17. Bering Sea and Aleutian Islands Skates

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Executive Summary

Summary of Major Changes

Changes in assessment methodology:

Last year, in addition to formatting the skate assessment as a stand-alone sub-section of the BSAI Squid and Other species SAFE chapter, we recommended splitting the BSAI skates assemblage into two categories, 'Alaska skate' (*Bathyraja parmifera*) and 'Other Skates'. The goal of these separate management categories is to provide increased protection to rare and endemic skate species in the Other Skates group. A new age-structured stock assessment model has been developed for the Alaska skate, which accounts for over 80% of the total skate biomass across the BSAI management area. The new Alaska skate model was used to prepare management recommendations based on Tier 3 criteria. We also present Tier 5 recommendations for the Alaska skate using two different values of M: the accepted aggregate skate M for the last several years (0.10) and a new estimate specific to the Alaska skate (0.13). We continue to apply the Tier 5 approach using the aggregate M of 0.10 to generate recommendations for the Other Skates group, which contains 14 species and makes up the remaining BSAI skate complex biomass, until new information becomes available.

Changes in the input data:

- Total catch (t) for the BSAI skate assemblage is updated with 2006 and partial 2007 data. Alaska skate catch is estimated from aggregate skate catch using species composition information.
- Biomass estimates from the 2007 EBS shelf survey are incorporated for all species.
- Independent estimates of survey selectivity and catchability have been incorporated into the Alaska skate model.
- Alaska skate length frequencies from survey data are included in the model.
- Alaska skate mean length at age from survey and fishery collections is incorporated into the model.
- Alaska skate life history information (natural mortality, growth, and maturity parameters) has been updated and included in the model.

Changes in assessment results:

We recommend applying Tier 3 criteria to the Alaska skate and Tier 5 criteria to the Other Skates complex, resulting in the following specifications for each management group. Tier 5 specifications for the Alaska skate are also provided for comparison.

		Alaska skate Tier 3 M = 0.13	Alaska skate Tier 5 M = 0.10	Alaska skate Tier 5 M = 0.13	Other Skates Tier 5 M = 0.10
2008	**Projected or avg total biomass (t)**	490,958	417,024	417,024	83,843
	ABC	24,964	31,277	40,660	6,288
	OFL	28,854	41,702	54,213	8,384
2009	**Projected or avg total biomass (t)**	483,291	417,024	417,024	83,843
	ABC	24,570	31,277	40,660	6,288
	OFL	28,399	41,702	54,213	8,384

The proposed FMP amendment to split the Other species complex into groups so that skates can be managed separately has not yet been implemented. This assessment is presented with both separate and combined recommendations for the two proposed skate management groups, so that the BSAI Plan Team and NPFMC SSC can use this information together with recommendations for sharks, sculpins, and octopus to best manage the Other species complex in the interim. We repeat our recommendation from 2006 that the BSAI Skates assemblage be split into "Alaska skates" and "Other skates", and we hope that the enhanced assessment of Alaska skates presented here provides additional support for this recommendation.

In the event the SSC chooses Tier 5 criteria for the Alaska skate, we strongly recommend using last year's default estimate of M=0.10 to estimate ABC and OFL. Increasing M from 0.10 to 0.13 results in a substantial increase (33%, or approximately 10,000 t) from last year's ABC. Because skates are managed with the rest of the Other species complex under a single TAC, such an increase would reduce protection to all the species within this complex, and could encourage the development of directed fisheries. Because we do not yet fully understand skate population dynamics or the effects of directed fishing on species within the Other species complex, we feel it is prudent to use the more conservative estimate of M until such information becomes available.

Responses to SSC Comments

SSC comments specific to the BSAI Skates assessment:

The SSC had a number of comments regarding the new Alaska skate stock assessment model following the October 2007 meeting. We appreciate the SSC's time and consideration of the new Alaska skate model. While we were not able to incorporate all of the suggested changes due to insufficient time, we will make every attempt to include them in next year's assessment. We address each concern below:

The SSC encourages further development of the age-structured model and recommends that the authors consider the following issues in future updates to the model:

1) Run several alternative models that look at plausible lower and upper bounds of historical catch.
Response: The assessment now includes two alternative models using "low" and "high" estimates of historical skate catch, based on the proportional increase in skate survey biomass from 1982-2007.

2) Examine any historical evidence for changes in species composition that may have occurred during the time of rapid increase, as well as the evidence for movement of skates onto the shelf over time, which may imply that a larger proportion of the population was unavailable to the survey in the early 1980s.
Response: Survey species identification is only reliable since 1999, after the period of rapid increase; therefore we are unable to confirm trends in species composition. However we intend to explore the distribution and movement of skates (in aggregate) over the shelf during this time period using survey data. The proportion of aggregate skates in the observed historical non-target catch will also be examined more closely.

3) Examine and show the observed level of variability in species composition in both the catch and the survey over time for the years where data are broken down by species.
Response: Survey estimates of the proportion of Alaska skates on the EBS shelf have remained relatively constant (between 91 and 97% of total skate biomass) since species identification became reliable in 1999. Species identification of the catch has improved significantly since 2004, when fishery observers

were trained to identify skates; however a significant portion (almost half) of the catch remains unidentified. Therefore actual trends in catch species composition may be difficult to discern. We recommend using alternative methods to estimate the proportion of each species in the catch, such as video monitoring.

