantial due to the relatively low fishing mortality expected.

AI pollock fishery effects on amount of large size walleye pollock

The AI pollock fishery in the Aleutian Islands was closed between 1999 and 2005. There was only a very limited fishery in 2005 (< 200t) and 2006 (932 t). Year to year differences observed in the previous seven years can not be attributed to the fishery and must be attributed to natural fluctuations in recruitment. Fishers have indicated that the larger pollock in the Aleutian Islands will be targeted. But the low level of fishing mortality is not expected to greatly affect the size distribution of pollock in the AI.

AI pollock fishery contribution to discards and offal production

The 2007 Aleutian Islands pollock fishery, if pursued, is expected to be conducted by catcher vessels delivering unsorted catch to the Adak Fisheries LLC. processing plant, and therefore very little discard or offal production is expected from this fishery.

AI Pollock fishery effects on AI pollock age-at-maturity and fecundity

The effects of the fishery on the age-at-maturity and fecundity of AI pollock are unknown. No studies on AI pollock age-at-maturity or fecundity have been conducted. Studies are needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

Data gaps and research priorities

Very little is known about the AI pollock stock structure and their relation to Western Bering Sea, Eastern Bering Sea, Gulf of Alaska, Bogoslof and Central Bering Sea pollock. Genetic work on the relationship of NRA pollock to other stocks in the North Pacific is essential for further assessment work. Tissue samples were collected during the 2006 AICASS for this analysis but genetic analysis of these samples are waiting on funding. In addition, studies on the migration of pollock in the North Pacific should be explored in order to obtain an understanding of how the stocks relate spatially and temporally and how neighboring fisheries affect local abundances. Time series data sets on prey species abundance in the Aleutian Islands would be useful for a more clear understanding of ecosystem affects. Studies to determine the impacts of environmental indicators such as temperature regime on AI Aleutian pollock are needed. Currently, we rely on studies from the eastern Bering Sea for our estimates of life history parameters (e.g. maturity-at-age, fecundity, and natural mortality) for the NRA pollock. Studies specific to the NRA to determine whether there are any differences from the eastern Bering Sea stock and whether there have been any changes in life history parameters over time would be informative.

Summary

Model 2B Parameters

Natural Morality: M = 0.235
Initial Biomass (1978): B_0 = 280,040 t

2007

Maximum permissible ABC:	Tier 3a Model 2B $F_{40\%}$ = 0.29	yield = 44,470 t
	Tier 5 (M=0.235)	yield = 16,800 t
	Tier 5 (M = 0.3)	yield = 21,370 t
Overfishing (OFL):	Tier 3a Model 2B $F_{35\%}$ = 0.38	yield = 54,540 t
	Tier 5(M = 0.235)	yield = 22,350 t
	Tier 5 (M=0.3)	yield = 28,500 t

2008

Maximum permissible ABC:	Tier 3a Model 2B $F_{40\%}$ = 0.29	yield = 33,090 t
	Tier 5 (M=0.235)	yield = 16,800 t
	Tier 5 (M = 0.3)	yield = 21,370 t
Overfishing (OFL):	Tier 3a Model 2B $F_{35\%}$ = 0.38	yield = 29,630 t
	Tier 5(M = 0.235)	yield = 22,350 t
	Tier 5 (M=0.3)	yield = 28,500 t

Model 2B Equilibrium female spawning biomass

$B_{100\%}$ = 100,945 t
$B_{40\%}$ = 40,378 t
$B_{35\%}$ = 35,331 t

Model 2B Projected 2007 biomass

Age 3+ biomass = 167,581 t
Female spawning biomass = 82,210 t

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Tables

Table 1A.1. Time series of ABC, TAC, and total catch for Aleutian Islands Region walleye pollock fisheries 1991-2006. Units are in metric tons. Note: There was no OFL level set in 1991 and the 1993 harvest specifications were not available

YEAR	ABC	TAC	OFL	CATCH	CATCH/TAC
1991	101,460	72,250	NA	98,604	136%
1992	51,600	47,730	62,400	52,352	110%
1993				57,132	
1994	56,600	56,600	60,400	58,659	104%
1995	56,600	56,600	60,400	64,925	115%
1996	35,600	35,600	47,000	29,062	82%
1997	28,000	28,000	38,000	25,940	93%
1998	23,800	23,800	31,700	23,822	100%
1999	23,800	2,000	31,700	1,010	51%
2000	23,800	2,000	31,700	1,244	62%
2001	23,800	2,000	31,700	824	41%
2002	23,800	1,000	31,700	1,156	116%
2003	39,400	1,000	52,600	1,653	165%
2004	39,400	1,000	52,600	1,150	115%
2005	29,400	19,000	39,100	1,556	8%
2006	29,400	19,000	39,100	1,829	10%

Table 1A.2. Estimates of walleye pollock catches from the entire Aleutian Islands Region by source, 1977-2003. Units are in metric tons.

Year	Official Foreign & JV Blend	Domestic Blend	Foreign Reported	NMFS Observer Data	Current estimates
1977	7,367		7,827	5	7,367
1978	6,283		6,283	234	6,283
1979	9,446		9,505	58	9,446
1980	58,157		58,477	883	58,157
1981	55,517		57,056	2,679	55,517
1982	57,753		62,624	11,847	57,753
1983	59,021		44,544	12,429	59,021
1984	77,595		67,103	48,538	77,595
1985	58,147		48,733	43,844	58,147
1986	45,439		14,392	29,464	45,439
1987	28,471			17,944	28,471
1988	41,203			21,987	41,203
1989	10,569			5,316	10,569
1990		79,025		51,137	79,025
1991		98,604		20,493	98,604
1992		52,352		20,853	52,352
1993		57,132		22,804	57,132
1994		58,659		37,707	58,659
1995		64,925		18,023	64,925
1996		29,062		5,982	29,062
1997		25,940		5,580	25,940
1998		23,822		1,882	23,822
1999		1,010		24	1,010
2000		1,244		75	1,244
2001		824		88	824
2002		1,156		144	1,156
2003		1,653			1,653
2004		1,150			1,150
2005		1,610			1,610
2006		1,829			1,829

Table 1A.3. Estimated walleye pollock catch discarded and retained for the Aleutian Islands Region based on NMFS blend data, 1991-2001.

Year	Catch Retained	Discard	Total	Discard Percentage
1990	69,682	9,343	79,025	12%
1991	93,059	5,441	98,500	6%
1992	49,375	2,986	52,361	6%
1993	55,399	1,740	57,138	3%
1994	57,308	1,373	58,681	2%
1995	63,545	1,380	64,925	2%
1996	28,067	994	29,062	3%
1997	25,323	617	25,940	2%
1998	23,657	164	23,822	1%
1999	361	446	807	55%
2000	455	790	1,244	64%
2001	445	380	824	46%
2002	398	758	1,156	66%
2003	1184	468	1,653	28%
2004	871	278	1,150	24%
2005	200	1,410	1,610	88%
2006	1,082	747	1,829	41%

Table 1A.4. Estimates of Aleutian Islands Region walleye pollock catch by the three management sub-areas. Foreign reported data were used from 1977-1984, from 1985-1998 observer data were used to partition catches among the areas. Units are in metric tons.

Year	East (541)	Central (542)	West (543)	Total
1977	4,402	0	2,965	7,367
1978	5,267	712	305	6,283
1979	1,488	1,756	6,203	9,446
1980	28,284	7,097	22,775	58,157
1981	43,461	10,074	1,982	55,517
1982	54,173	1,205	2,376	57,753
1983	56,577	1,250	1,194	59,021
1984	64,172	5,760	7,663	77,595
1985	19,885	38,163	100	58,147
1986	38,361	7,078	0	45,439
1987	28,086	386	0	28,471
1988	40,685	517	0	41,203
1989	10,569	0	0	10,569
1990	69,170	9,425	430	79,025
1991	98,032	561	11	98,604
1992	52,140	206	6	52,352
1993	54,512	2,536	83	57,132
1994	58,091	554	15	58,659
1995	28,109	36,714	102	64,925
1996	9,226	19,574	261	29,062
1997	8,110	16,799	1,031	25,940
1998	1,837	3,858	18,127	23,822

Table 1A.5. Estimates of pollock catch (metric tons) by new area definitions. "NRA" stands for Near, Rat, and Andreanof island groups, "NRA w/o E" signifies the NRA region without the area east of 174°W, "Basin" represents the northern portions of areas 541 and 542. See Fig. 1A.3 for locations on a map. (*Note: 1977-1984 area assignments are based on foreign reported data, 1985- 2006 are based on observer data).*

Year	NRA	NRA w/o E	Basin	Basin + E
1977	7,367	2,965	0	4,402
1978	6,283	1,016	0	5,267
1979	9,446	7,959	0	1,488
1980	58,157	29,873	0	28,284
1981	31,258	14,811	24,259	40,706
1982	50,322	3,149	7,863	54,605
1983	44,442	1,669	15,354	57,352
1984	42,901	9,171	39,140	68,424
1985	47,070	870	48,472	57,278
1986	23,810	704	28,003	44,735
1987	26,257	2,720	2,251	25,752
1988	36,864	574	4,339	40,628
1989	10,569	0	0	10,569
1990	79,025	10,477	0	68,548
1991	98,604	561	230	98,043
1992	52,352	8,519	29,455	43,833
1993	57,132	16,162	22,404	40,970
1994	58,659	5,965	26,288	52,694
1995	64,925	58,203	3,015	6,723
1996	29,062	23,187	899	5,875
1997	25,940	25,774	0	166
1998	23,822	23,335	67	486
1999	1,010	631	0	378
2000	1,244	891	0	354
2001	824	575	0	249
2002	1,156	351	1	805
2003	1,653	1,430	0	222
2004	1,150	962	0	188
2005	1,610	1,330	0	280
2006	1,829	1,657	0	172

Table 1A.6. Sampling levels in Aleutian Islands Region sub-regions based on foreign, J.V., and domestic walleye pollock observer data 1978 – 1998.

	NRA West of 174° Longitude			**NRA East of 174° Longitude**			**Aleutian Islands Area Basin**		
Year	Fish Measured	Hauls Sampled	Vessels Sampled	Fish Measured	Hauls Sampled	Vessels Sampled	Fish Measured	Hauls Sampled	Vessels Sampled
1978	1,503	64	4	4,831	135	11	0	0	0
1979	1,317	16	4	977	33	6	0	0	0
1980	2,154	53	4	4,753	119	10	0	0	0
1981	4,782	37	7	6,617	96	14	1,913	15	3
1982	7,713	102	13	29,549	331	30	11,151	84	7
1983	2,977	35	12	24,793	242	27	20,744	174	21
1984	10,844	111	22	46,037	541	49	157,388	1,223	81
1985	780	9	2	33,471	259	37	68,923	460	58
1986	0	0	0	22,939	195	18	39,875	268	48
1987	4,045	26	5	43,093	352	29	2,665	26	8
1988	378	3	2	28,423	249	24	4,528	37	14
1989	0	0	0	7,424	57	8	0	0	0
1990	12,303	131	14	55,837	587	47	55	1	1
1991	0	1	1	26,035	211	32	24,025	194	26
1992	7,405	59	15	18,771	178	50	20,769	179	27
1993	13,471	130	15	13,264	137	34	22,022	185	30
1994	5,025	47	18	29,805	305	64	5,314	56	16
1995	29,070	324	34	2,963	212	31	1,922	19	7
1996	15,307	160	35	3,462	179	41	0	0	0
1997	17,239	189	33	64	122	26	77	1	1
1998	10,439	122	15	148	107	12	0	0	0
Total	146,752	1,619	255	403,256	4,647	600	381,371	2,922	348

Table 1A.7. NRA pollock fishery average weight-at-age in kilograms. Shaded cells had missing observations and were filled with their mean values

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1978	0.3318	0.3933	0.7603	0.6877	0.8097	0.9151	0.9065	0.9722	0.9281	1.0613	1.1674	1.187	1.6149	1.0729
1979	0.2314	0.3476	0.5293	0.7306	0.6727	0.825	0.9435	0.9532	1.0381	1.1638	1.0598	1.5186	1.5788	1.0206
1980	0.2392	0.5526	0.7651	0.8412	0.8629	0.9129	1.0002	1.089	1.0628	1.0204	1.1568	1.1019	0.8521	1.5242
1981	0.3392	0.4778	0.5521	0.7286	0.7637	0.7817	0.8096	0.8953	0.9021	0.8598	1.0199	1.0259	0.8929	0.9079
1982	0.3392	0.4179	0.5414	0.6436	0.7838	0.822	0.8417	0.8921	0.9842	1.0011	0.9575	0.9546	0.9058	0.966
1983	0.3392	0.4736	0.6609	0.7333	0.7796	0.7954	0.9264	0.9574	1.0146	0.9024	1.1892	1.1496	0.974	1.14
1984	0.426	0.4459	0.6609	0.7419	0.8099	0.8721	0.968	0.9963	1.2704	1.6431	1.1351	1.2212	1.1943	1.14
1985	0.4675	0.5656	0.6705	0.6896	0.8028	0.8536	0.8567	1.0909	1.233	1.5996	1.6644	1.1496	1.6448	1.14
1986	0.3392	0.5114	0.6019	0.7472	0.8266	0.8698	0.9506	0.9266	1.0137	0.9428	1.0702	0.8963	1.1943	1.14
1987	0.3392	0.4736	0.6852	0.7562	0.8335	0.8504	0.8715	0.9809	1.0725	0.9915	1.3379	1.1546	1.0065	1.0935
1988	0.3392	0.4736	0.6609	0.8013	0.7905	0.8208	0.9279	0.8883	0.9839	0.8933	0.7843	0.7223	0.8976	1.0621
1989	0.3392	0.4736	0.6609	0.7536	0.851	0.926	0.9927	1.0611	1.1106	1.1501	1.1892	1.1496	1.1943	1.14
1990	0.3392	0.4778	0.5521	0.7286	0.7637	0.7817	0.8096	0.8953	0.9021	0.8598	1.0199	1.0259	0.8929	0.9079
1991	0.3392	0.4736	0.6668	0.6551	0.7989	0.962	1.0755	1.1731	1.0994	1.2177	1.1573	1.0955	1.2898	1.0856
1992	0.3392	0.4736	0.6401	0.7418	0.7254	0.797	0.9356	1.2457	1.0267	1.0034	1.2501	1.1451	1.0514	1.0976
1993	0.3392	0.4736	0.8862	0.8237	1.0335	1.0315	1.1399	1.0808	1.1638	1.1905	1.2027	1.3256	1.1373	1.1352
1994	0.3392	0.4736	0.6373	0.8437	0.9743	1.1361	1.14	1.1216	1.1907	1.2437	1.2659	1.0591	1.09	1.1517
1995	0.3392	0.5512	0.8471	0.7536	1.1264	1.3303	1.3972	1.3551	1.4333	1.4197	1.501	1.4466	1.6582	1.3206
1996	0.3392	0.5391	0.4753	0.9301	1.0287	1.1796	1.2751	1.3945	1.4682	1.3548	1.3777	1.3619	1.4562	1.3013
1997	0.3392	0.4736	0.6609	0.7536	0.851	0.926	0.9927	1.0611	1.1106	1.1501	1.1892	1.1496	1.1943	1.14
1998	0.3392	0.403	0.7631	0.7398	0.9826	1.0575	1.085	1.2532	1.3137	1.4826	1.2785	1.3012	1.3597	1.4522
1999	0.3392	0.4736	0.6609	0.7536	0.851	0.926	0.9927	1.0611	1.1106	1.1501	1.1892	1.1496	1.1943	1.14
2000	0.3392	0.4736	0.6609	0.7536	0.851	0.926	0.9927	1.0611	1.1106	1.1501	1.1892	1.1496	1.1943	1.14
2001	0.3392	0.4736	0.6609	0.7536	0.851	0.926	0.9927	1.0611	1.1106	1.1501	1.1892	1.1496	1.1943	1.14
2002	0.3392	0.4736	0.6609	0.7536	0.851	0.926	0.9927	1.0611	1.1106	1.1501	1.1892	1.1496	1.1943	1.14
2003	0.3318	0.3933	0.7603	0.6877	0.8097	0.9151	0.9065	0.9722	0.9281	1.0613	1.1674	1.187	1.6149	1.0729
2004	0.3318	0.3933	0.7603	0.6877	0.8097	0.9151	0.9065	0.9722	0.9281	1.0613	1.1674	1.187	1.6149	1.0729
2005	0.3318	0.3933	0.7603	0.6877	0.8097	0.9151	0.9065	0.9722	0.9281	1.0613	1.1674	1.187	1.6149	1.0729
2006	0.3318	0.3933	0.7603	0.6877	0.8097	0.9151	0.9065	0.9722	0.9281	1.0613	1.1674	1.187	1.6149	1.0729

Table 1A.8. Number of aged and measured fish in the NRA pollock fishery used to estimate fishery age composition. Shaded values were not used in assessment. Data for 2006 from 2006 AICASS.

	Number Aged			Number Measured		
Year	Males	Females	Total	Males	Females	Total
1978	209	322	531	490	1,013	1,503
1979	124	178	302	611	706	1,317
1980	93	167	260	971	1,183	2,154
1981	124	152	276	2,226	2,556	4,782
1982	564	640	1,204	3,655	4,058	7,713
1983	132	145	277	1,493	1,484	2,977
1984	294	312	606	5,273	5,571	10,844
1985	210	265	475	349	431	780
1986	77	113	190	0	0	0
1987	131	142	273	1,670	2,375	4,045
1988	34	33	67	188	190	378
1989	0	0	0	0	0	0
1990	46	49	95	5,209	7,094	12,303
1991	36	47	83	0	0	80
1992	110	121	231	3,755	3,650	7,405
1993	81	82	163	7,701	5,770	13,471
1994	157	151	308	2,644	2,381	5,025
1995	74	106	180	16,518	12,552	29,070
1996	95	84	179	8,933	6,374	15,307
1997	15	15	30	9,232	8,007	17,239
1998	144	170	314	5,992	4,447	10,439
1999	0	0	0	75	60	135
2000	0	1	1	70	114	184
2001	0	1	1	52	106	158
2002	0	0	0	46	61	107
2003	0	0	0	0	0	0
2004	0	0	0	153	212	365
2005	0	0	0	309	260	569
2006	74	87	161	1,315	1,630	2,945

Table 1A.9. Number of individual vessels and hauls sampled by observers in the NRA pollock fishery west of 174°W longitude, 1990-1998.

	NRA Area 541 West of 174W				NRA Area 542				NRA Area 543			
	Catcher Processor		Catcher Only		Catcher Processor		Catcher Only		Catcher Processor		Catcher Only	
Year	Vessels	Hauls	Vessels	Hauls	Vessels	Hauls	Vessels	Hauls	Vessels	Hauls	Vessels	Hauls
1990	12	50	0	0	16	132	0	0	2	4	0	0
1991	2	3	0	0	2	2	0	0	0	0	0	0
1992	18	126	0	0	4	5	0	0	0	0	0	0
1993	18	195	0	0	6	25	0	0	3	5	0	0
1994	18	76	0	0	3	6	0	0	0	0	0	0
1995	22	200	8	39	15	272	11	77	0	0	0	0
1996	5	12	7	15	25	198	10	38	0	0	0	0
1997	13	66	11	30	14	93	10	60	1	6	0	0
1998	4	6	5	16	3	24	5	19	2	97	4	24

Table 1A.10. Estimated NRA region pollock catch at age (millions). Highest mode for each year is shaded.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1978	0.01	0.14	0.12	0.07	0.36	0.10	0.14	0.13	0.13	0.06	0.02	0.01		0.00	1.27
1979	0.01	2.18	2.22	2.02	2.43	1.73	0.65	0.63	0.37	0.03	0.22			0.05	12.53
1980	8.20	3.24	2.64	3.71	6.94	4.05	2.47	0.73	1.07	0.53	0.16	0.01	0.14	0.01	33.91
1981		5.72	3.36	2.19	1.65	2.55	2.54	1.93	1.37	0.73	0.20	0.15	0.20	0.04	22.64
1982		0.01	3.00	0.51	0.23	0.31	0.38	0.35	0.15	0.07	0.04	0.03	0.01	0.01	5.10
1983				0.74	0.44	0.17	0.11	0.24	0.23	0.05	0.04	0.01	0.00	0.00	2.04
1984	0.14	3.97		4.12	4.12	1.46	1.10	0.74	0.51	0.34	0.09	0.06	0.03	0.01	16.68
1985	0.01	0.01	0.17	0.06	0.17	0.46	0.20	0.08	0.08	0.04	0.01	0.01	0.00	0.00	1.30
1986															
1987			1.40	0.31	0.23	0.04	0.09	1.01	0.09	0.12	0.00	0.03	0.01	0.04	3.36
1988															
1989															
1990		0.95	0.26	0.96	0.78	0.78	0.93	0.17	1.10	0.34	0.56	0.28	0.13	0.21	7.45
1991															
1992			0.03	0.33	0.60	0.30	0.60	0.12	0.69	0.39	0.52	0.36	1.71	1.91	7.55
1993			0.18	0.47	1.12	1.34	0.54	1.46	0.81	0.88	0.83	0.38	0.70	4.34	13.05
1994			0.07	1.00	0.31	0.42	0.60	0.43	0.33	0.17	0.39	0.10	0.08	1.30	5.20
1995		0.22	0.38	0.00	10.22	1.19	5.10	4.84	1.42	2.36	2.08	3.82	0.77	8.32	40.71
1996		0.17	0.15	0.56	1.42	5.15	1.53	2.09	1.21	0.92	0.64	0.20	0.77	2.00	16.79
1997															
1998		0.05	0.08	5.66	1.65	1.05	0.96	1.71	1.20	1.00	2.40	1.30	1.17	1.49	19.73
2006				0.01	0.33	0.13	0.04	0.02	0.08	0.06	0.06	0.05	0.12	0.12	1.02

Table 1A.11. Pollock biomass estimates from the Aleutian Islands Groundfish Survey, 1980-2002.

	Aleutian Islands Region				
	NRA West (174W-170E)	NRA East (170W-174W)	NRA total	Unalaska-Umnak area (~165W-170W)	Combined
1980			243,695	56,732	300,427
1983			495,775	282,648	778,423
1986			439,461	102,379	541,840
1991	83,337	53,865	137,202	51,644	188,846
1994	47,623	29,879	77,502	39,696	117,199
1997	57,577	39,935	97,512	65,400	158,912
2000	76,613	28,985	105,598	22,462	128,060
2002	121,915	53,368	175,283	181,334	356,617
2004	19,201	111,250	130,451	235,658	366,110
2006	25,471	69,522	94,993	18,006	112,999

Table 1A.12. Results of the 2002 Aleutian Islands echo integration-trawl survey conducted by the R/V Kaiyo Maru.

	Leg 2-1	Leg 2-2	Leg 2-3	Leg 2-4
Area (km^2)	27,902	10,433	4,045	1,413
Density (t/km^2)	2.18	1.82	2.46	1.79
Population (10^6)	37	12	6	2
Biomass (10^3 t)	61	19	10	3
CV	0.31	0.33	0.21	0.76

Table 1A.13. Results from the 2006 Aleutian Islands Cooperative Acoustic Survey.

Survey	Area ($n.mi.^2$)	Deadzone (Y/N)	Biomass (t)	Relative Precision (E_i)	High Biom. (t)	Low Biom. (t)	Density (t / $n.mi.^2$)
2	180	N	8233.8	8.67%	9632.5	6835.1	45.7
2	180	Y	8809.9	8.04%	10198.4	7421.4	48.9
2	72	N	6484.5	12.29%	8046.1	4922.9	90.1
2	72	Y	6706.6	14.32%	8589.2	4824.0	93.1
4	180	N	6600.4	7.96%	7630.1	5570.7	36.7
4	180	Y	7980.2	7.87%	9210.6	6749.8	44.3
4	72	N	5246.4	12.31%	6512.6	3980.2	72.9
4	72	Y	6149.8	11.89%	7582.5	4717.1	85.4
5	9	N	890.8	5.29%	983.2	798.4	99.0
5	9	Y	1036.6	4.75%	1133.1	940.1	115.2
6	72	N	3015.0	6.64%	3407.4	2622.6	41.9
6	72	Y	3458.5	6.44%	3894.9	3022.1	48.0
7	72	N	1159.0	6.83%	1314.2	1003.8	16.1
7	72	Y	2179.7	5.05%	2395.4	1964.0	30.3
8	180	N	2313.6	14.51%	2971.6	1655.6	12.9
8	180	Y	2845.2	14.24%	3639.0	2051.4	15.8
8	72	N	559.2	14.32%	716.1	402.3	7.8
8	72	Y	677.0	12.96%	848.9	505.1	9.4

Table 1A.14. Estimated instantaneous natural mortality rates (M) by age from Wespestad and Terry (1984).

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
M	0.85	0.45	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6

Table 1A.15. Estimated von Bertalanffy growth curve parameters and length-weight regression parameters for walleye pollock sampled during the U.S.-Japan 1980, 1983, and 1986 groundfish surveys and the 1991, 1994, 1997, 2000, 2002, and 2004 RACE groundfish surveys.

	L_{inf}	K	t_0	A	b
1980	51.92	0.414	-0.525	0.0132	2.858
1983	53.26	0.383	0.002	0.0178	2.768
1986	51.02	0.443	-0.084	0.0142	2.831
1991	54.55	0.392	-0.361	0.0104	2.912
1994	61.58	0.330	-0.102	0.0069	3.022
1997	61.41	0.286	-0.397	0.0081	2.983
2000	62.58	0.306	-0.048	0.0064	3.019
2002	64.36	0.289	-0.127	0.0066	3.018
2004	61.76	0.332	-0.189	0.0065	3.022

Table 1A.16. Average weight-at-age for Aleutian Islands pollock as estimated from NMFS summer bottom trawl survey estimates. Values between survey years (shaded) were set to the mean of the nearest two surveys (or single year for 1978-79, 2003-04).

	Age													
Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1978	0.31	0.50	0.65	0.78	0.87	0.93	0.97	1.00	1.02	1.03	1.04	1.04	1.05	1.05
1979	0.31	0.50	0.65	0.78	0.87	0.93	0.97	1.00	1.02	1.03	1.04	1.04	1.05	1.05
1980	0.31	0.50	0.65	0.78	0.87	0.93	0.97	1.00	1.02	1.03	1.04	1.04	1.05	1.05
1981	0.25	0.43	0.60	0.73	0.83	0.90	0.95	0.99	1.01	1.03	1.04	1.05	1.05	1.05
1982	0.25	0.43	0.60	0.73	0.83	0.90	0.95	0.99	1.01	1.03	1.04	1.05	1.05	1.05
1983	0.19	0.37	0.54	0.69	0.80	0.88	0.94	0.98	1.01	1.02	1.04	1.05	1.05	1.06
1984	0.21	0.40	0.56	0.70	0.80	0.87	0.92	0.95	0.97	0.99	1.00	1.01	1.01	1.01
1985	0.21	0.40	0.56	0.70	0.80	0.87	0.92	0.95	0.97	0.99	1.00	1.01	1.01	1.01
1986	0.23	0.42	0.59	0.71	0.80	0.86	0.90	0.92	0.94	0.95	0.96	0.96	0.97	0.97
1987	0.23	0.46	0.64	0.75	0.91	1.01	1.08	1.06	1.10	1.08	1.06	1.04	1.06	1.03
1988	0.23	0.46	0.64	0.75	0.91	1.01	1.08	1.06	1.10	1.08	1.06	1.04	1.06	1.03
1989	0.23	0.46	0.64	0.75	0.91	1.01	1.08	1.06	1.10	1.08	1.06	1.04	1.06	1.03
1990	0.23	0.46	0.64	0.75	0.91	1.01	1.08	1.06	1.10	1.08	1.06	1.04	1.06	1.03
1991	0.22	0.51	0.69	0.79	1.01	1.15	1.26	1.21	1.27	1.21	1.16	1.12	1.16	1.10
1992	0.21	0.51	0.78	0.89	1.08	1.22	1.25	1.33	1.36	1.32	1.35	1.33	1.35	1.22
1993	0.21	0.51	0.78	0.89	1.08	1.22	1.25	1.33	1.36	1.32	1.35	1.33	1.35	1.22
1994	0.20	0.52	0.87	1.00	1.14	1.29	1.24	1.45	1.44	1.43	1.54	1.54	1.54	1.35
1995	0.22	0.48	0.82	0.97	1.07	1.24	1.26	1.38	1.44	1.45	1.53	1.52	1.57	1.47
1996	0.22	0.48	0.82	0.97	1.07	1.24	1.26	1.38	1.44	1.45	1.53	1.52	1.57	1.47
1997	0.25	0.43	0.78	0.95	1.00	1.19	1.29	1.31	1.44	1.47	1.52	1.51	1.60	1.60
1998	0.21	0.47	0.77	0.92	0.95	1.17	1.28	1.31	1.43	1.50	1.62	1.59	1.53	1.65
1999	0.21	0.47	0.77	0.92	0.95	1.17	1.28	1.31	1.43	1.50	1.62	1.59	1.53	1.65
2000	0.17	0.51	0.77	0.89	0.90	1.15	1.26	1.32	1.41	1.52	1.71	1.67	1.47	1.70
2001	0.19	0.49	0.74	1.02	1.03	1.23	1.29	1.43	1.53	1.56	1.74	1.68	1.58	1.67
2002	0.21	0.47	0.70	1.15	1.16	1.32	1.32	1.53	1.65	1.61	1.76	1.69	1.68	1.64
2003	0.21	0.47	0.70	1.15	1.16	1.32	1.32	1.53	1.65	1.61	1.76	1.69	1.68	1.64
2004	0.22	0.46	0.70	0.83	0.96	1.21	1.15	1.38	1.48	1.55	1.63	1.65	1.55	1.68
2005	0.22	0.46	0.70	0.83	0.96	1.21	1.15	1.38	1.48	1.55	1.63	1.65	1.55	1.68
2006	0.22	0.46	0.70	0.83	0.96	1.21	1.15	1.38	1.48	1.55	1.63	1.65	1.55	1.68

Table 1A.17. Average weight-at-age for Aleutian Islands pollock as estimated from fishery data.

	Age													
Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1978	0.33	0.39	0.76	0.69	0.81	0.92	0.91	0.97	0.93	1.06	1.17	1.19	1.61	1.07
1979	0.23	0.35	0.53	0.73	0.67	0.83	0.94	0.95	1.04	1.16	1.06	1.52	1.58	1.02
1980	0.24	0.55	0.77	0.84	0.86	0.91	1.00	1.09	1.06	1.02	1.16	1.10	0.85	1.52
1981	0.34	0.48	0.55	0.73	0.76	0.78	0.81	0.90	0.90	0.86	1.02	1.03	0.89	0.91
1982	0.34	0.42	0.54	0.64	0.78	0.82	0.84	0.89	0.98	1.00	0.96	0.95	0.91	0.97
1983	0.34	0.47	0.66	0.73	0.78	0.80	0.93	0.96	1.01	0.90	1.19	1.15	0.97	1.14
1984	0.43	0.45	0.66	0.74	0.81	0.87	0.97	1.00	1.27	1.64	1.14	1.22	1.19	1.14
1985	0.47	0.57	0.67	0.69	0.80	0.85	0.86	1.09	1.23	1.60	1.66	1.15	1.64	1.14
1986	0.34	0.51	0.60	0.75	0.83	0.87	0.95	0.93	1.01	0.94	1.07	0.90	1.19	1.14
1987	0.34	0.47	0.69	0.76	0.83	0.85	0.87	0.98	1.07	0.99	1.34	1.15	1.01	1.09
1988	0.34	0.47	0.66	0.80	0.79	0.82	0.93	0.89	0.98	0.89	0.78	0.72	0.90	1.06
1989	0.34	0.47	0.66	0.75	0.85	0.93	0.99	1.06	1.11	1.15	1.19	1.15	1.19	1.14
1990	0.34	0.48	0.55	0.73	0.76	0.78	0.81	0.90	0.90	0.86	1.02	1.03	0.89	0.91
1991	0.34	0.47	0.67	0.66	0.80	0.96	1.08	1.17	1.10	1.22	1.16	1.10	1.29	1.09
1992	0.34	0.47	0.64	0.74	0.73	0.80	0.94	1.25	1.03	1.00	1.25	1.15	1.05	1.10
1993	0.34	0.47	0.89	0.82	1.03	1.03	1.14	1.08	1.16	1.19	1.20	1.33	1.14	1.14
1994	0.34	0.47	0.64	0.84	0.97	1.14	1.14	1.12	1.19	1.24	1.27	1.06	1.09	1.15
1995	0.34	0.55	0.85	0.75	1.13	1.33	1.40	1.36	1.43	1.42	1.50	1.45	1.66	1.32
1996	0.34	0.54	0.48	0.93	1.03	1.18	1.28	1.39	1.47	1.35	1.38	1.36	1.46	1.30
1997	0.34	0.47	0.66	0.75	0.85	0.93	0.99	1.06	1.11	1.15	1.19	1.15	1.19	1.14
1998	0.34	0.40	0.76	0.74	0.98	1.06	1.09	1.25	1.31	1.48	1.28	1.30	1.36	1.45
1999	0.34	0.47	0.66	0.75	0.85	0.93	0.99	1.06	1.11	1.15	1.19	1.15	1.19	1.14
2000	0.34	0.47	0.66	0.75	0.85	0.93	0.99	1.06	1.11	1.15	1.19	1.15	1.19	1.14
2001	0.34	0.47	0.66	0.75	0.85	0.93	0.99	1.06	1.11	1.15	1.19	1.15	1.19	1.14
2002	0.34	0.47	0.66	0.75	0.85	0.93	0.99	1.06	1.11	1.15	1.19	1.15	1.19	1.14
2003	0.33	0.39	0.76	0.69	0.81	0.92	0.91	0.97	0.93	1.06	1.17	1.19	1.61	1.07
2004	0.33	0.39	0.76	0.69	0.81	0.92	0.91	0.97	0.93	1.06	1.17	1.19	1.61	1.07
2005	0.33	0.39	0.76	0.69	0.81	0.92	0.91	0.97	0.93	1.06	1.17	1.19	1.61	1.07
2006	0.33	0.39	0.76	0.69	0.81	0.92	0.91	0.97	0.93	1.06	1.17	1.19	1.61	1.07

Table 1A.18. Percentage mature females at age from Wespestad and Terry (1984).

Age	1	2	3	4	5	6	7	8	9	10	11	12	13-16
Percent	0.0	0.8	28.9	64.1	84.2	90.1	94.7	96.3	97.0	97.8	98.4	99.0	100.0

Table 1A.19. Comparisons of fits for the evaluations of Aleutian Islands pollock Model 1 and Model 2.

	Model 1	**Model 2A**	**Model 2B**
Number of Parameters	194	278	279
Survey catchability	1.00	1.00	1.00
Fishery Average Effective N	37	43	44
Survey Average Effective N	115	190	205
RMSE Survey	0.667	0.363	0.356
-log Likelihoods			
Survey index	28.17	8.97	8.20
Fishery age comp	89.26	76.59	72.83
Survey age comp	27.91	20.34	19.42
Sub total	145.34	105.91	100.45
-log Penalties			
Recruitment	-4.86	-14.41	-14.85
Selectivity constraint	15.53	15.42	17.08
Prior	1.20	0.00	0.08
Total	162.27	115.89	111.02

Table 1A.20. Key results for the evaluations of Aleutian Islands pollock Model 1 and Model 2.

	Model 1	**Model 2A**	**Model 2B**
Model conditions			
Survey catchability	1.00	1.00	1.00
Natural mortality	0.30	0.30	0.22
Fishing mortalities			
Max F 1978-2006	0.909	0.742	0.699
F 2006	0.030	0.013	0.029
Stock abundance			
Initial Biomass (1978; thousands of tons)	327	467	280
CV	16%	17%	19%
2006 total biomass (thousands of tons)	140	354	225
CV	22%	18%	20%
2007 Age 3+ biomass (thousands of tons)	141	363	229
1978 year class (at age 2)	140	354	225
CV	22%	18%	20%
Recruitment Variability	0.64	0.44	0.42
Specified Sigma R	0.60	0.60	0.60
Steepness (h)	0.7	0.7	0.7
Projected catch (unadjusted)			
F50% 2006 catch	21.2	66.4	34.5
CV	21%	20%	27%
F40% 2006 catch	31.6	96.7	50.9
CV	21%	20%	27%
F35% 2006 catch	38.3	114.9	61.8
CV	21%	20%	27%

Table 1A.21. Model 2B estimates of pollock biomass with approximate lower (LCI) and upper (UCI) 95% confidence bounds for age 2+ biomass. Also included are the age 3+ biomass and female spawning stock biomass (SSB) estimates.

M 2B Year	Total Biomass (age 2+)	LCI	UCI	Biomass Age 3+	Female SSB
1978	280,040	173,988	386,092	229,574	98,023
1979	286,860	180,416	393,304	212,469	102,161
1980	330,910	200,418	461,402	257,290	105,797
1981	343,790	192,886	494,694	279,021	107,579
1982	346,550	190,000	503,100	257,546	103,767
1983	342,060	193,970	490,150	274,820	106,445
1984	335,280	198,728	471,832	279,987	124,051
1985	329,870	200,668	459,072	275,938	133,284
1986	325,790	208,136	443,444	259,501	130,771
1987	321,530	214,894	428,166	258,733	129,452
1988	314,320	218,188	410,452	234,958	127,921
1989	309,980	223,008	396,952	256,822	127,718
1990	308,690	229,096	388,284	224,199	124,334
1991	310,680	232,162	389,198	241,176	120,865
1992	316,670	241,098	392,242	257,961	118,736
1993	302,600	231,996	373,204	297,755	115,371
1994	282,190	217,486	346,894	259,711	115,861
1995	272,210	211,834	332,586	289,642	113,767
1996	218,720	160,800	276,640	214,014	110,218
1997	198,570	140,972	256,168	163,659	102,222
1998	175,220	115,374	235,066	154,908	82,340
1999	158,800	96,656	220,944	132,515	72,929
2000	167,890	102,650	233,130	136,434	62,024
2001	178,240	108,294	248,186	143,819	57,292
2002	201,260	119,648	282,872	156,677	61,644
2003	217,390	127,544	307,236	185,704	64,425
2004	221,000	129,030	312,970	185,179	68,821
2005	220,130	129,564	310,696	173,778	76,233
2006	219,820	130,172	309,468	173,463	83,038

Table 1A.22. Results from MCMC simulations with 1 million iterations sampled every 200th iteration for reference Model 2B.