4) If possible, incorporate an alternative growth model into SS2 that may improve the model fit to the available length-at-age data.
Response: We acknowledge that the von Bertalanffy growth model does not provide the best fit to the length-at-age data and hope to include alternative growth models, such as the Gompertz model, in future assessments.

5) Examine potential problems with aging of older fish (i.e. do they all accumulate in a large size class without further growth and without depositing growth rings in vertebrae).
Response: We plan to examine the effects of underestimating maximum age in future assessments. A preliminary analysis extending the maximum age to 30 years had a minimal effect on the model results.

6) Include a discussion of trophic relationships and other ecosystem relationships for Alaska skate (ecosystem considerations, similar to other assessments), with attention to the main prey and predators (based on available diet data) and including evidence for predation on adult skate.
Response: Diet composition and predation mortality for the Alaska skate are described in the Ecosystem Considerations section of this assessment.

7) The base model is not responsive to the recent increase in the trawl survey biomass apparent since 2001 and further evaluation of possible misspecification should be made.
Response: The decreasing trend in expected survey biomass is likely due to model estimates of reduced recruitment during recent years. Lower recruitment estimates may in turn be the result of the slight decline in the number of small skates observed in the EBS shelf survey from 2000-2007. However, as we develop the model further we expect that we will be able to obtain better agreement between the expected and observed survey biomass estimates.

8) Consider using an average recruitment level, rather than trying to fit a Beverton-Holt model that appears to fit poorly and has issues with strong autocorrelation in the residuals.
Response: We explored the use of a constant average recruitment by fixing the Beverton-Holt steepness parameter at 1 (our only option in SS2). There was little effect on the model results using this approach. We have decided to retain use of the Beverton-Holt model until the model is developed further.

9) Fix Fig A5 to clarify the ages represented on the x-axis.
The observed length-at-age graphs (Figures A5 and A6 in the September 2007 draft) have been modified to show the embryonic development (eggcase) stage in the model.

SSC comments on assessments in general:

There were no SSC comments on assessments in general.

General Introduction

Description, scientific names, and general distribution

Skates (family Rajidae) are cartilaginous fishes which are related to sharks. They are dorso-ventrally depressed animals with large pectoral "wings" attached to the sides of the head, and long, narrow whiplike tails (Figure 17-1). At least 15 species of skates in three genera, *Raja*, *Bathyraja*, and *Amblyraja*, are distributed throughout the eastern North Pacific and are common from shallow inshore waters to very deep benthic habitats (Eschmeyer et al. 1983, Stevenson et al. 2006). Table 17-1 lists the species found in Alaskan waters, with their depth distributions and selected life history characteristics (which are outlined in more detail below).

The species within the skate assemblage occupy different habitats and regions within the BSAI FMP area (Figure 17-2). In this assessment, we distinguish three habitat areas: the EBS shelf (< 200 m depth), the EBS slope (> 200 m depth), and the Aleutian Islands (AI) region (all depths) (Figure 17-3). Within the Eastern Bering Sea (EBS), the skate species composition varies by depth, and species diversity is generally greatest on the upper continental slope (250 to 500 m depth) (Stevenson et al. 2006) (Figure 17-4). The EBS shelf skate complex is dominated by a single species, the Alaska skate (*Bathyraja parmifera*) (Table 17-2, Figure 17-3). The Alaska skate is distributed throughout the EBS shelf habitat area (Figure 17-5), most commonly at depths of 50 to 200 m (Stevenson 2004), and has accounted for between 91% and 97% of aggregate skate biomass estimates since species identification became reliable in 1999. The Bering or sandpaper skate (*B. interrupta*) is the next most common species on the EBS shelf, and is distributed on the outer continental shelf (Figure 17-6).

While skate biomass is much higher on the EBS shelf than on the slope, skate diversity is substantially greater on the EBS slope (Figure 17-3). The dominant species on the EBS slope is the Aleutian skate (*B. aleutica*) (Table 17-2, Figure 17-3). A number of other species are found on the EBS slope in significant numbers, including the Alaska skate, Commander skate (*B. lindbergi*), whiteblotched skate (*B. maculata*), whitebrow skate (*B. minispinosa*), roughtail skate (*B. trachura*), and mud skate (*B. taranetzi*) (Table 17-2). Two rare species, the deepsea skate (*B. abyssicola*) and roughshoulder skate (*Amblyraja badia*), have only recently been reported from EBS slope bottom trawl surveys (Stevenson and Orr 2005). The Okhotsk skate (*B. violacea*) is also occasionally found on the EBS slope.

The skate complex in the AI is quite distinct from the EBS shelf and slope complexes, with different species dominating the biomass, as well as at least one endemic species, the recently described butterfly skate, *Bathyraja mariposa* (Stevenson et al. 2004). In the AI, the most abundant species is the whiteblotched skate, *B. maculata* (Table 17-2, Figure 17-3). The whiteblotched skate is found primarily in the eastern and far western Aleutian Islands (Figure 17-7). Aleutian and Alaska skates are also common in the AI. The mud skate (*B. taranetzi*) is relatively common in the AI but represents a lower proportion of total biomass because of its smaller body size. We note that the common species formerly known as the Alaska skate in the western Aleutians looks very different from the Alaska skate found on the EBS shelf (Figure 17-8). The Aleutian Islands type or "leopard skate" (*Bathyraja* sp. cf. *parmifera*) has been confirmed to be a separate species (J. Orr pers. comm.).