Parameter	Mean	CV
Natural Mortality	0.235	10%
Steepness	0.65	27%
Depletion	0.78	20%
2006 Total Biomass	248.45	22%
$F_{35\%}$	0.90	32%
$F_{40\%}$	0.68	30%
$F_{50\%}$	0.40	27%

Table 1A.23. Estimates of full-selection fishing mortality and exploitation rates for pollock based on the reference model (Model 2B).

Year	*F*[a]	Catch/Biomass Rate[b]
1978	0.008	0.004
1979	0.063	0.037
1980	0.211	0.116
1981	0.125	0.053
1982	0.022	0.012
1983	0.010	0.006
1984	0.055	0.033
1985	0.005	0.003
1986	0.004	0.003
1987	0.017	0.011
1988	0.004	0.002
1989	0.000	0.000
1990	0.085	0.047
1991	0.006	0.002
1992	0.093	0.033
1993	0.177	0.054
1994	0.067	0.023
1995	0.699	0.201
1996	0.359	0.108
1997	0.653	0.157
1998	0.642	0.151
1999	0.018	0.005
2000	0.024	0.007
2001	0.014	0.004
2002	0.008	0.002
2003	0.030	0.008
2004	0.032	0.009
2005	0.029	0.009
2006	0.034	0.009

[a] Full selection fishing mortality rates.
[b] Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.

Table 1A.24. Estimated pollock numbers at age in millions, 1978-2006 for reference Model 2B.

Model 2B	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total	% of 15+
1978	70	62	55	42	39	18	16	13	11	8	6	5	4	21	368	5.66%
1979	92	56	49	44	33	31	14	13	10	9	7	5	4	20	387	5.10%
1980	315	73	44	39	34	25	23	11	10	8	7	5	4	18	616	2.97%
1981	71	249	56	32	27	23	17	15	7	7	5	5	4	16	533	2.99%
1982	46	57	195	42	24	20	16	12	11	5	5	4	4	15	455	3.28%
1983	75	37	45	154	33	19	16	13	9	8	4	4	3	15	436	3.38%
1984	77	60	30	36	123	27	15	12	10	7	7	3	3	14	425	3.38%
1985	78	62	48	23	28	95	20	11	9	8	6	5	2	14	410	3.32%
1986	71	62	50	38	19	22	76	16	9	8	6	5	4	13	399	3.22%
1987	57	57	50	40	31	15	18	61	13	7	6	5	4	14	377	3.63%
1988	85	45	46	40	32	24	12	14	48	10	6	5	4	14	385	3.58%
1989	78	68	36	37	32	25	19	9	11	38	8	5	4	14	387	3.67%
1990	73	63	55	29	30	26	20	16	8	9	31	7	4	14	384	3.78%
1991	140	58	50	43	22	22	19	15	12	6	7	23	5	14	437	3.13%
1992	69	113	47	40	34	18	18	15	12	9	4	5	19	15	419	3.55%
1993	54	55	90	37	32	27	14	14	12	9	7	3	4	24	383	6.38%
1994	56	44	44	71	29	24	20	10	10	9	7	5	2	19	350	5.43%
1995	61	45	35	35	57	23	19	16	8	8	7	5	4	16	337	4.73%
1996	45	49	36	27	25	37	14	11	9	5	4	3	2	7	274	2.63%
1997	55	36	39	28	20	18	26	10	8	6	3	3	2	5	257	1.94%
1998	61	44	28	30	20	14	12	16	6	5	4	1	1	3	243	1.07%
1999	42	48	34	22	21	14	9	7	10	4	3	2	1	1	218	0.65%
2000	57	34	39	28	17	17	11	7	6	8	3	2	1	2	232	0.68%
2001	71	46	27	31	22	14	14	9	6	5	6	2	2	2	256	0.90%
2002	114	57	37	22	25	18	11	11	7	4	4	5	2	3	319	0.98%
2003	45	91	46	30	17	20	14	9	9	5	4	3	4	4	302	1.31%
2004	41	36	73	37	24	14	16	11	7	7	4	3	2	6	281	2.23%
2005	55	33	29	59	29	19	11	13	9	6	5	3	2	7	280	2.39%
2006	59	45	26	23	47	23	15	9	10	7	4	4	3	7	283	2.44%

Table 1A.25. Estimates of age-2 pollock recruitment (in millions) based on reference model.

Year	Index at age 2
1978	69.8
1979	91.9
1980	314.5
1981	71.4
1982	46.0
1983	74.9
1984	77.1
1985	77.6
1986	71.3
1987	56.6
1988	84.8
1989	78.5
1990	73.0
1991	140.5
1992	68.9
1993	54.3
1994	56.4
1995	61.1
1996	44.6
1997	54.5
1998	60.5
1999	41.8
2000	57.2
2001	71.1
2002	114.0
2003	45.4
2004	40.5
2005	55.4
2006	59.4
Ave 83-06	66.2
Med 83-06	60.0

Table 1A.26 Estimates of 2005 pollock fishery, survey, and projected fishery selectivity-at-age for Model 2B.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
M2B Fishery	0.025	0.060	0.153	0.376	0.716	0.814	0.801	0.843	0.987	1.216	1.647	2.121	2.121	2.121
Projected*	0.016	0.110	0.438	0.949	1.470	1.639	1.621	1.470	1.290	1.198	1.198	1.198	1.198	1.198
M2B Survey	0.065	0.183	0.404	0.565	0.656	0.714	0.783	0.861	0.982	1.157	1.282	1.286	1.286	1.286

* From the 2005 EBS pollock stock assessment (Ianelli et al. 2005).

Table 1A.27. Projections of Model 2B (with adjusted selectivity) female spawning biomass (in thousands of t), *F*, and catch (in thousands of t) for NRA pollock for the 8 scenarios. Fishing mortality rates given are based on the *average* fishing mortality over all ages.

Sp.Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
2006	90.45	90.45	90.45	90.45	90.45	90.45	90.45	90.45
2007	82.21	82.21	84.86	87.04	87.61	80.70	82.21	87.19
2008	58.41	58.41	70.37	82.14	85.56	52.63	58.41	82.60
2009	48.47	48.47	63.75	81.48	87.13	42.11	47.77	80.32
2010	44.48	44.48	60.40	81.46	88.69	38.79	41.43	77.53
2011	42.97	42.97	58.61	81.65	90.06	38.08	39.13	70.52
2012	42.42	42.42	57.78	82.52	92.00	37.91	38.31	65.41
2013	42.04	42.04	57.35	83.82	94.42	37.71	37.86	61.54
2014	41.70	41.70	56.69	83.82	95.02	37.50	37.54	57.76
2015	41.55	41.55	56.29	83.80	95.41	37.42	37.43	54.78
2016	41.63	41.63	56.40	84.84	97.14	37.53	37.53	52.75
2017	41.77	41.77	56.55	85.65	98.49	37.67	37.67	51.09
2018	41.72	41.72	56.56	86.25	99.55	37.62	37.62	49.58
2019	41.46	41.46	56.32	86.33	99.95	37.35	37.35	48.06
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
2006	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2007	0.29	0.29	0.15	0.03	0.00	0.38	0.29	0.02
2008	0.29	0.29	0.15	0.03	0.00	0.38	0.29	0.05
2009	0.29	0.29	0.15	0.03	0.00	0.37	0.38	0.05
2010	0.29	0.29	0.15	0.03	0.00	0.34	0.36	0.14
2011	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.15
2012	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.17
2013	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.18
2014	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.20
2015	0.28	0.28	0.15	0.03	0.00	0.33	0.33	0.21
2016	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.23
2017	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.24
2018	0.28	0.28	0.15	0.03	0.00	0.34	0.34	0.25
2019	0.28	0.28	0.15	0.03	0.00	0.33	0.33	0.26
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
2006	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
2007	44.47	44.47	24.40	5.39	0.00	54.54	44.47	4.00
2008	29.63	29.63	19.23	4.89	0.00	33.09	29.63	7.60
2009	22.86	22.86	16.33	4.57	0.00	23.98	28.29	7.60
2010	20.12	20.12	15.17	4.48	0.00	20.45	22.77	19.00
2011	19.56	19.56	15.15	4.65	0.00	20.26	21.20	19.00
2012	19.47	19.47	15.21	4.80	0.00	20.40	20.74	19.00
2013	19.33	19.33	15.17	4.91	0.00	20.33	20.45	19.00
2014	19.18	19.18	15.09	4.99	0.00	20.20	20.24	19.00
2015	18.99	18.99	14.85	4.93	0.00	20.05	20.06	19.00
2016	18.95	18.95	14.80	4.96	0.00	20.04	20.05	19.00
2017	19.02	19.02	14.81	4.98	0.00	20.15	20.15	19.00
2018	19.04	19.04	14.80	5.01	0.00	20.17	20.17	19.00
2019	18.95	18.95	14.79	5.03	0.00	20.04	20.04	19.00

Table 1A.28. **Ecosystem effects on AI walleye pollock**

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on walleye pollock	No concern
Birds	Stable, some increasing some decreasing	May affect young-of-year mortality	Unknown
Fish (Pacific cod, arrowtooth flounder)	Pacific cod—decreasing, arrowtooth--stable	Possible decreases to walleye pollock mortality	No concern
Changes in habitat quality			
Temperature regime	The 2004 and 2006AI summer bottom temperature was near average. A warming since 2000 and 2002 were coldest and second coldest survey years respectively.	Warming from 2002 could affect apparent distribution.	Unknown

***The AI walleye pollock* effects on ecosystem**

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Expected to be heavily monitored	Likely to be a minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Expected to be heavily monitored.	Bycatch levels should be low.	Unknown
HAPC biota (seapens/whips, corals, sponges, anemones)	Very low bycatch levels of seapens/whips, sponge and coral catches expected in the pelagic fishery	Bycatch levels and destruction of benthic habitat expected to be minor given the pelagic fishery.	No concern
Marine mammals and birds	Very minor direct-take expected	Likely to be very minor contribution to mortality	No concern
Sensitive non-target species	Expected to be heavily monitored	Unknown given that this fishery was closed between 1999 and 2005. The 2006 AICASS had 3% POP bycatch, the only significant bycatch. The 2005 fishery had a high bycatch of POP, but bycatch of other species was very low in fishery prior to 1999.	No concern
Other non-target species	Very little bycatch.	Unknown	No concern
Fishery concentration in space and time	Steller sea lion protection measures may concentrate fishery spatially to very small areas between 20 nm closures	Depending on concentration of pollock outside of critical habitat could possibly have an effect.	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Possible Concern
Fishery contribution to discards and offal production	Offal production—unknown. Fishery in 2005 expected to be conducted by CPs which may have fish meal production capabilities	Unknown	Unknown
Fishery effects on age-at-maturity and fecundity	Unknown	Unknown	Unknown

Figures

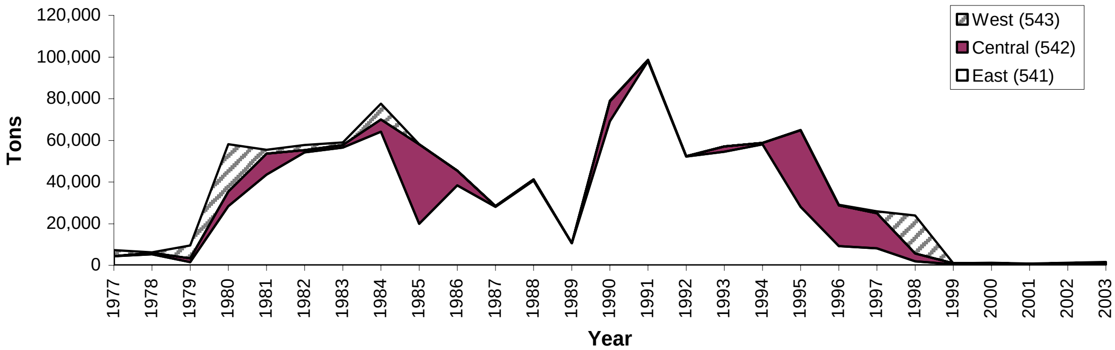


Figure 1A.1. Estimated pollock catch by sub-area of the Aleutian Islands Region, 1977-2003. Units in metric tons.

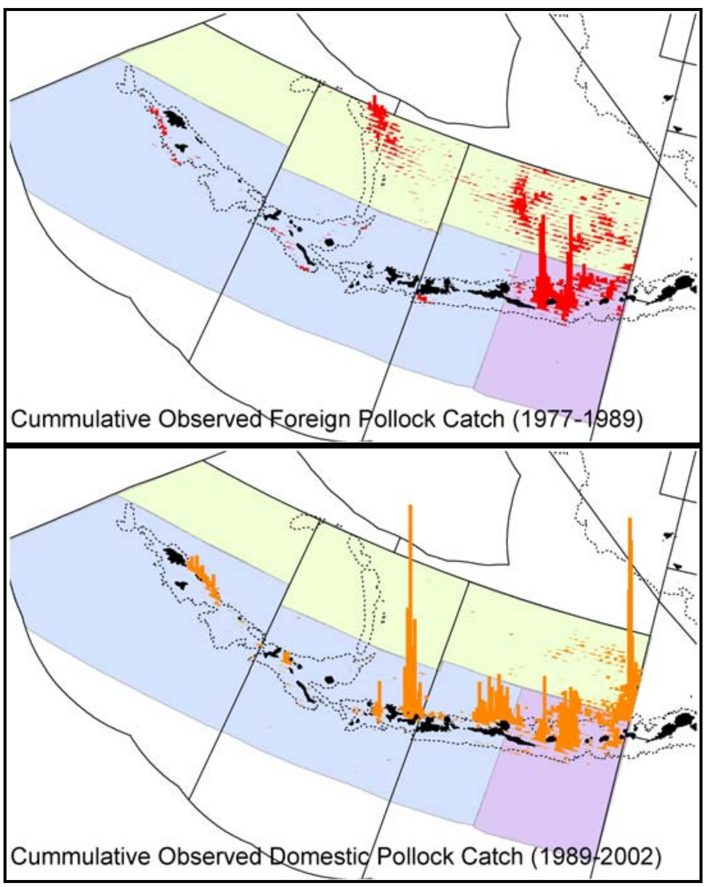


Figure 1A.2. Observed foreign and J.V. (1978-1989), and domestic (1989-2002) pollock catch in the Aleutian Islands Area summed over all years and 10 minute latitude and longitude blocks. Both maps use the same scale (maximum observed catch per 10 minute block: foreign and J.V. 8,000 t and Domestic 19,000 t). Catches of less than 1 t were excluded from cumulative totals.

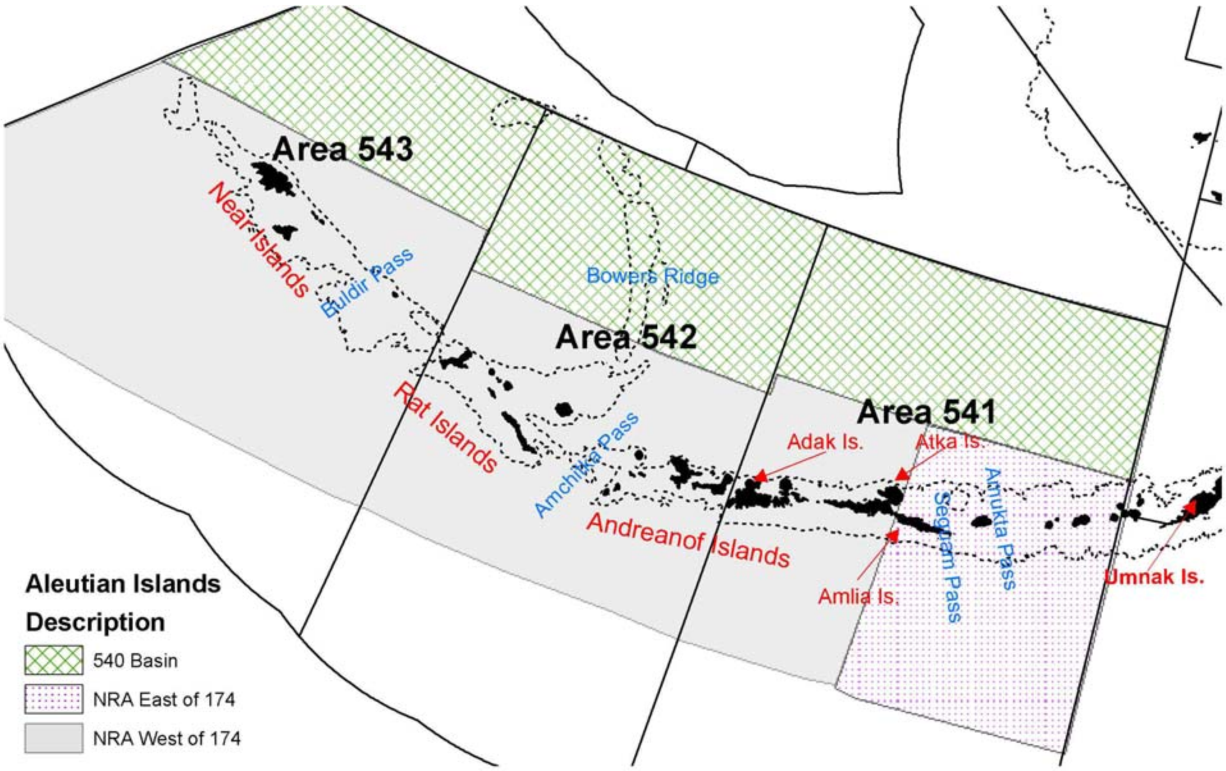


Figure 1A.3. Regions defined for consideration of alternative data partitions for Aleutian Islands Region pollock. The abbreviation "NRA" represents the Near, Rat, and Andreanof Island groups.