Management units

In the North Pacific, skate species are part of the "Other species" management category within the Bering Sea Aleutian Islands (BSAI) Fishery Management Plan (FMP). Skate catch is reported as "Other" in aggregate with the catch of sharks, sculpins, and octopus. Because catch is officially reported within the Other species complex, estimates of skate catch must be made independently (see Bycatch and discards, below).

In the BSAI, catch of Other species is limited by a Total Allowable Catch (TAC) which is based on an Allowable Biological Catch (ABC) estimated by the NPFMC Scientific and Statistical Committee (SSC). Right now, skates are taken only as bycatch in fisheries directed at target species in the BSAI, so future catches of skates are more dependent on the distribution and limitations placed on target fisheries than on any harvest level established for this category. An FMP amendment was initiated by the NPFMC in 1999 to remove both skates and sharks from the Other species category to increase the level of management attention and control for these potentially vulnerable species groups; this action is still in the process of revision and review. In response to a developing fishery in the GOA, the GOA FMP was amended to remove skates from the Other species category. FMP amendments are being proposed to split the Other species category into component groups in both the BSAI and GOA, and this assessment is written as a stand-alone skate assessment in support of this effort to improve Other species management.

Life history and stock structure (general)

Skate life cycles are similar to sharks, with relatively low fecundity, slow growth to large body sizes, and dependence of population stability on high survival rates of a few well developed offspring (Moyle and Cech 1996). Sharks and skates in general have been classified as “equilibrium” life history strategists (Winemiller and Rose 1992), with very low intrinsic rates of population increase implying that sustainable harvest is possible only at very low to moderate fishing mortality rates (King and McFarlane 2003). Within this general equilibrium life history strategy, there can still be considerable variability between skate species in terms of life history parameters (Walker and Hislop 1998). While smaller sized species have been observed to be somewhat more productive, large skate species with late maturation (11+ years) are most vulnerable to heavy fishing pressure (Walker and Hislop 1998; Frisk et al. 2001; Frisk et al. 2002). The most extreme cases of overexploitation have been reported in the North Atlantic, where the "common" skate *Dipturus batis* has been extirpated from the Irish Sea (Brander 1981) and much of the North Sea (Walker and Hislop 1998), and the barndoor skate *Dipturus laevis* disappeared from much of its range off New England (Casey and Myers 1998). The relative difference in life history traits between smaller and larger skate species has led to apparent population stability for the aggregated “skate” group in many areas where fisheries occur, and this combined with the common practice of managing skate species within aggregate complexes has masked the decline of individual skate species in European fisheries (Dulvy et al. 2000). A similar situation has occurred off the northeast coast of the United States, where skates are managed as a complex and are the subject of skate wing and lobster bait target fisheries; skates are also taken incidentally in other fisheries (NEFSC 2007). Aggregate skate biomass was relatively stable in the 1970s, but has fluctuated since the early 1980s, with apparent shifts in the relative abundance of individual species (NEFSC 2007). Declines in barndoor skate abundance were concurrent with an increase in the biomass of skates as a group (Sosebee 1998). While barndoor skate biomass is now above minimum threshold levels, winter skates (*Leucoraja ocellata*) and thorny skates (*Amblyraja radiata*) have become overfished, and smooth skates (*Malacoraja senta*) and little skates (*Leucoraja erinacea*) are in danger of becoming overfished according to the New England Fishery Management Council’s definitions, requiring immediate action to reduce mortality and initiate rebuilding of overfished stocks (NEFSC 2007 and http://www.nefmc.org/skates/index.html).

Several recent studies have explored the effects of fishing on a variety of skate species in order to determine which life history traits might indicate the most effective management measures for each species. While full age-structured modeling is difficult for many relatively information-poor species, Leslie matrix models parameterized with fecundity, age/size at maturity, and longevity have been applied to identify the life stages most important to population stability. Major life stages include the egg stage, the juvenile stage, and the adult stage (summarized here based on Frisk et al. 2002). All skate species are oviparous (egg-laying), investing considerably more energy per large, well-protected embryo than most commercially exploited teleost groundfish. The large, leathery egg cases incubate for extended periods (several months to over a year) in benthic habitats, exposed to some level of predation and physical damage, until the fully formed juveniles hatch. The juvenile stage lasts from hatching through maturity, several years to over a decade depending on the species. The reproductive adult stage may last several more years to decades depending on the species.

Age and size at maturity and adult size/longevity appear to be more important predictors of resilience to fishing pressure than fecundity or egg survival in the skate populations studied to date. Frisk et al. (2002) estimated that although annual fecundity per female may be on the order of less than 50 eggs per year (extremely low compared with teleost groundfish), there is relatively high survival of eggs due to the high parental investment, and therefore egg survival did not appear to be the most important life history stage contributing to population stability under fishing pressure. Juvenile survival appears to be most important to population stability for most North Sea species studied (Walker and Hislop 1998) and for the small and intermediate sized skates from New England (Frisk et al. 2002). For the large and long-lived barndoor skate, adult survival was the most important contributor to population stability (Frisk et al. 2002). Comparisons of length frequencies for surveyed North Sea skates from the mid and late 1900s led Walker and Hislop (1998, p. 399) to the conclusion that after years of very heavy exploitation "all the breeding females, and a large majority of the juveniles, of *Dipturus batis*, *Leucoraja fullonica* and *R. clavata* have disappeared, whilst the other species have lost only the very largest individuals." Although juvenile and adult survival may have different importance by skate species, all studies found that one metric, adult size, reflected overall sensitivity to fishing. After modeling several New England skate populations, Frisk et al. (2002, p. 582) found "a significant negative, nonlinear association between species total allowable mortality, and species maximum size." This may be an oversimplification of the potential response of skate populations to fishing; in reality it is the interaction of natural mortality, age at maturity, and the selectivity of fisheries which determines a given species' sensitivity to fishing and therefore the total allowable mortality (ABC).