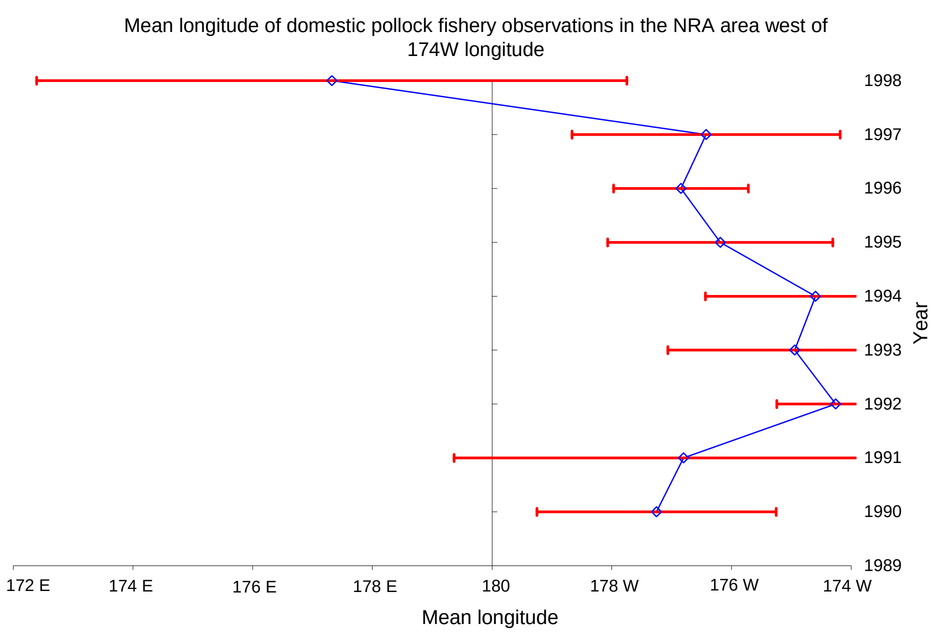


Figure 1A.4. Mean longitude of observed targeted domestic (1990-1998) pollock catch in the NRA west of 174 W longitude. Error bars indicate one standard deviation from the mean.

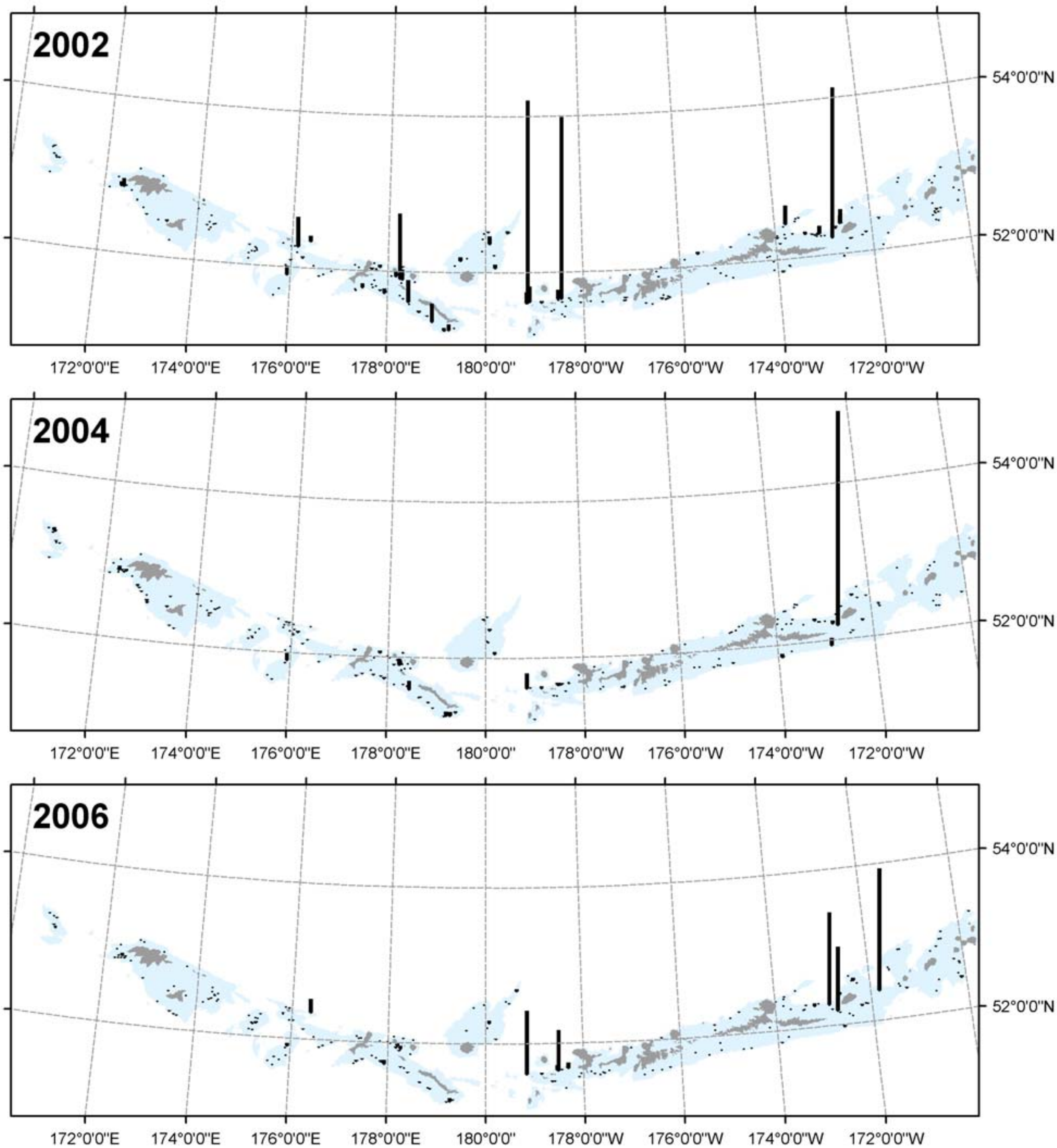


Figure 1A.5. Catch per unit effort (kg per m^3) for surveys of pollock in the Aleutian Islands Region, 2002-2006. The shaded area is the region surveyed.

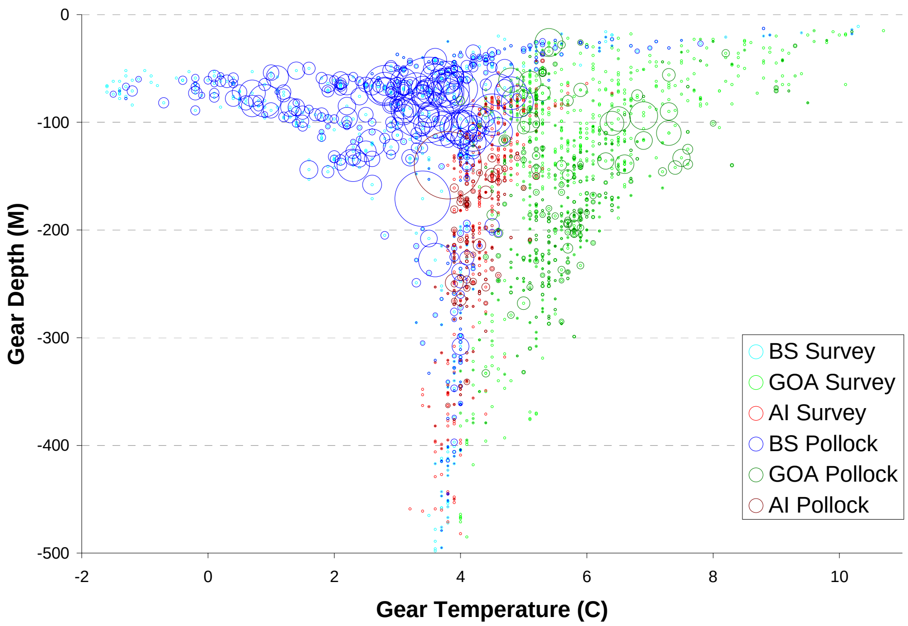


Figure 1A.6. Pollock CPUE (KG per m^3) by depth and temperature from the 2004 Aleutian Islands and Bering Sea and 2005 Gulf of Alaska bottom trawl surveys. Circle area is proportional to CPUE.

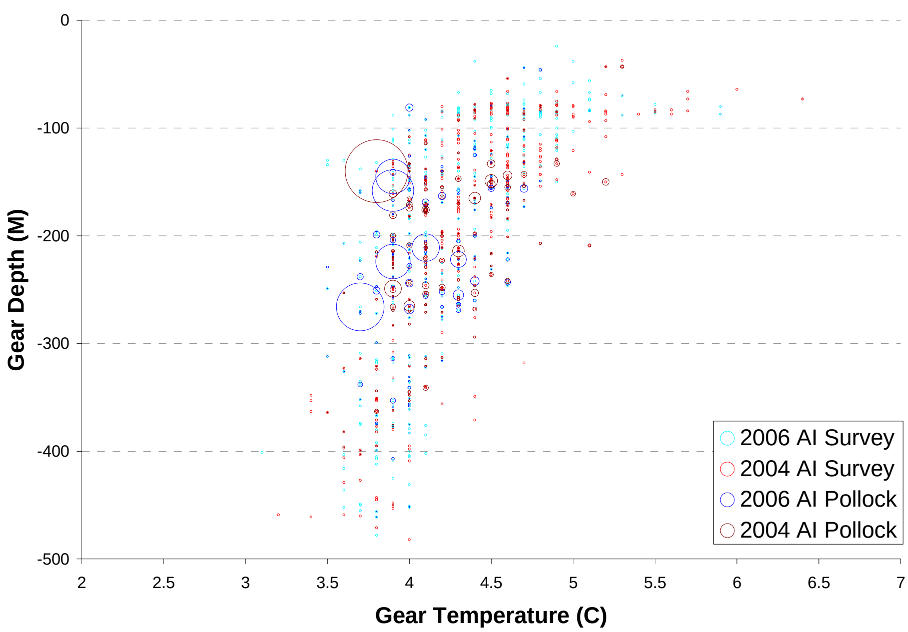


Figure 1A.7. Pollock CPUE (KG per m^3) by depth and temperature from the 2004 (red) and 2006 (blue) Aleutian Islands bottom trawl surveys. Circle area is proportion to CPUE.

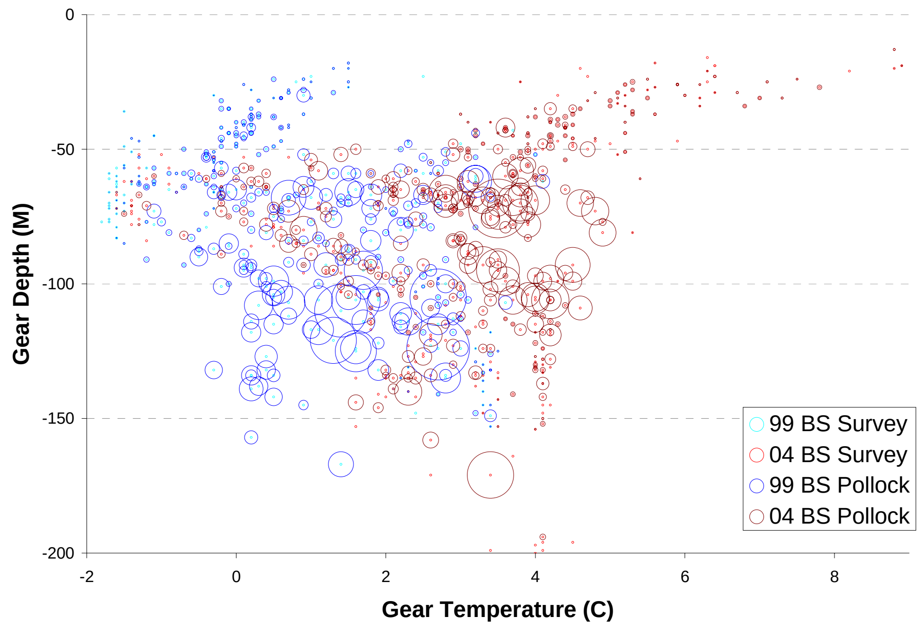


Figure 1A.8. Pollock CPUE (KG per m^3) by depth and temperature from the 1999 (blue) and 2004 (red) Bering Sea bottom trawl surveys. Circle area is proportional to CPUE.

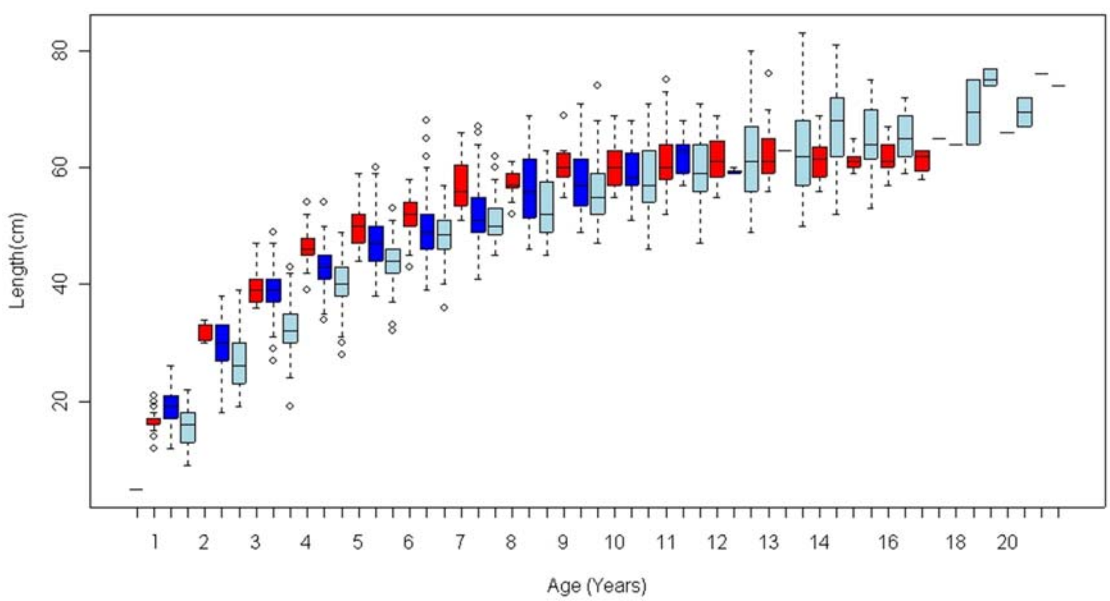


Figure 1A.9. Length at age for Aleutian Islands (red), Gulf of Alaska (blue), and Bering Sea (grey) pollock from the 2004 Aleutian Islands, 2004 Bering Sea, and 2005 Gulf of Alaska bottom trawl surveys.

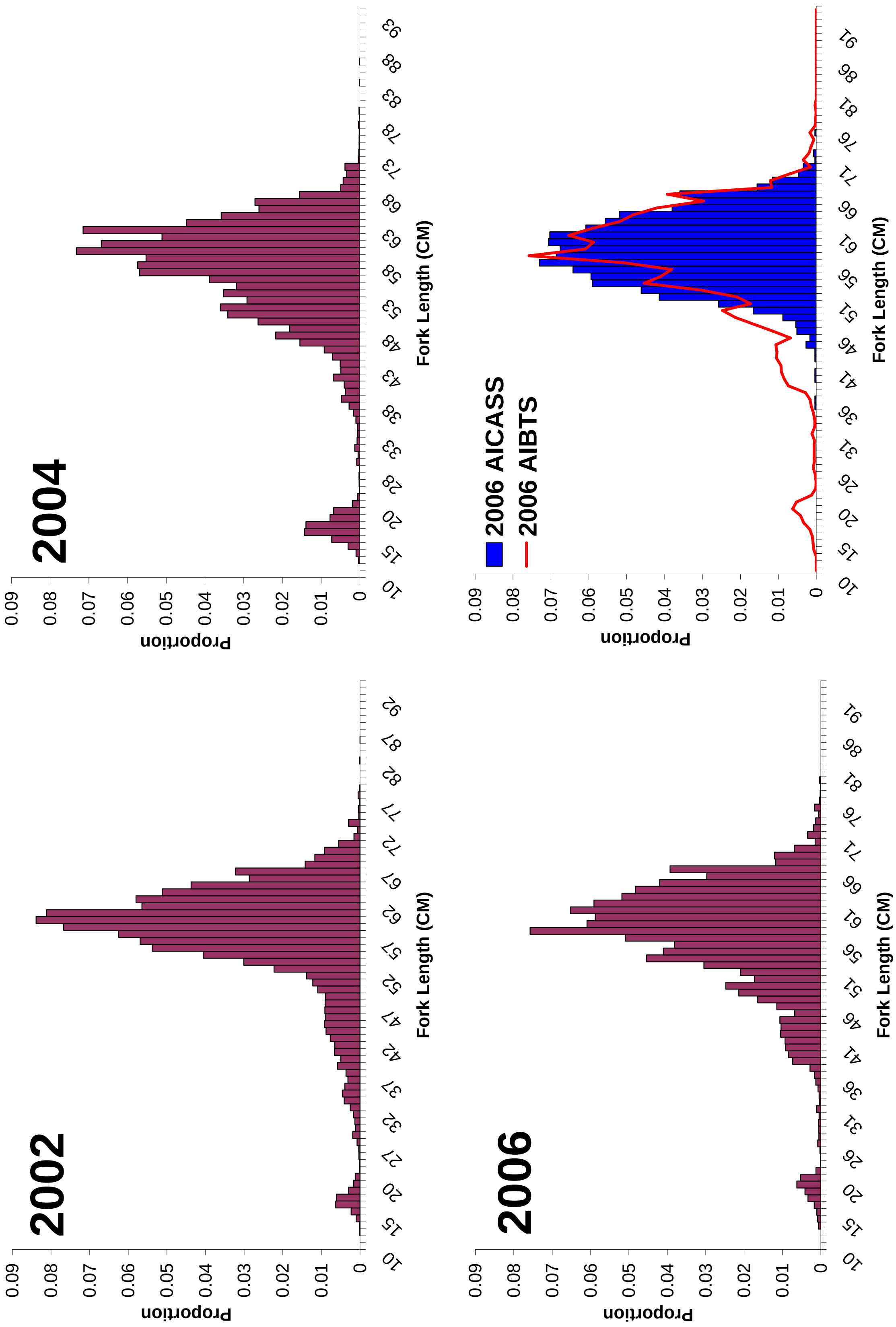


Figure 1A.10. Length distribution for 2002-2006 Aleutian Islands bottom trawl surveys and the 2006 Aleutian Islands cooperative acoustic survey study.