<u>Life history and stock structure (Alaska-specific)</u>

Known life history parameters of Alaskan skate species are presented in Table 17-1. Zeiner and Wolf (1993) determined age at maturity and maximum age for big skates (*Raja binoculata*) and longnose skates (*R. rhina*) from Monterey Bay, CA. The maximum age of CA big skates was 11-12 years, with maturity occurring at 8-11 years; estimates of maximum age for CA longnose skates were 12-13 years, with maturity occurring at 6-9 years. McFarlane and King (2006) recently completed a study of age, growth, and maturation of big and longnose skates in the waters off British Columbia (BC), finding maximum ages of 26 years for both species, much older than the estimates of Zeiner and Wolf. Age at 50% maturity occurs at 6-8 years in BC big skates, and at 7-10 years in BC longnose skates. However, these parameter values may not apply to Alaskan stocks. The AFSC Age and Growth Program has recently reported a maximum observed age of 25 years for the longnose skate in the GOA, significantly higher than that found by Zeiner and Wolf but close to that observed by McFarlane and King (Gburski et al. 2007). In the same study, the maximum observed age for GOA big skates was 15 years, closer to Zeiner and Wolf's results for California big skates. The life histories of these two species are reported in more detail in the GOA skate SAFE (Ormseth and Matta 2007).

Considerable research has been directed at skates in the Bering Sea within the past few years. Graduate students at the University of Washington and California State University (Moss Landing Marine Laboratories) have begun or completed projects detailing aspects of life history and population dynamics of several Bering Sea species. A comprehensive study on the age, growth, and reproductive biology of the Alaska skate, the most common skate species on the eastern Bering Sea shelf, was recently completed (Matta 2006). Life history aspects examined in this study include estimates of maximum age, instantaneous rate of natural mortality (M), length and age at maturity, growth parameters, annual fecundity, and seasonal reproductive timing. Age and size at 50% maturity were 9 years and 92 cm TL for males and 10 years and 93 cm TL for females (Table 17-1). Von Bertalanffy growth parameters were estimated for males (L_∞ = 126.29 cm TL, k = 0.120 year^{-1}, t_0 = -1.39 year) and females (L_∞ = 144.62 cm

TL, k = 0.087 year^{-1}, t_0 = -1.75 year), although length-at-age data were fit slightly better by a Gompertz growth function for both sexes. Based on seasonal reproductive data, including ova diameter, gonadosomatic index (GSI), and the presence of egg cases, the Alaska skate appears to be reproductively active throughout the year. A reproductive resting phase (e.g. 'spent' gonads) was never observed in either large males or females, and females containing egg cases were encountered during each month of collection. Annual fecundity was estimated to average 21 to 37 eggs per year, based on the relationship between annual reproductive effort and natural mortality (Gunderson 1997). While the fecundity estimate should be validated using direct methods, fecundity is still likely to be low for the Alaska skate, as is typical for most elasmobranchs.

Hoff (2007) recently completed a dissertation examining skate reproduction and skate nursery habitat of the Alaska skate and the Aleutian skate from the eastern Bering Sea. The relationships between successful skate reproduction and selected nursery grounds were examined. Vulnerability sources, reproductive cycles, habitat selection criteria, and physical factors controlling reproduction were addressed. To date, six nursery sites for three different skate species have been described in the eastern Bering Sea (Figure 17-9), and there is ample evidence that additional nursery areas exist. All sites are located along the shelf-slope interface in approximately 140-360 m of water. Two sites, those of the Alaska and Aleutian skates, have been studied in detail through seasonal monitoring. An index location at each nursery site was re-sampled approximately once every 60 days from June 2004 through July 2005 for a total of eight sampling periods. During each sampling period data on mortality, reproductive cycles, embryo developmental, species utilization and adult reproductive states were examined.

The Alaska skate nursery is located in 149 meters of water near the shelf-slope interface in a highly productive area of the eastern Bering Sea. The nursery is small in area (< 2 nautical miles), persistent, and highly productive. Density estimates from trawling showed the most active part of the nursery contained >100,000 eggs/km^2. Two peak reproductive periods during summer and winter were evident in the Alaska skate nursery. During each active period the nursery showed high densities of mature reproductive adults and high numbers of newly deposited egg cases. Although there are peak reproductive periods at any single sampling time, the nursery contained embryos in all stages of development, and specific cohorts were easily discernable from frequency stage monitoring. Cohort analysis based on embryo lengths measured at an Alaska skate nursery site in the EBS suggested that the Alaska skate has an eggcase development time of over 3 years, possibly due to the cold ocean temperatures in the EBS (Hoff 2007). Captive studies are currently underway at the Alaska Sealife Center (Seward, AK) to validate this finding, but the field observations are consistent with development times observed in other skate species (Hoff 2007). For example, thorny skate (*Raja radiata*) embryos spend approximately 2.5 years in the eggcase development stage at warmer temperatures than those found in the EBS (Berestovskii 1994 in Hoff 2007).