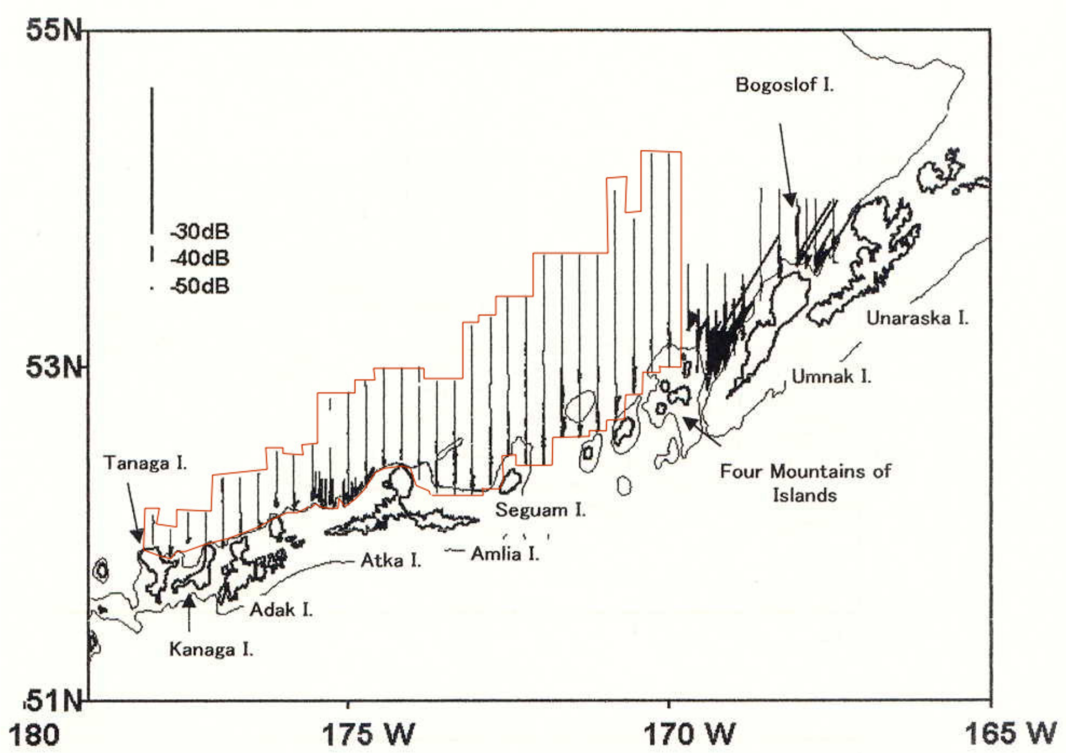


Figure 1A.11. R/V Kaiyo Maru 2002 echo integration-trawl survey (above) strata for leg2 and below observed S_A in both legs. Please note that in the bottom picture the encircled area is leg 2.

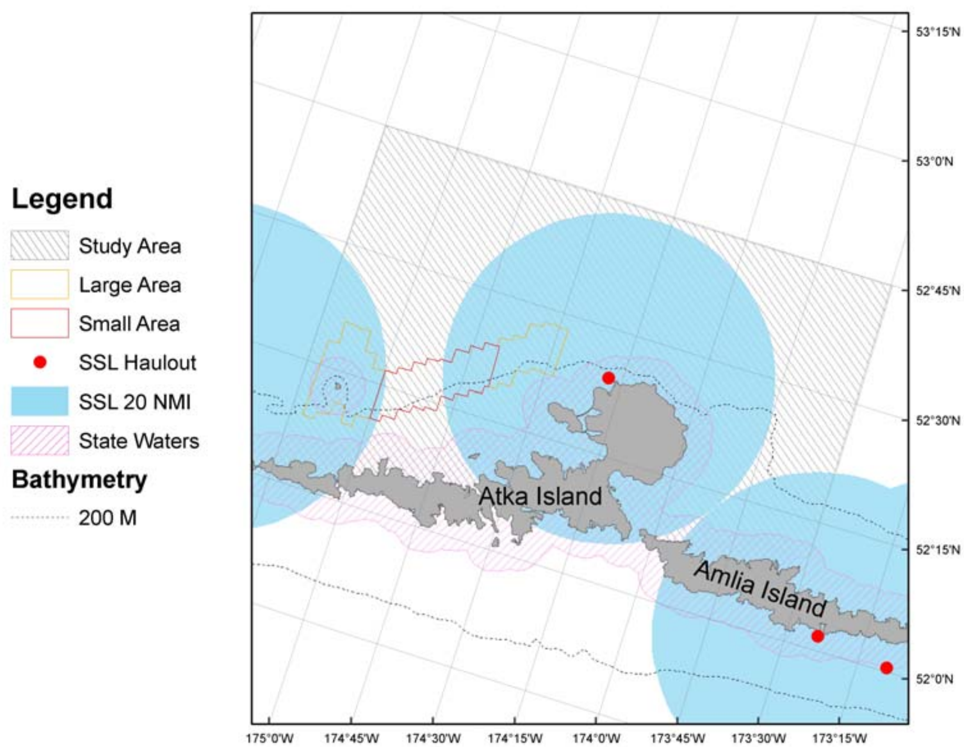


Figure 1A.12. 2006 AICASS Survey Area.

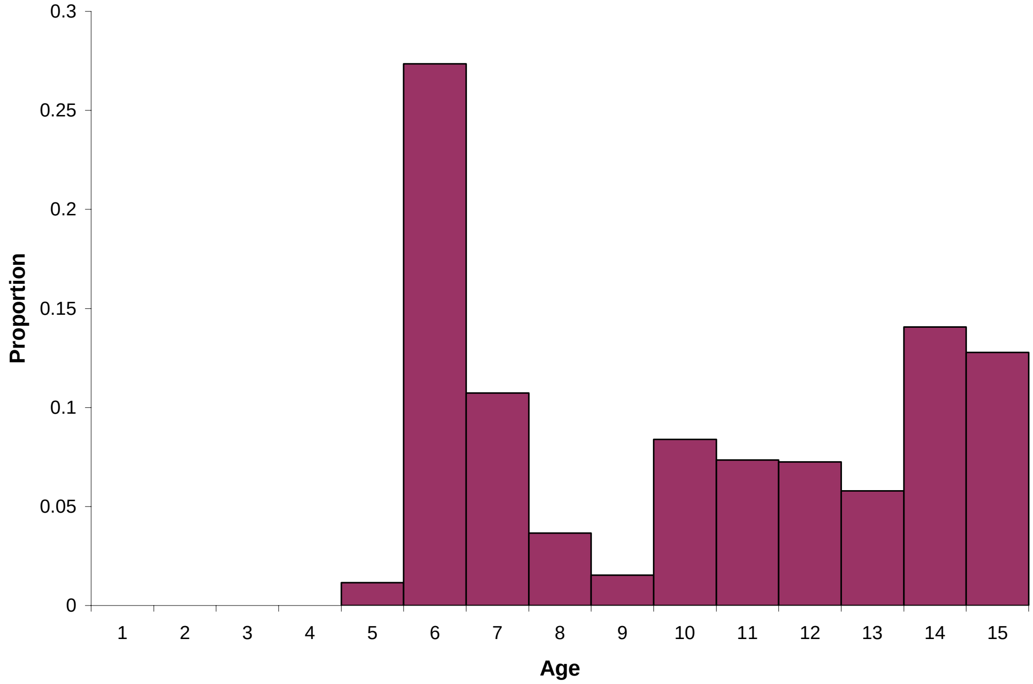


Figure 1A.13. Proportion of total weight of pollock at age from the 2006 AICASS. The age 15 group represents all fish age 15 and older.

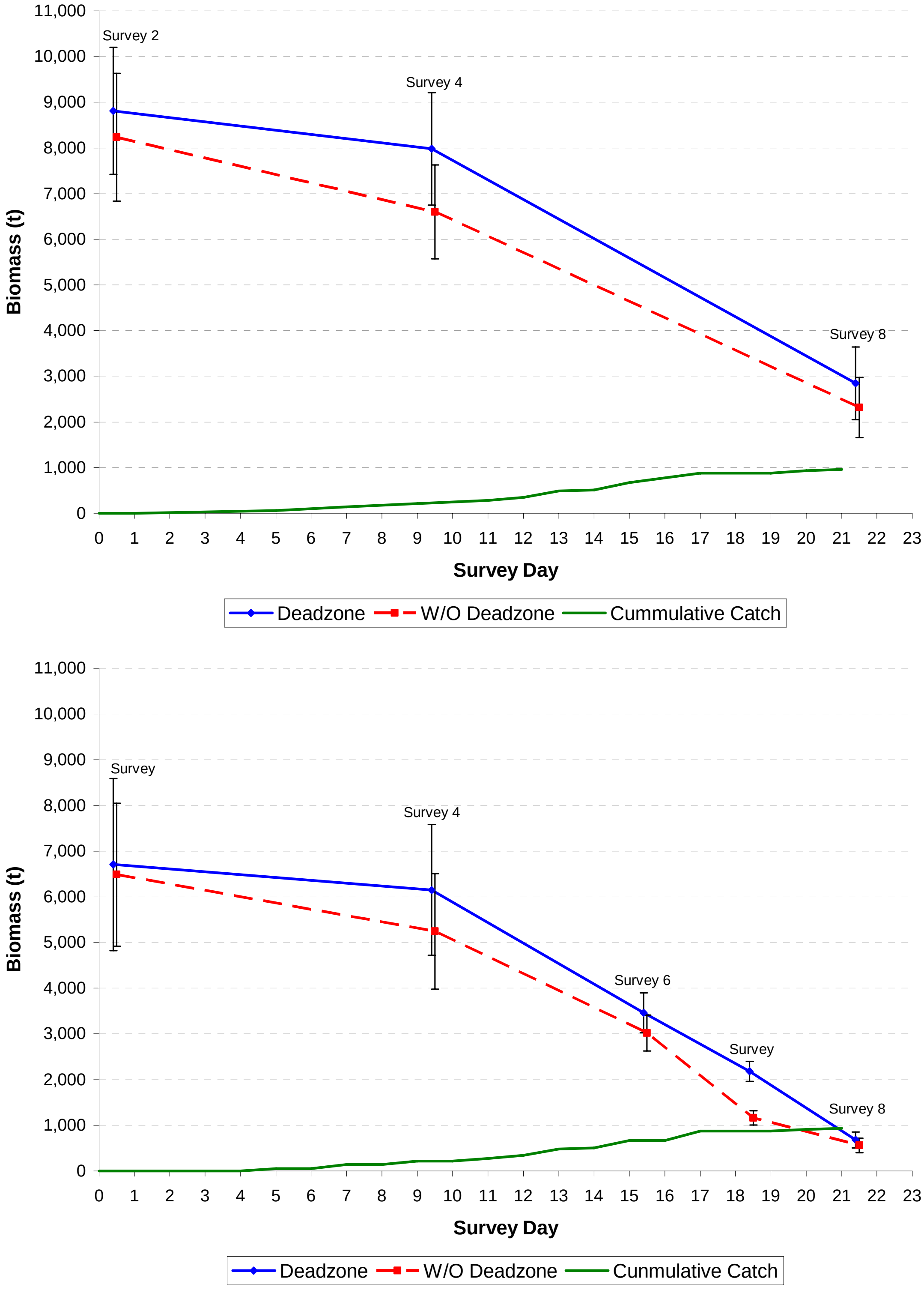


Figure 1A.14. Pollock abundance estimation and cumulative catch for large (top) and small (bottom) survey areas. Note error bars are $\pm 1.96 \times E_i \times B_i$. Method proposed by Kloser 1996 used to estimate biomass in the "Deadzone."

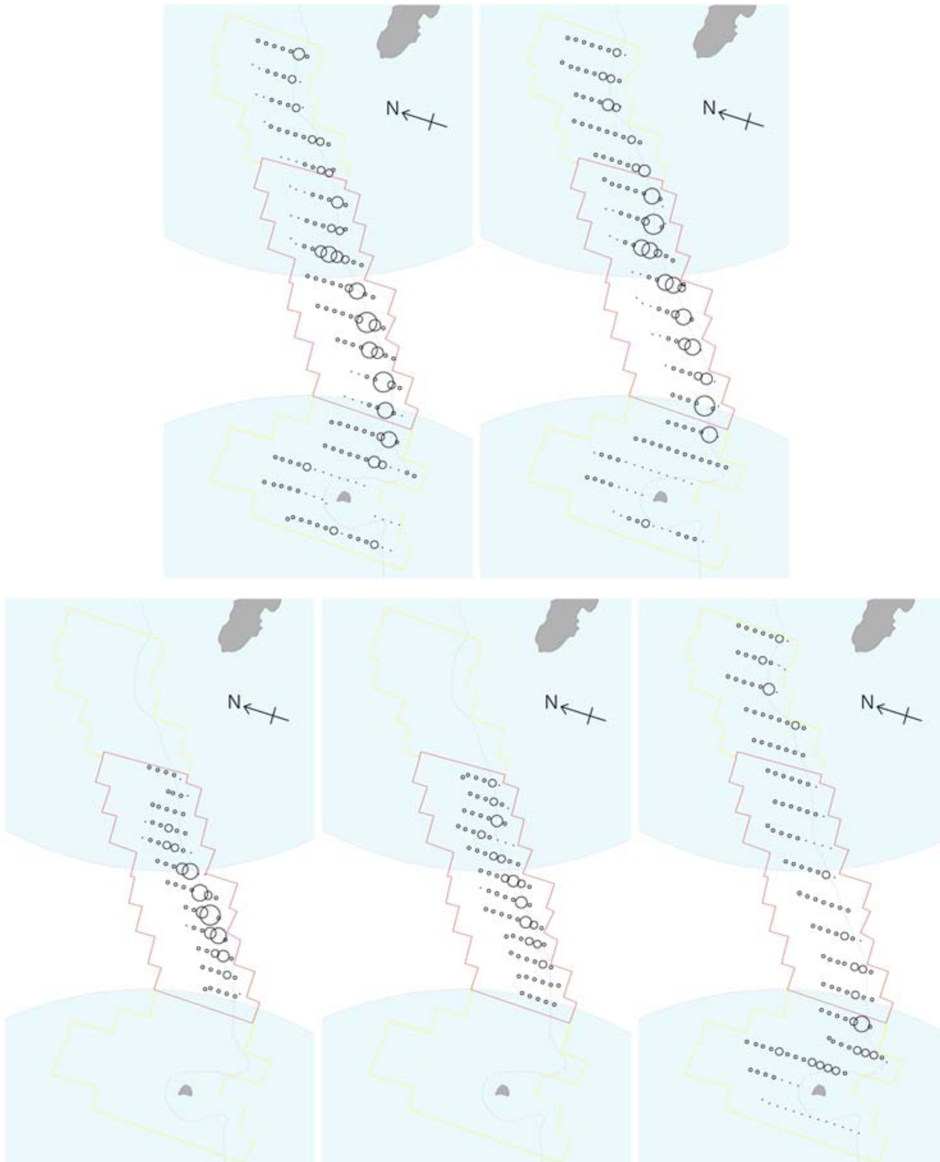


Figure 1A.15. 2006 AICASS distributions of pollock. Figures from left to right correspond to Surveys 2, 4, 6, 7, and 8.

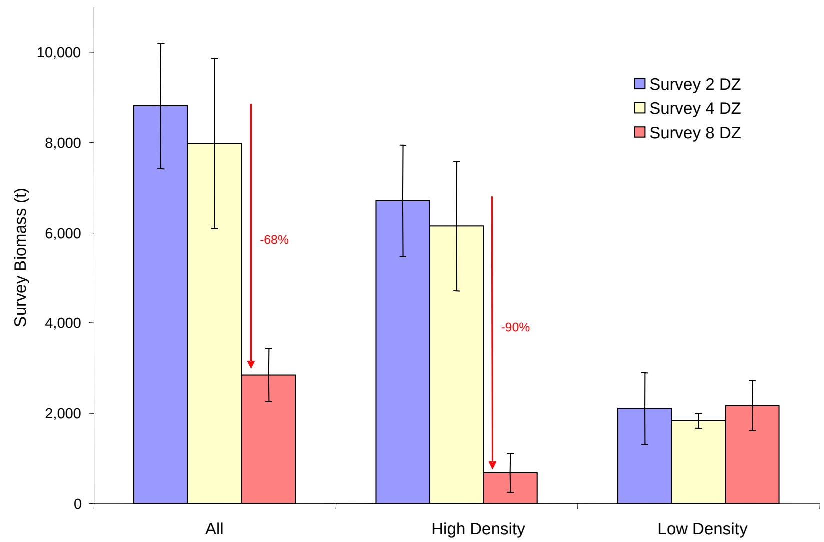
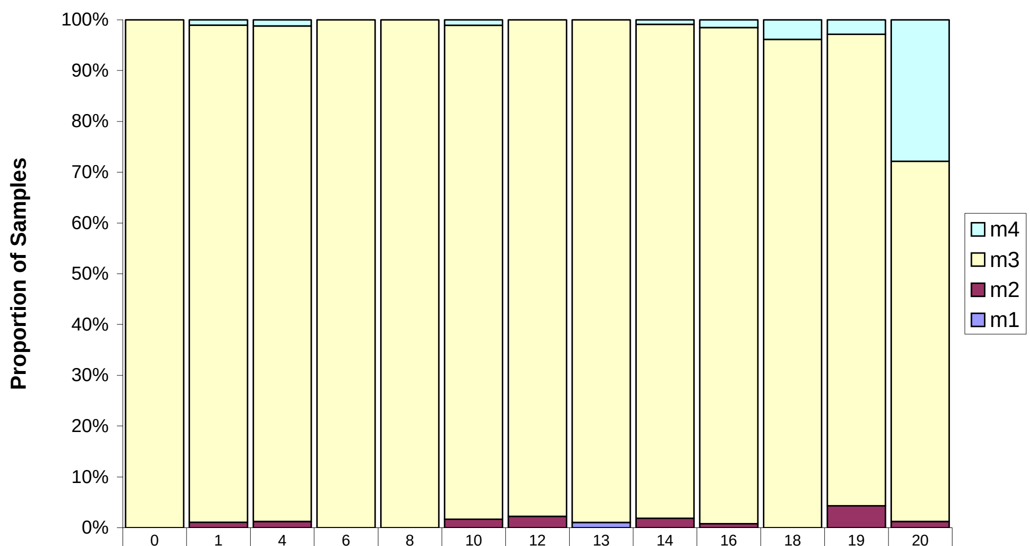


Figure 1A.16. Change in abundance for All, High Density, and Low Density areas. The High Density area corresponds with the small survey area while All corresponds with the large survey area, and Low Density corresponds with the large survey area outside of the small survey area. Arrows indicate a significant change in abundance from the first survey. Note: 935 t of the total 965 t caught during the 2006 AICASS were removed from the High Density area.



	0	1	4	6	8	10	12	13	14	16	18	19	20
m4	0	2	1	0	0	2	0	0	1	2	1	2	46
m3	5	183	82	147	112	176	310	98	105	128	25	65	117
m2	0	2	1	0	0	3	7	0	2	1	0	3	2
m1	0	0	0	0	0	0	0	1	0	0	0	0	0

Survey Day

Figure 1A.17. Female pollock maturity over the duration of the 2006 AICASS, m1 = immature, m2 = developing, m3 = pre-spawning, m4 = spawning, and m5 = spent. There were no spent fish observed during this survey.