The Oregon triton *Fusitriton oregonensis* was the most likely predator on newly deposited egg cases and mortality rate was estimated at 3.64%. After hatching, young skates were vulnerable to predation by Pacific cod, *Gadus macrocephalus* and Pacific halibut, *Hippoglossus stenolepis*. Predation by these two large fish species peaked during the summer and winter periods and was highly correlated with hatching events. The Alaska skate nursery site was occupied by mature male and female skates throughout the year, with juvenile and newly hatched individuals extremely rare. Evidence suggests that newly hatched skates quickly move out of the nursery site and immature skates are infrequent visitors to nursery sites. The nursery is located in a highly fished area and is vulnerable to disturbances due to continuous use of the nursery grounds by skates throughout the year. Some degree of intra-species habitat partitioning is evident and is being examined for the Alaska skate throughout the eastern Bering Sea shelf environment.

Researchers at the Pacific Shark Research Center (PSRC), Moss Landing Marine Laboratories (MLML) are currently conducting investigations into aspects of the age, growth, reproduction, demography, and diet of several Alaskan skates. In cooperation with the Alaska Department of Fish and Game and the

AFSC, they have examined more than 5,000 specimens comprising 13 species, including Aleutian skate, Commander skate, whiteblotched skate, whitebrow skate, Alaska skate, roughtail skate, Bering skate, and mud skate (Ebert, 2005). Currently, four graduate students are working towards their Masters degrees with thesis projects on Alaskan skate species. In addition, two other students, Chante Davis (2006) and Heather Robinson (2006), have recently completed their respective thesis research on two skate species (roughtail skate and longnose skate) that occur in Alaskan waters. Although their studies were conducted outside of Alaskan waters, their findings represent new and original information on the life history of these two skate species.

Age determination and validation studies are currently ongoing at the PSRC to obtain essential information on the age at maturity, growth rates and longevity of seven Alaskan skate species: Aleutian skate, Commander skate, whiteblotched skate, whitebrow skate, roughtail skate, Bering skate, and mud skate. Theoretical longevity and indirect estimates of natural morality will be calculated from the resulting growth parameters. Additionally, the suitability of caudal thorns as an alternative ageing structure is being investigated, potentially providing a valuable, non-lethal ageing technique for this group. Preliminary estimates of maximum ages for Aleutian and Bering skates are 17 and 13 years, respectively (Ebert et al. 2007). Age validation remains to be completed for these species (D. Ebert, PSRC, pers. comm.). Additional age and growth studies are currently being conducted by Jasmine Fry (mud skate), and Shaara Ainsley (whitebrow skate) for their thesis research.

Reproductive studies are also currently ongoing at the PSRC to obtain information on the size at maturity, seasonality, and fecundity of several Alaskan skate species. The reproductive biology of the Aleutian skate, Bering skate, big skate, and longnose skate has been investigated as part of a NPRB funded study to assess life history characteristics of Alaskan skate species (Ebert et al. 2007). Median length at maturity (cm TL) was estimated to be 124.4 for the Aleutian skate, 70.2 for the Bering skate, 148.6 for the big skate, and 113.1 for the longnose skate (Ebert et al. 2007). Reproductive studies are also being conducted on mud and whitebrow skates by graduate students affiliated with the PSRC.

The PSRC has also conducted demographic analyses to improve understanding of the population dynamics and vulnerability of these species to fisheries exploitation. Preliminary estimates of annual population growth rates are 25% for the Aleutian skate, 36% for the Bering skate, 33% for the big skate, and 20% for the longnose skate (Ebert et al. 2007). Other demographic parameters have also been estimated for these species (Ebert et al. 2007). Information generated from this project will be incorporated into a life history data matrix (LHDM) developed by the PSRC for eastern North Pacific chondrichthyans; the most recent version of the LHDM is currently available via the worldwide web (http://psrc.mlml.calstate.edu/).

Fishery

Directed fishery

In the BSAI, there is no directed fishery for skates at present; however, skates support directed fisheries in other parts of the world (Agnew et al. 1999, NE stock assessment 1999, Martin and Zorzi 1993). A directed skate fishery developed in the Gulf of Alaska in 2003 (Gaichas et al. 2003). There has been interest in developing markets for skates in Alaska (J. Bang and S. Bolton, Alaska Fishworks Inc., 11 March 2002 personal communication), and the resource was economically valuable to the GOA participants in 2003, although the price apparently dropped in 2004. Nevertheless, we should expect continued interest in skates as a potential future target fishery in the BSAI as well as in the GOA.

Bycatch and discards

Skate catch in the BSAI is officially reported as "Other" in aggregate with the catch of sharks, sculpins, and octopus, and thus estimates of skate catch must be made independently for each year using observer data, shoreside processor landings data, and processor weekly production report data. In 2003 the Alaska Regional Office (AKRO) converted to the Catch Accounting System (CAS), an improvement over the previous "Blend" system. However, at present the CAS is only capable of reporting aggregate skate catch in the BSAI; species composition of the catch can only be inferred from the observed portion of the catch or from survey species composition (see Data section below). The CAS data are continuously updated and checked for errors by AKRO; the CAS estimates reported here represent the best and most accurate data available.