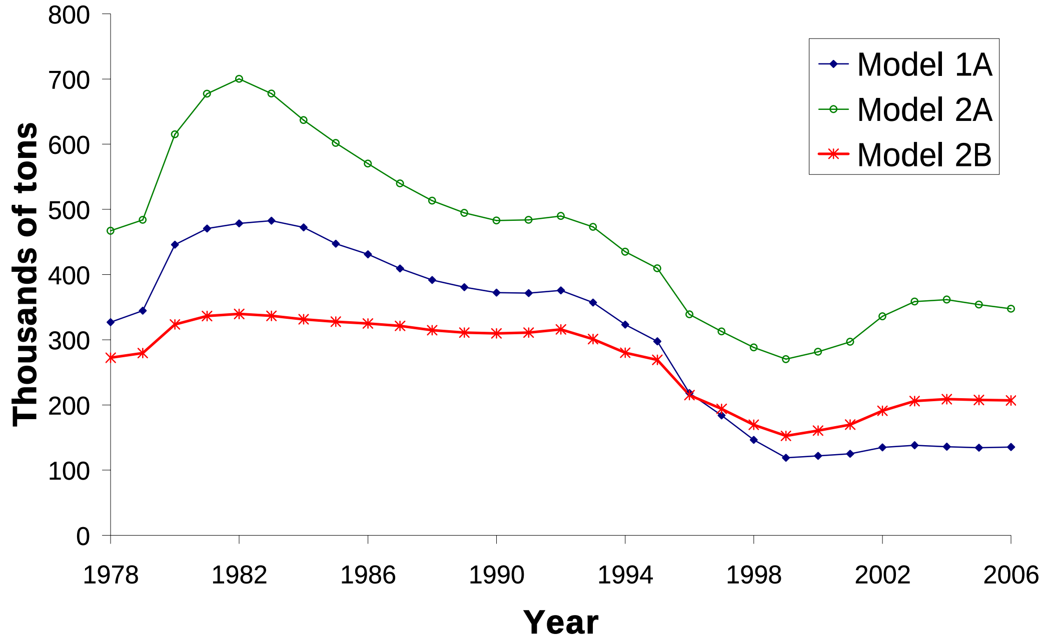


Figure 1A.18. Biomass trajectories under the three evaluated models.

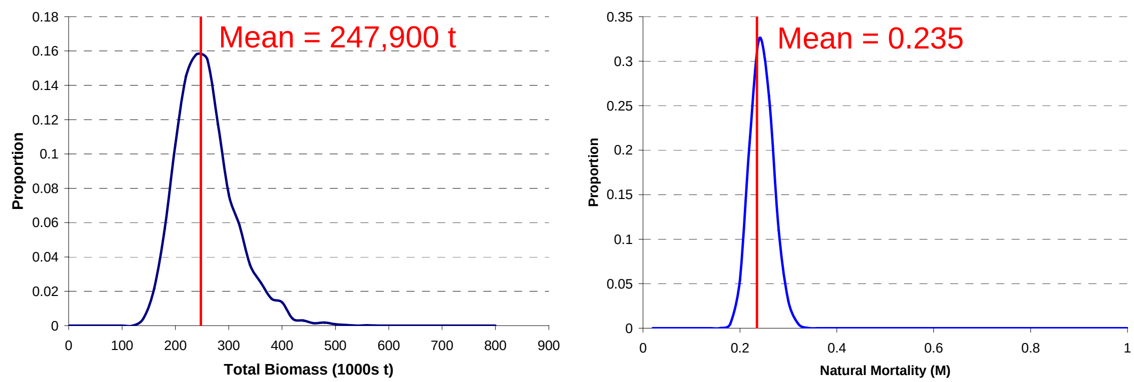


Figure 1A.19 2006 total biomass (right) and natural mortality (left) distributions from MCMC runs of Model 2B. Distributions were generated through 1,000,000 MCMC simulations sampled every 200 simulation.

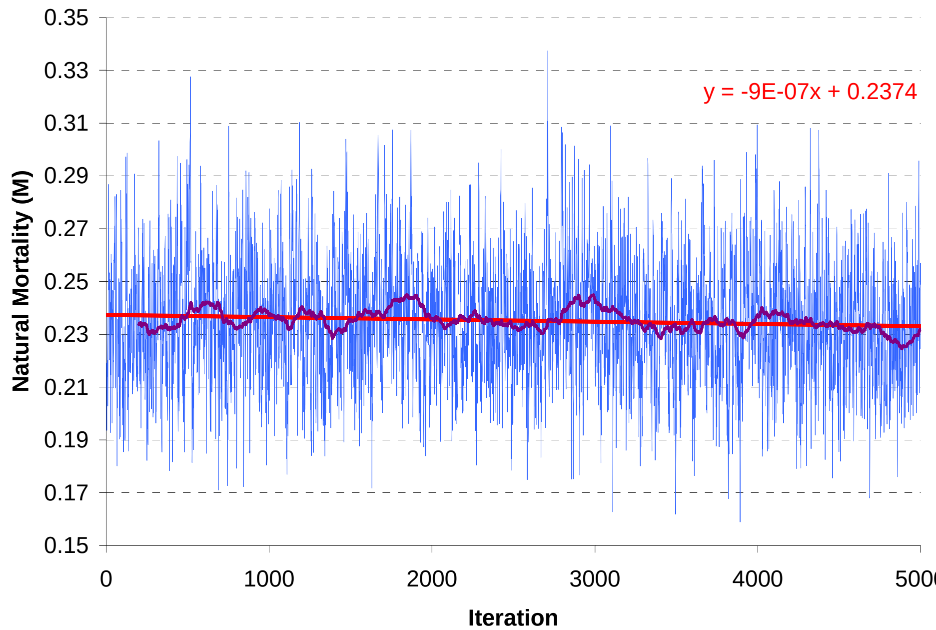


Figure 1A.20 Trace of natural mortality from MCMC simulations generated through 1,000,000 simulations sampled every 200th iteration for the two 6models. The purple line is a running mean for every 200th sampled iteration and the red line is a linear fit to the data showing a flat (slope of -9×10^{-7}) trajectory over 5000 iterations.

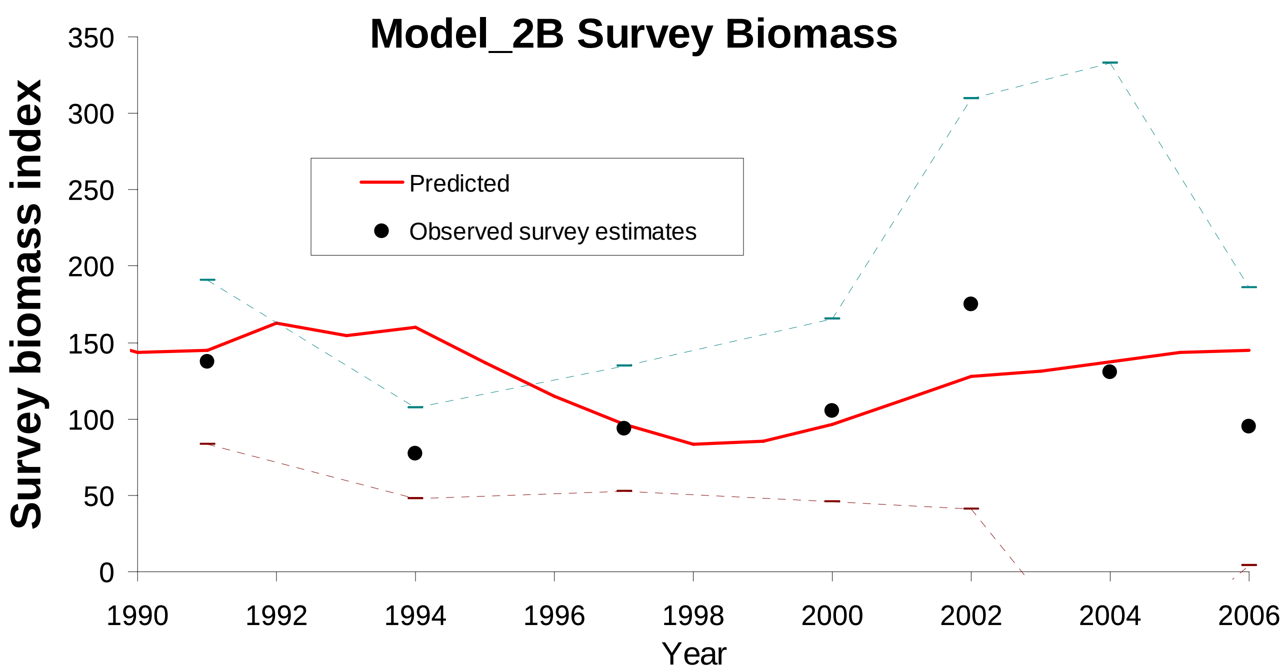


Figure 1A.21. Fit (solid line) to NMFS summer trawl survey (dots) for Model 2B. Dashed lines represent upper and lower confidence bounds of survey estimates.

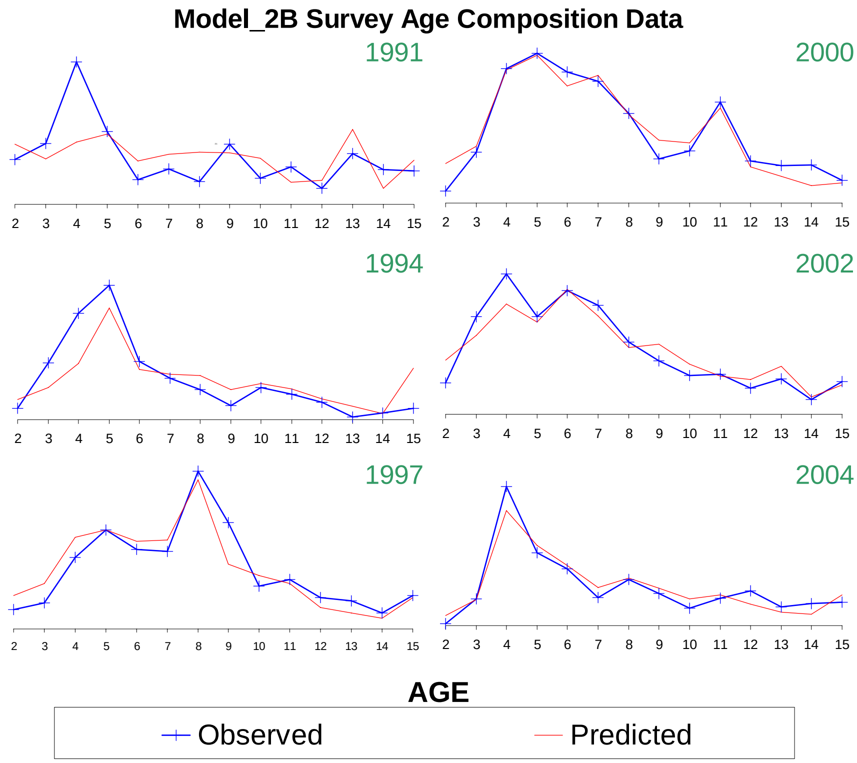


Figure 1A.22. Fits to NMFS summer trawl survey age composition data for Model 2B for Aleutian Islands pollock.

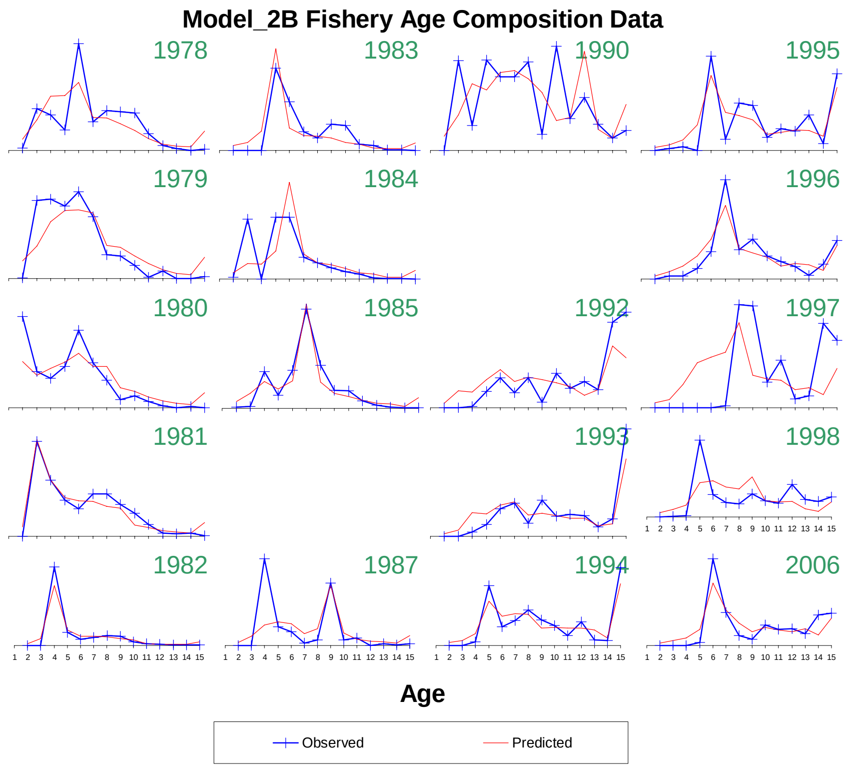


Figure 1A.23. Fit to fishery age composition data for Model 2B for Aleutian Islands (NRA) pollock.

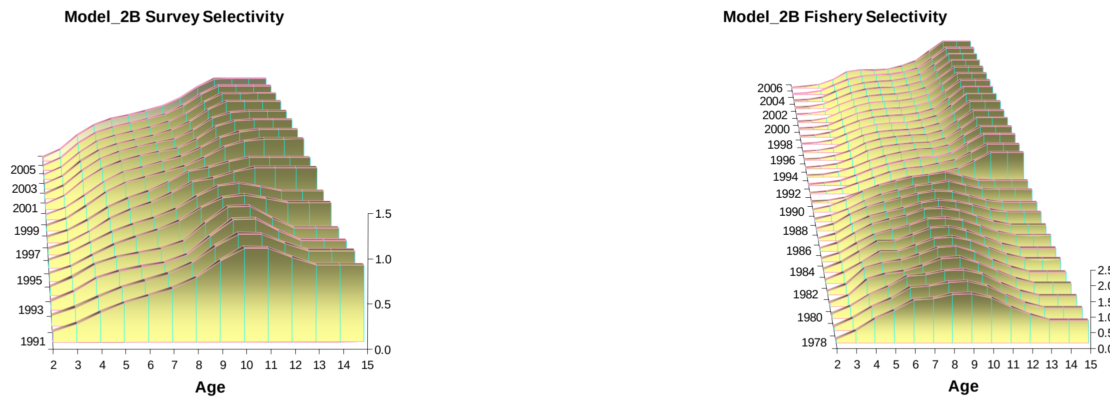


Figure 1A.24. Selectivity estimates for Aleutian Islands pollock for the bottom trawl survey (left) and the fishery (right) Model 2B.

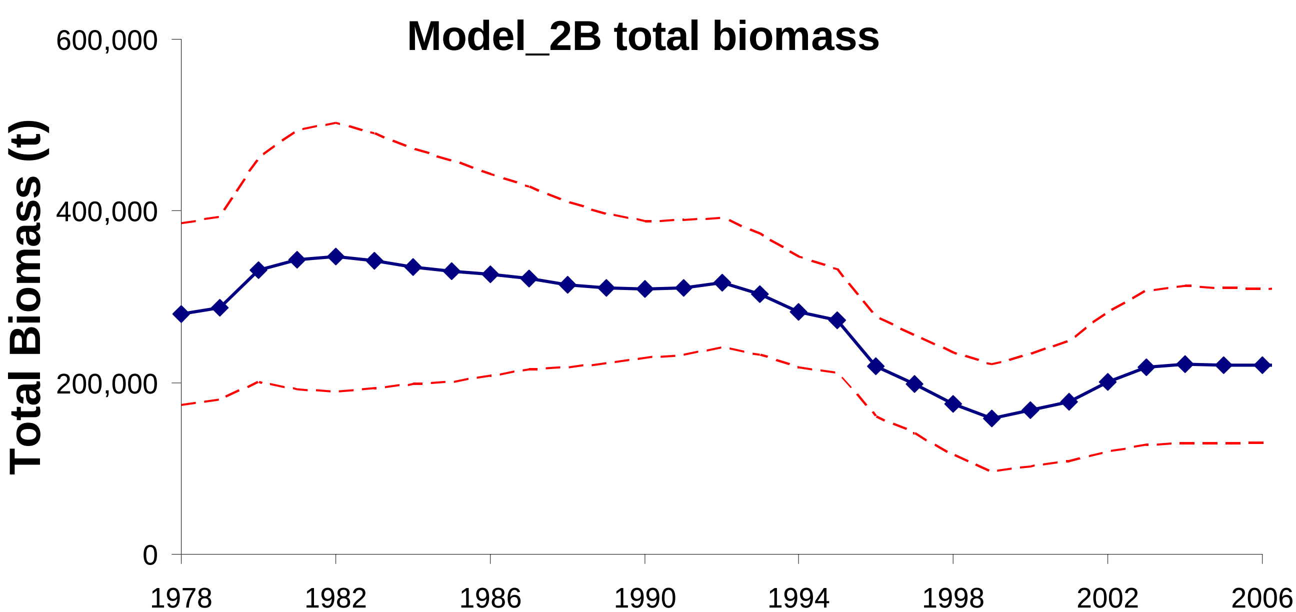


Figure 1A.25. Model 2B estimates of Aleutian Islands pollock age 2+ total biomass (in tons); dashed lines represent approximate upper and lower confidence bounds.

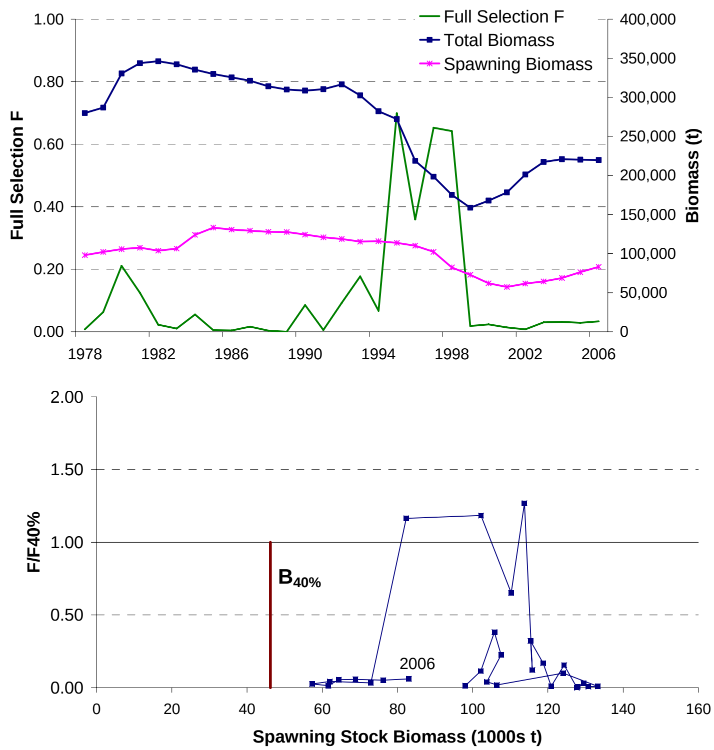


Figure 1A.26 Spawning biomass relative to $F_{40\%}$ values and fishing mortality rates for Model 2B AI pollock over time (top) and plotted jointly (bottom) for 1978-2006. Fishing mortality rates are based on the average over ages 2-15.

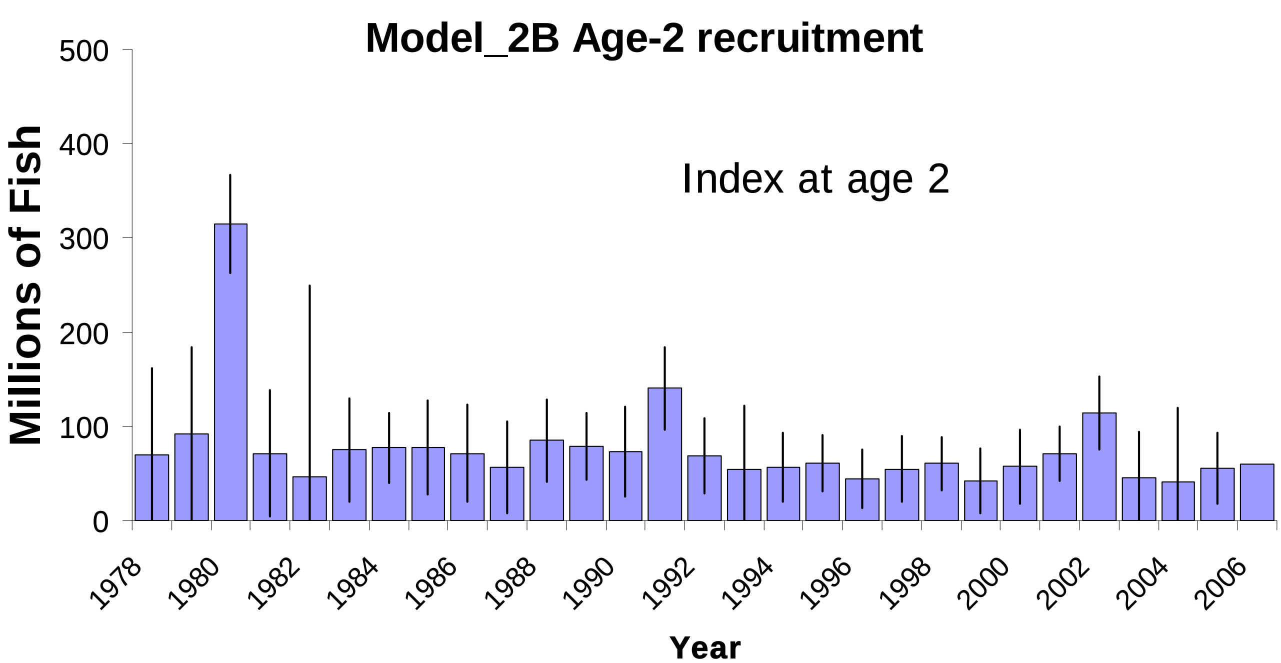


Figure 1A.27. Model 2B estimates of Aleutian Islands (NRA assessment area) pollock year-class estimates; vertical bars represent approximate upper and lower confidence bounds.

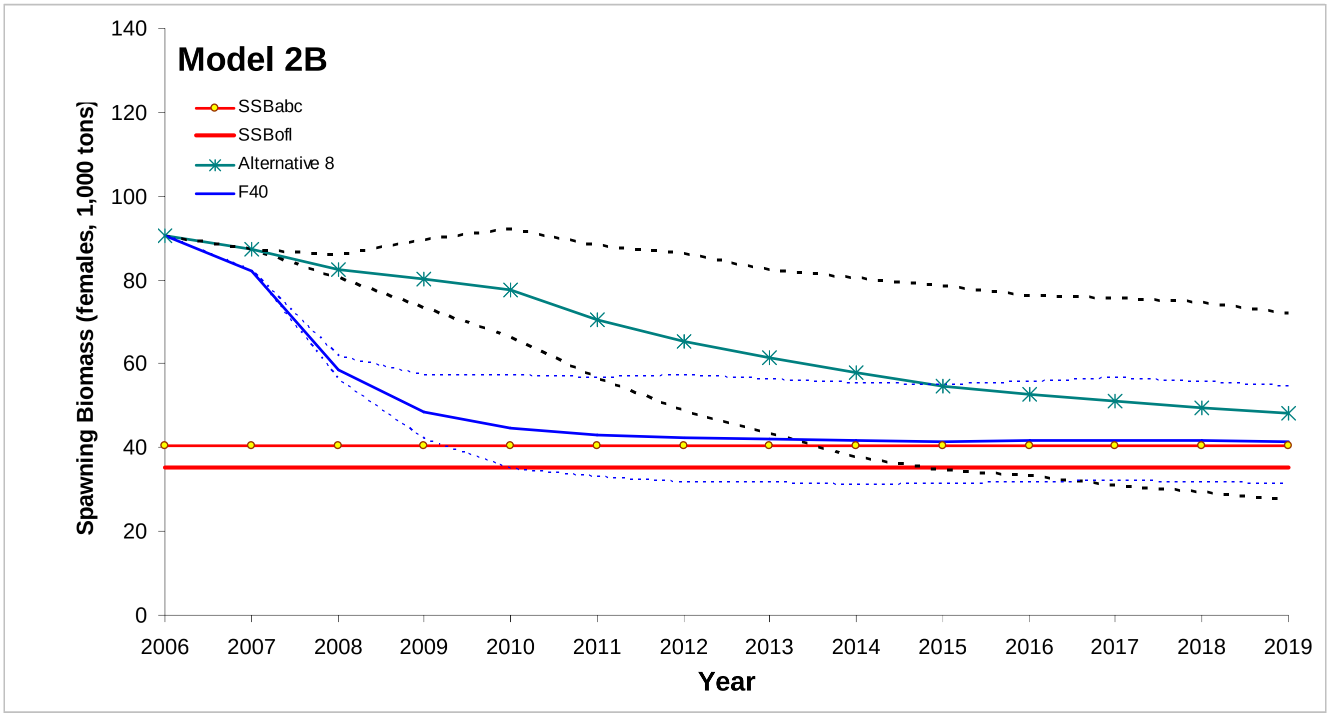


Figure 1A.28 Projected spawning biomass for $F_{40\%}$ and Alternative 8 ABC scenarios from Model 2B with adjusted selectivity-at-age.

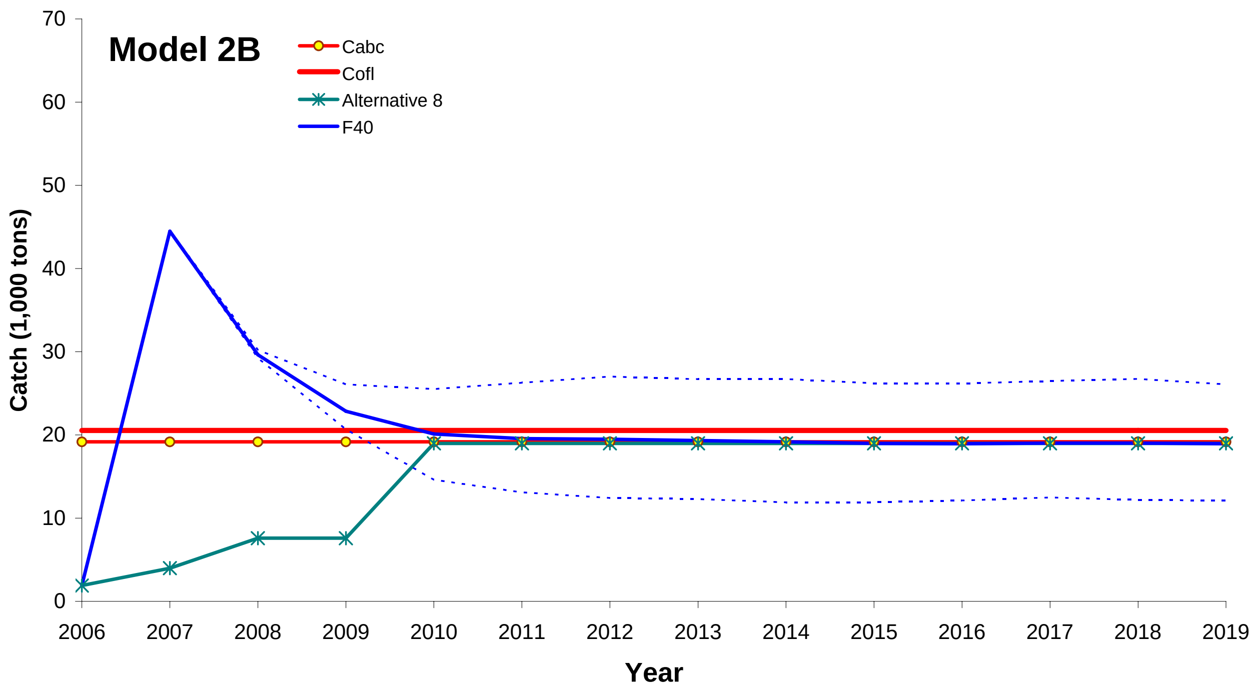


Figure 1A.29 Projected catch for $F_{40\%}$ and Alternative 8 ABC scenarios from Model 2B with adjusted selectivity-at-age.

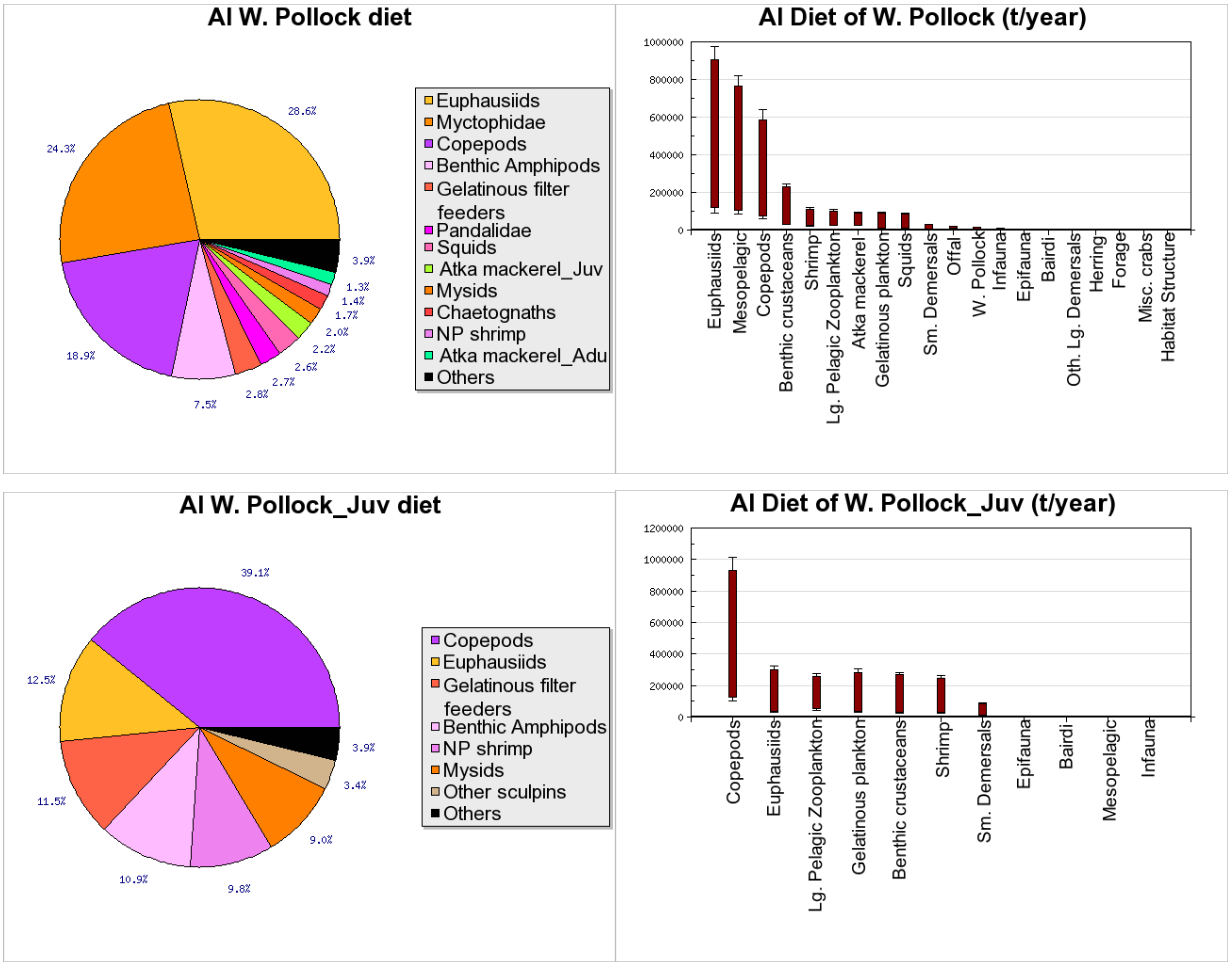


Figure 1A.30. Diet composition (left) and estimated consumption of prey (right) by AI adult (top) and juvenile (bottom) pollock. Diets are estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1991-1994. See Appendix A for detailed methods.

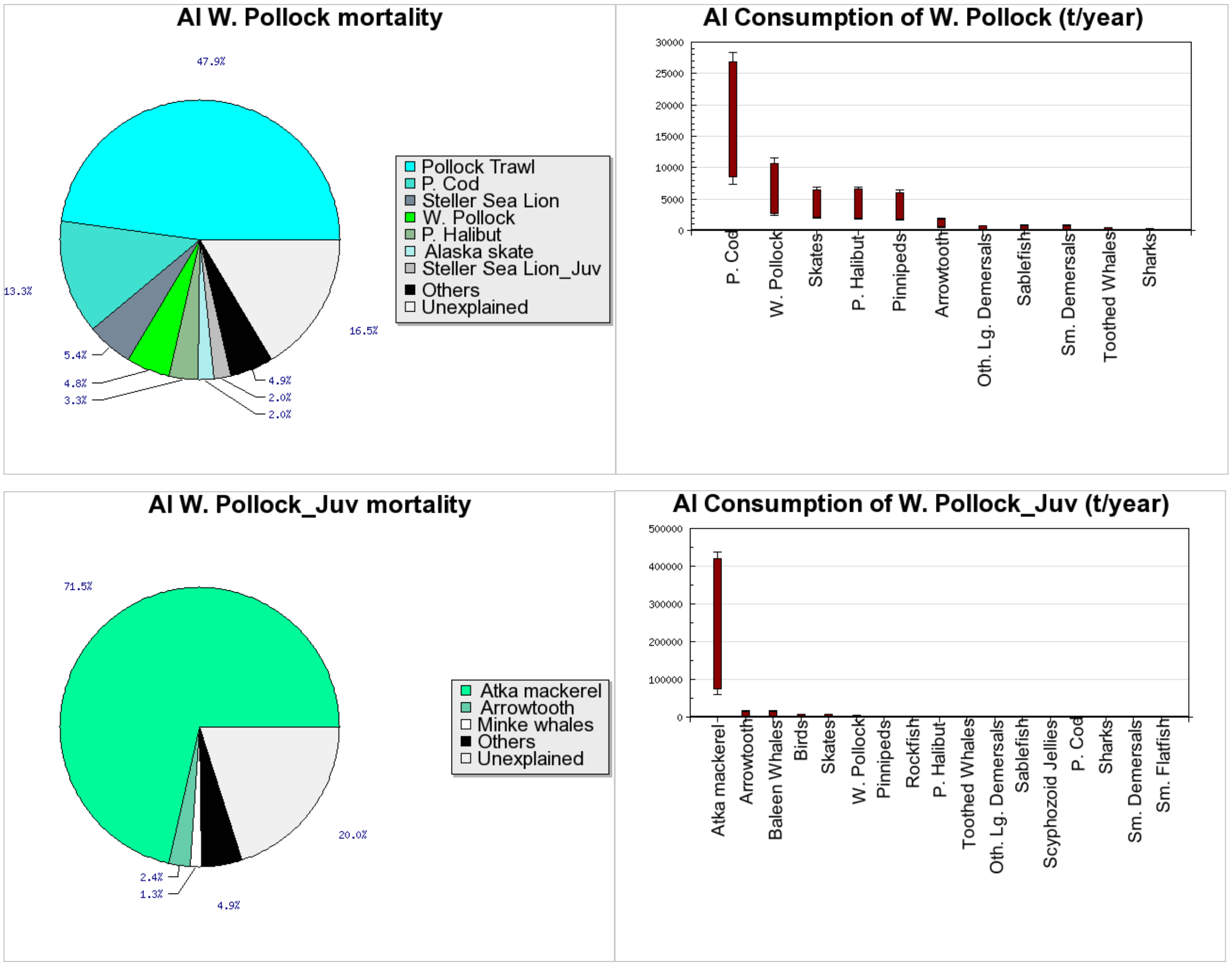


Figure 1A.31. Mortality sources (left) and estimated consumption by predators (right) of AI adult (top) and juvenile (bottom) pollock. Mortality sources reflect pollock predator diets estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1991-1994, pollock predator consumption rates estimated from stock assessments and other studies, and catch of pollock by all fisheries in the same time periods. Annual consumption ranges incorporating uncertainty in food web model parameters were estimated by the Sense routines (Aydin et al in review). See Appendix A for detailed methods.