Skates constitute the bulk of the Other species FMP category catches, accounting for between 51% and 75% of the estimated totals in 1992-2006 (Table 17-3). While skates are caught in almost all fisheries and areas of the Bering Sea shelf, most of the skate bycatch is in the hook and line fishery for Pacific cod, with trawl fisheries for pollock, rock sole, flathead sole, and yellowfin sole also catching significant amounts (Tables 17-4 and 17-5). In this assessment, "bycatch" means incidental or unintentional catch regardless of the disposition of catch – it can be either retained or discarded. We do not use the Magnuson Act definition of "bycatch," which always implies discard. When caught as bycatch, skates may be discarded (and may survive depending upon catch handling practices) although skates caught incidentally are sometimes retained and processed. Due to incomplete observer coverage, it is difficult to determine how many skates are actually retained. However, between 24% and 39% of the total observed skate catch was retained during the years 2003-2006 (Table 17-6). More skates were retained in the EBS than the AI, and it appears that species that grow to a larger maximum size (>100 cm TL) are more likely to be retained than smaller-bodied species. For example, while the Aleutian skate, a large-bodied species, made up a relatively small portion of the observed skate catch in 2005 (approximately 2%), 31% of the Aleutian skates caught were retained. However, Bering skates (a small-bodied species less than 100 cm TL) were retained less frequently (10% in 2005). Larger percentages of Alaska skates and *Raja* species (big and longnose skates) are also retained; all three are relatively large-bodied skates.

Historically, skates were almost always recorded as "skate unidentified", with very few exceptions between 1990 and 2002. However, due to improvements in species identification by fishery observers initiated by Dr. Duane Stevenson (AFSC) within the Observer program in 2003, we can estimate the species composition of observed skate catches 2004-2006 (Figure 17-10). Recent observer data indicates that only about 50% of skate catch is not identified to the species level. This is largely because most skates are caught in longline fisheries, and if the animal drops off the longline as unretained incidental catch, it cannot be identified to species by the observer (approximately 80% of longline-caught skates are unidentified, and longline catch accounts for the majority of observed skate catch).

In 2005, observers were encouraged to identify skates dropped off longlines to genus, which can be done without retaining the skate; hence in 2005 more than half of the unidentified skates were at least assigned to the genus *Bathyraja*. Of the identified skates, the majority (90%) were Alaska skates, as would be expected by their dominance in terms of overall skate biomass in the BSAI. The next most commonly identified species BSAI-wide was Aleutian skate, at 6.6% of identified catch, followed by Bering skates at 4.3 %, big skates at 3.6%, and whiteblotched at approximately 1.3% across the BSAI. It should be noted that the observed skate catch composition may not reflect the true catch composition, possibly due to selective retention of larger species or to a higher likelihood of identifying distinctive species. However, when viewed by area (EBS vs. AI), it is clear that the majority of identified Aleutian and whiteblotched skates are caught in AI fisheries, and that the species composition of the observed catch in the AI is very different from the EBS (Figure 17-10).

Reporting areas encompassing the EBS outer shelf and upper continental slope experienced high catch rates during 2003-2005 (Figure 17-11). Longline fisheries targeting Pacific cod take much of the incidental skate catch, and they tend to operate on the outer EBS shelf and slope where skate species diversity is high and where Aleutian skates are more prevalent than Alaska skates. Therefore it is possible that the species composition of the catch is not in proportion to the overall species composition (from survey data) across the BSAI. However, depth analysis of the observed catch demonstrates that most of the skate catch occurs <200m (98%). More work is needed to determine the actual species composition of the catch.

ALASKA SKATE – Tier 3 assessment

Data

Survey biomass

Three bottom trawl surveys are conducted in the BSAI region: EBS shelf, EBS slope, and the Aleutian Islands. Because the Alaska skate population is concentrated on the EBS shelf, and the EBS shelf survey provides yearly estimates of biomass, we used biomass data from only the EBS shelf survey in this assessment. Recent (1999-2007) survey information on species composition is used to describe the relative proportion of the Alaska skate to all other skate species ("Other Skates") within each of three areas, the EBS shelf, the EBS slope, and the Aleutian Islands (Figure 17-12). Biomass estimates from 1992 through 2007 were utilized in the Alaska skate stock assessment base model (Table 17-7). For each survey prior to 1999, total skate biomass estimates were partitioned into Alaska skate and Other Skates based on the average proportion of each group in each area from 1999-2007. The model employs the standard deviation (*s*) associated with each estimate, which as calculated using the equation: $\ln(1 + CV)$, where CV is the standard error of the observation divided by the value of the observation (Methot 2007). For the estimates prior to 1999, *s* was approximated.

Survey length composition

Total length (TL) data were collected for skate species during recent EBS shelf bottom trawl surveys. Alaska skate length compositions from 2000-2007 trawl survey data are shown in Figure 17-13 and Table 17-8. In the assessment model, size data were aggregated into 5 cm length bins and treated separately by year.

Total catch

Commercial catches of BSAI skates are reported FMP area-wide in aggregate with sculpins, octopus, and squid. Independent estimates of BSAI skate catch from 1992-2007 were made by the Blend system and AKRO CAS as described earlier. For the base model, catches were broken down by habitat area (EBS shelf, EBS slope, and AI) and by fishery gear type from 1992-2007 (Table 17-9). Total skate catch estimates for the EBS and AI are available since 1997; the average proportion of the skate catch in both of these areas (94% EBS and 6% AI) was assumed to remain constant prior to 1997 in order to reconstruct the area-specific catch. Catch is not estimated separately for the EBS shelf and EBS slope habitat areas by Blend or CAS; therefore a proxy based on fishery observer depth data was developed. The observed total skate catch from 2003-2006 in the EBS was partitioned by depth in order to approximate the proportion of the catch occurring in each of the two EBS habitat areas; catches less than 200 m were considered to occur on the EBS shelf (about 98%) and catches deeper than 200 m were considered to occur on the EBS slope (about 2%). The average area-specific species compositions from the 1999-2007 bottom trawl surveys (Figure 17-12) were utilized to further partition the catch into Alaska skates and Other Skates. Two major fishery gear types with different size selectivities for skates operate in the BSAI management area: trawlers and longliners. (Pot gear also accounts for a minor portion of the skate catch (<0.1%) and was considered negligible for the purposes of this assessment.) The proportion of the catch by each fishery gear type differs by habitat area; for years without gear type data, the average proportion of each gear type from 2003 to 2005 was applied (Figure 17-14). The results were then totaled to obtain the total Alaska skate catch for each fishery across the entire BSAI management area, which was incorporated into the model (Table 17-9).

Catch length composition

Length data for the Alaska skate were collected as a special project by fishery observers aboard trawl and longline vessels operating in the EBS in 2007. Observers were requested to randomly sample up to 20 skates in one set per week during the study period. Length data were aggregated into 5 cm bins for incorporation into the stock assessment model (Figure 17-15, Table 17-10).

Length at age

Mean length at age data were obtained from Matta (2006). Age was determined through examination of annual growth rings in vertebral thin sections. Two sample sets were included in the model; one from the 2003 EBS shelf survey (n=182; Figure 17-16) and one from the 2005 longline fishery (n=208; Figure 17-17). An additional sample set was collected in 2004, but it was not included in the analysis because it was very small and came from mixed (fishery dependent and fishery independent) sources.

Because all age sample sizes were small and were sometimes collected opportunistically, we chose not to create age compositions from the data to avoid introducing additional bias into the model.

Analytical approach

Model structure

The Stock Synthesis 2 (SS2) assessment program[1] (Methot 2005, 2007) was used to develop an age-structured population model of Alaska skates. SS2 allows the flexibility to incorporate both age-and size-structured information in the model. In the model described here, natural mortality is the only parameter that is explicitly age-based; selectivity, maturity, and mean body weight are length-based parameters. Length-at-age data and estimates of ageing error are used by SS2 to convert the size-based information into age-specific values that can be used to model the population through time.

SS2 is comprised of three submodels. A population submodel captures the dynamics of an age-structured population and an observation model specifies likelihood components for comparing model predictions to observed data. A statistical model incorporates those components and others into an objective function that SS2 uses to maximize the overall likelihood by altering the parameters that govern the population dynamics model. SS2 also contains a forecasting routine that specifies fishery management targets and projects the population into the future, but we used an alternative projection model that was designed exclusively for use in Alaska fisheries by Jim Ianelli (AFSC, NMFS). The structure of SS2 is explained in detail elsewhere (Methot 1990, 2005, 2007), and we offer here only a limited explanation of the model structure.

The population dynamics model is depicted schematically in Figure 17-18. Briefly, unfished recruitment and M determine the age structure of an unfished population. The unfished age structure is then modified by M and equilibrium catch to produce an initial age structure. For each subsequent year in the model, individuals are added through recruitment and subtracted through M and catch. The level of recruitment in each year results from estimates of spawning biomass in the previous year and the parameters of the Beverton-Holt stock-recruit curve. In all cases, catch is modified by fishery selectivity at length. For Alaska skates, the observation submodel includes three likelihood components based on model fits to observed data: EBS shelf survey biomass, length compositions from the shelf survey and each of the fisheries, and mean length at age. An additional likelihood component compares the deviations in recruitment to the standard deviation of recruitment, which is fixed in this model. The objective function

[1] NOAA Fisheries Toolbox Version 2.10, 2006. Stock Synthesis 2, Version 2.00g, Richard Methot, Northwest Fisheries Science Center, Seattle, WA. [Internet address: http://nft/nefsc.noaa.gov]

combines these four components to calculate overall likelihood. Weighting of individual likelihood components was not performed in this model.

Our assessment model resembles teleost groundfish models in many ways, but we made some changes to incorporate life history features unique to elasmobranchs. All skate species have an extended embryonic period during which they develop within protective eggcases on the seafloor. As described earlier, the Alaska skate appears to have an eggcase development period of over 3 years. We assigned the first three age classes of Alaska skates (ages 0-2) to an embryonic period where growth differed from older age classes and individuals were not available to either the fishery or survey. Thus, free-swimming skates in their first year were considered to be three years old. This allowed us to more accurately model skate population dynamics and ensured that characteristics of the spawning population would correspond to the appropriate year class. In addition, we considered the equilibrium life history strategy in specifying recruitment parameters and evaluating our model results.