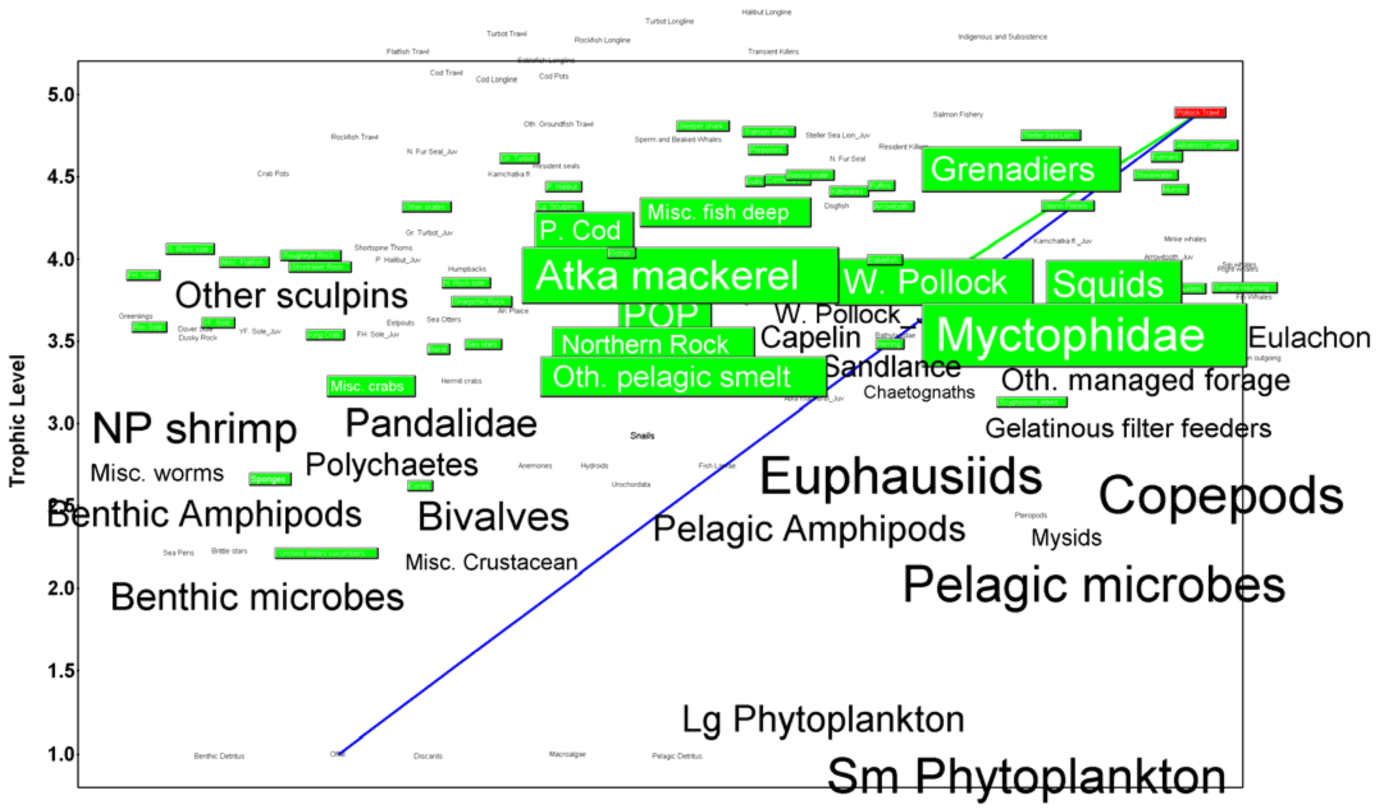


Figure 1A.32. The pollock trawl fishery in the AI food web. Species taken by the pollock fishery (in red) are highlighted in green, with the most significant flow to pollock indicated with a green line. Box size is proportional to biomass and lines between boxes represent the most significant energy flows. From Aydin et al (in review).

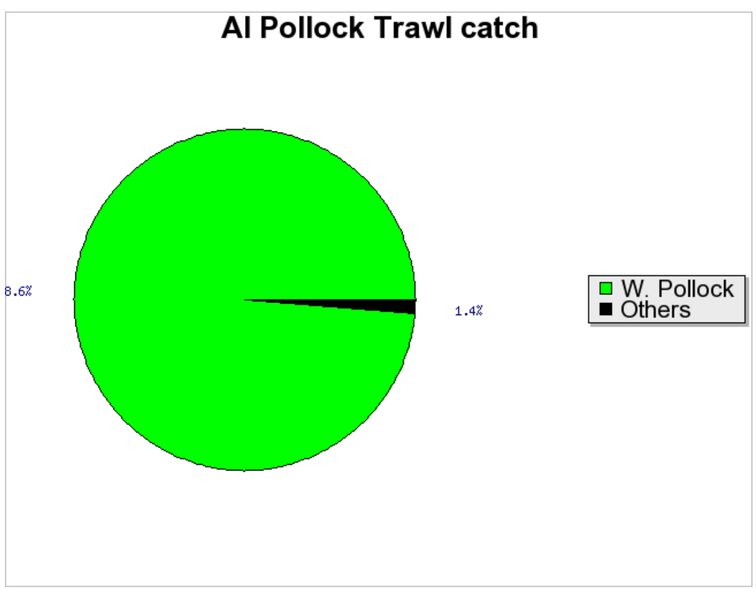


Figure 1A.33. Catch composition of the AI pollock trawl fishery during the early 1990's, as used in the food web model (Aydin et al Tech Memo).

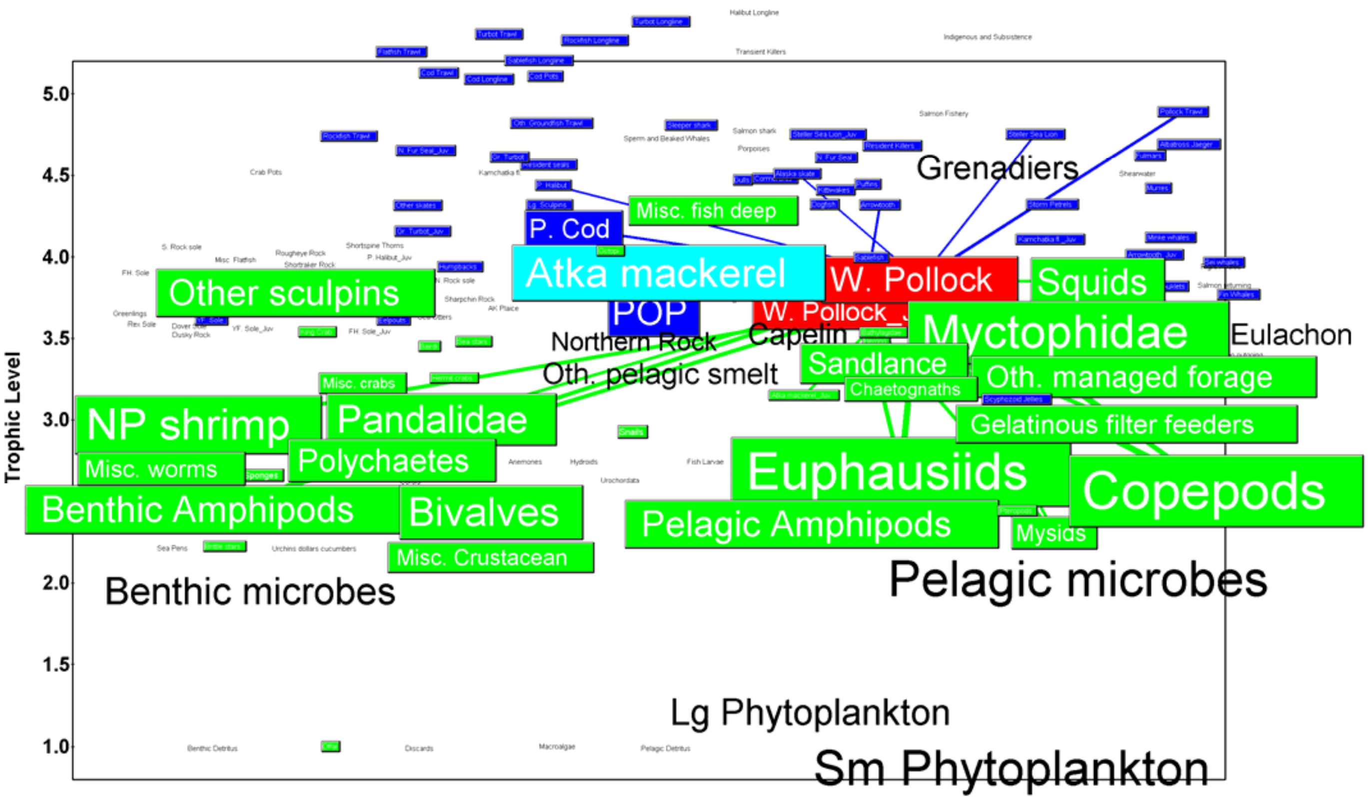


Figure 1A.34. Adult and juvenile pollock (highlighted in red) in the AI food web (Aydin et al Tech Memo). Predators of pollock are dark blue, prey of pollock are green, and species that are both predators and prey of pollock are light blue. Box size is proportional to biomass and lines between boxes represent the most significant energy flows.

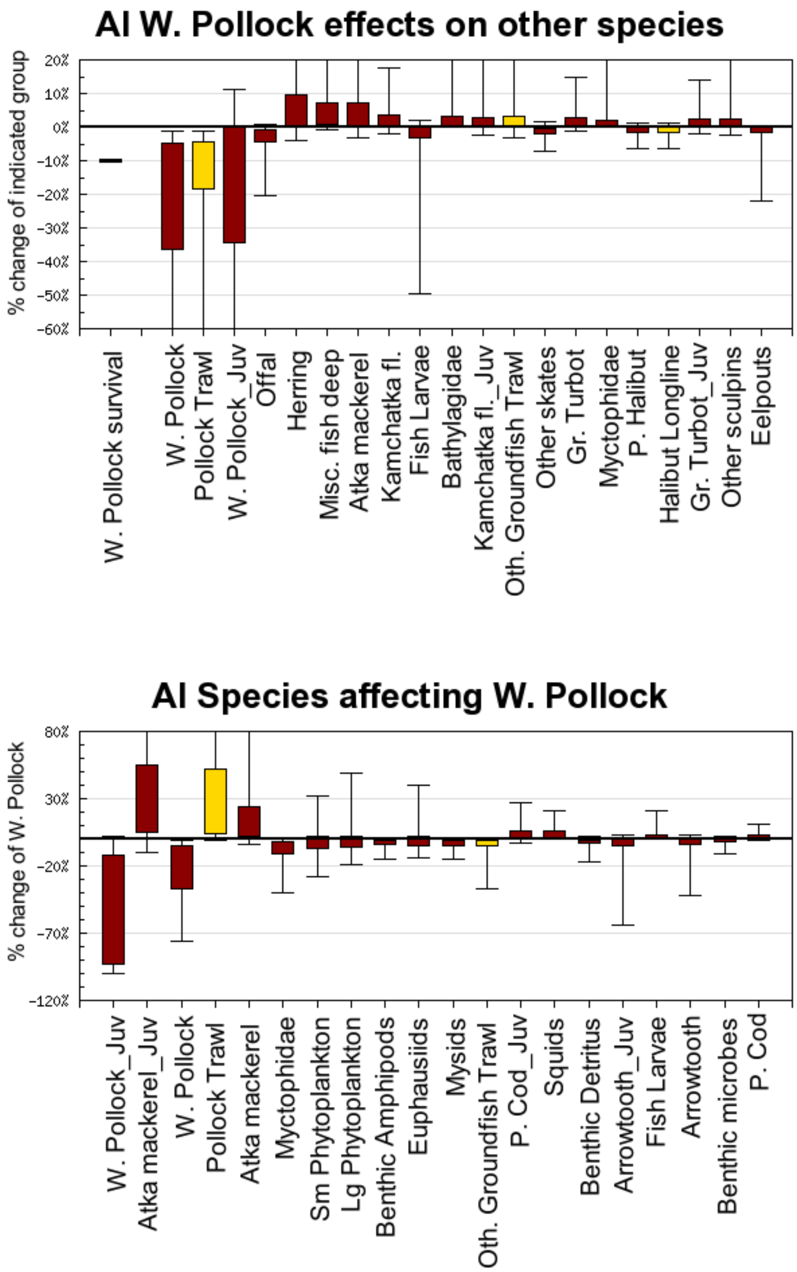


Figure 1A.35. (upper panel) Effect of changing pollock survival on fishery catch (yellow) and biomass of other species (dark red), from a simulation analysis where pollock survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. (lower panel) Effect of reducing fisheries catch (yellow) and other species survival (dark red) on pollock biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. In both panels, boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al in review for detailed Sense methods).

Appendix A

Diet composition calculations

Notation:

DC = diet composition

W = weight in stomach

n = prey

p = predator

s = predator size class

h = survey haul

r = survey stratum

B = biomass estimate

v = survey

a = assessment

R = ration estimate

The diet composition for a species is calculated from stomach sampling beginning at the level of the individual survey haul (1), combining across hauls within a survey stratum (2), weighting stratum diet compositions by stratum biomass (3), and finally combining across predator size classes by weighting according to size-specific ration estimates and biomass from stock assessment estimated age structure (4). Ration calculations are described in detail below.

Diet composition (DC) of prey n in predator p of size s in haul h is the total weight of prey n in all of the stomachs of predator p of size s in the haul divided by the sum over all prey in all of the stomachs for that predator size class in that haul:

$$DC_{n,p,s,h} = W_{n,p,s,h} \Big/ \sum_{n} W_{n,p,s,h} \qquad (1)$$

Diet composition of prey n in predator p of size s in survey stratum r is the average of the diet compositions across hauls within that stratum:

$$DC_{n,p,s,r} = \sum_{h} DC_{n,p,s,h} \Big/ h \qquad (2)$$

Diet composition of prey n in predator p of size s for the entire area t is the sum over all strata of the diet composition in stratum r weighted by the survey biomass proportion of predator p of size s in stratum r:

$$DC_{n,p,s,t} = \sum_{r} DC_{n,p,s,r} * B^{v}_{p,s,r} \Big/ \sum_{r} B^{v}_{p,s,r} \qquad (3)$$

Diet composition of prey n in predator p for the entire area t is the sum over all predator sizes of the diet composition for predator p of size s as weighted by the relative stock assessment biomass of predator size s times the ration of predator p of size s:

$$DC_{n,p,t} = \sum_{s} DC_{n,p,s,t} * B^{a}_{p,s} * R_{p,s} \Big/ \sum_{s} B^{a}_{p,s} * R_{p,s} \qquad (4)$$

Ration Calculations

Size specific ration (consumption rate) for each predator was determined by the method of fitting the generalized Von Bertalanffy growth equations (Essington et al. 2001) to weight-at-age data collected aboard NMFS bottom trawl surveys.

The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time (dW/dT) is calculated as follows (Paloheimo and Dickie 1965):

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n \qquad (5)$$

Here, W_t is body mass, t is the age of the fish (in years), and H, d, k, and n are allometric parameters. The term $H \cdot W_t^d$ is an allometric term for "useable" consumption over a year, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption (Q) is calculated as $(1/A) \cdot H \cdot W_t^d$, where A is a scaling fraction between predator and prey wet weights that accounts for indigestible portions of the prey and differences in caloric density. The term $k \cdot W_t^n$ is an allometric term for the amount of biomass lost yearly as respiration.

Based on an analysis performed across a range of fish species, Essington et al. (2001) suggested that it is reasonable to assume that the respiration exponent n is equal to 1 (respiration linearly proportional to body weight). In this case, the differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right)^{\frac{1}{1-d}} \qquad (6)$$

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. If the consumption exponent d is set equal to 2/3, this equation simplifies into the "specialized" von Bertalanffy length-at-age equation most used in fisheries management, with the "traditional" von Bertalanffy K parameter being equal to the k parameter from the above equations divided by 3.

From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, d, k, and t_0) and the relationship between W_∞ and the H, k, and d parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given age class of fish. For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights as calculated by minimizing negative log likelihood: observation error was assumed to be in weight but not aging. A process-error model was also examined but did not give significantly different results.

Initial fitting of 4-parameter models showed, in many cases, poor convergence to unique minima and shallow sum-of-squares surfaces: the fits suffered especially from lack of data at the younger age classes that would allow fitting to body weights near t=0 or during juvenile, rapidly growing life stages. To counter this, the following multiple models were tested for goodness-of-fit:

1. All four parameters estimated by minimization;
2. d fixed at 2/3 (specialized von Bertalanffy assumption)
3. d fixed at 0.8 (median value based on metaanalysis by Essington et al. 2001).
4. t_0 fixed at 0.
5. d fixed at 2/3 with t_0 fixed at 0, and d fixed at 0.8 with t_0 fixed at 0.

The multiple models were evaluated using Aikeike's Information Criterion, AIC (spreadsheet review). In general, the different methods resulted in a twofold range of consumption rate estimates; consistently, model #3, d fixed at 0.8 while the other three parameters were free, gave the most consistently good results using the AIC. In some cases model #1 was marginally better, but in some cases, model #1 failed to converge. The poorest fits were almost always obtained by assuming that d was fixed at 2/3.

To obtain absolute consumption (Q) for a given age class, the additional parameter A is required to account for indigestible and otherwise unassimilated portions of prey. We noted that the range of indigestible percentage for a wide range of North Pacific zooplankton and fish summarized in Davis (2003) was between 5-30%, with major zooplankton (copepods and euphasiids), as well as many forage fish, having a narrower range of indigestible percentages, generally between 10-20%. Further, bioenergetics models, for example for walleye pollock (Buckley and Livingston), indicate that nitrogenous waste (excretion) and egestion resulted in an additional 20-30% loss of consumed biomass. As specific bioenergetics models were not available for most species, we made a uniform assumption of a total non-respirative loss of 40% (from a range of 25-60%) for all fish species, with a corresponding *A* value of 0.6.

Finally, consumption for a given age class was scaled to population-level consumption using the available numbers-at-age data from stock assessments, or using mortality rates from stock assessments and the assumption of an equilibrium age structure in cases where numbers-at-age reconstructions were not available.

Production rates

Production per unit biomass (P/B) and consumption per unit biomass (Q/B = R, ration above) for a given population depend heavily on the age structure, and thus mortality rate of that population. For a population with an equilibrium age structure, assuming exponential mortality and Von Bertalanffy growth, P/B is in fact equal to total mortality Z (Allen 1971) and Q/B is equal to (Z+3K)/A, where K is Von Bertalanffy's K, and A is a scaling factor for indigestible proportions of prey (Aydin 2004). If a population is not in equilibrium, P/B may differ substantially from Z although it will still be a function of mortality.

For the Bering Sea, Aleutian Islands, and Gulf of Alaska ECOPATH models, P/B and Q/B values depend on available mortality rates, which were taken from estimates or literature values used in single-species models of the region. It is noted that the single-species model assumptions of constant natural mortality are violated by definition in multispecies modeling; therefore, these estimates should be seen as "priors" to be input into the ECOPATH balancing procedures or other parameter-fitting (e.g. Bayesian) techniques.

Several methods were used to calculate P/B, depending on the level of data available. Proceeding from most data to least data, the following methods were used:

1. If a population is not in equilibrium, total production P for a given age class over the course of a year can be approximated as ($N_{at} \cdot \Delta W_{at}$), where N_{at} is the number of fish of a given age class in a given year, exponentially averaged to account for mortality throughout the year, and ΔW_{at} is the change in body weight of that age class over that year. For a particular stock, if weight-at-age data existed for multiple years, and stock-assessment reconstructed numbers-at-age were also available, production was calculated by summing this equation over all assessed age classes. Walleye pollock P/B for both the EBS and GOA were calculated using this method: examining the components of this sum over the years showed that numbers-at-age variation was responsible for considerably more variability in overall P/B than was weight-at-age variation.
2. If stock assessment numbers-at-age were available, but a time series of weight-at-age was not available and some weight-at-age data was available, the equation in (1), above, was used, however, the change in body weight over time was estimated using fits to the generalized Von Bertalanffy equations described in the consumption section, above.
3. If no stock assessment of numbers-at-age was available, the population was assumed to be in equilibrium, so that P/B was taken to equal Z. In cases for many nontarget species, estimates of Z were not available so estimates of M were taken from conspecifics with little assumed fishing mortality for this particular calculation.