We developed a “base” model, starting in 1992 and assuming an equilibrium level of catch equal to 1992 catch levels. We also considered two alternative models starting in 1958, simulating high and low catch scenarios. These models both incorporated the entire historical catch record and assumed zero catch prior to the model start date.

All three models included a number of simplifications and assumptions. The entire BSAI was treated as one homogenous area. Because growth and maturity patterns are similar for males and females, we specified only one sex. Spawning was assumed to occur at the midpoint of the year, and fecundity (in terms of eggs/kilogram) was assumed to scale directly with female spawning biomass. SS2 has the capability for assigning Bayesian priors, but we treated all parameters as either fixed or estimated conditionally using only starting values and bounds. We also assumed that parameters did not vary with season or year and were not influenced by environmental conditions. All parameters used in the final (base) model are listed in Table 17-11 and described in more detail below.

Parameters Estimated Independently:

M

As in previous skate SAFEs, natural mortality (M) was estimated based on other life history parameters. Several methods were employed based on correlations of M with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Rikhter and Efanov 1976, Roff 1986). For the Alaska skate, life history parameters used to derive M were obtained from Matta (2006). The methods described above were used to obtain estimates of M, in addition to new two methods based on the relationship between M and k (Jensen 1996, Gunderson 2003) and between M and age at maturity (Jensen 1996); the way in which these methods were employed are described in further detail in Matta (2006). The value of M used in the SS2 model was conservatively set to the lowest value obtained from all methods combined (M=0.13, Table 17-12).

Length at maturity

SS2 incorporates female maturity parameters into the model using the following equation:

$$\text{Proportion Mature} = \frac{1}{1+e^{b(L-L_{50})}},$$

where L_{50} is the length at 50% maturity and b is a slope parameter. Maturity parameters were obtained from Matta (2006), where b = -0.548 and L_{50} = 93.28 cm TL (Figure 17-19). Maturity was estimated directly from paired length and maturity stage data; maturity stage was easily assessed through macroscopic examination of the reproductive organs.

Ageing error

Each vertebra was aged three independent times by a primary age reader without knowledge of the specimen's biological information. For each true age, the standard deviation of the estimated age was calculated from the three reads of each vertebra and incorporated into the model to account for variability in age determination.

Survey catchability

EBS shelf survey catchability (Q) was fixed at 0.836. Two factors were considered in making this decision. Alaska skates are very abundant over the shelf and less so on the EBS slope and in the AI, so the shelf survey should adequately sample their spatial distribution. However, empirical evidence suggests that the capture probability of a combined *Bathyraja* species group in the shelf bottom survey is highly length-dependent with a maximum value of 0.846 for the largest skates (Kotwicki and Weinberg 2005). Because the greatest observed length of Alaska skate (125 cm) is less than the maximum size of skates in Kotwicki and Weinberg's study (133 cm), we rescaled their length-based capture probability equation to obtain a maximum capture probability of 0.836 for the Alaska skate. We fixed Q at the maximum capture probability and then adjusted the shelf-survey size-selectivity parameters (see below) so that the value of (Q) * (size-selectivity) approximated the empirical estimates of size-based capture probability (Kotwicki and Weinberg 2005; Figure 17-20).

Selectivity

We constructed the model so that fishery and survey selectivity were based on size. The fisheries and surveys were assumed to have knife-edged age selectivity beginning at age 3: embryos had a selectivity of 0 and ages ≥ 3 were selected based on length. Size selectivity was governed by a double-normal function defined by six parameters for each fishery or survey, where p1 was the peak or ascending inflection size, p2 was the width of the plateau, p3 was the ascending width, p4 was the descending width, p5 was the selectivity at the first length bin, and p6 was the selectivity at the last length bin. For the longline fishery, selectivity at the last length bin was fixed to be asymptotic and the remaining parameters were estimated conditionally. Prior to adding the 2007 survey length composition data, only the selectivity at the smallest size bin (p5) was fixed for the trawl fishery, and the model produced reasonable estimates of trawl fishery selectivity. However, adding the trawl survey data resulted in an unrealistic pattern of selectivity in the trawl fishery, including an abrupt spike in selectivity and a higher probability of large skates being selected than expected. Therefore, all trawl fishery selectivity parameters were fixed at the original estimates. All parameters for the shelf survey were fixed so that survey catchability and selectivity corresponded to the independent analysis of shelf trawl survey behavior described above (Kotwicki and Weinberg 2005).

Weight at length

Parameters from the allometric length-weight relationship ($W = a\mathrm{TL}^{b}$, where W is weight in kg and TL is total length in cm) were obtained from Matta (2006) for the Alaska skate. For sexes combined, *a* was estimated as 4.01×10^{-6} and *b* was estimated as 3.149 (n = 526) (Figure 17-21).

<u>Parameters Estimated Conditionally:</u>

Growth parameters

The form of the von Bertalanffy growth equation (LVB) used in SS2 is:

$$L_A = L_\infty + (L_1 - L_\infty)e^{-k(A-A_1)},$$

where L_A is the mean length at age A, A_1 is a reference age near the youngest age well represented in the data, L_1 is the mean length at age A_1, k is the von Bertalanffy growth coefficient, and L_∞ is the mean asymptotic length, calculated from the equation:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-k(A_2-A_1)}},$$

where A_2 is a reference age near the oldest age well represented in the data, and L_2 is the mean length at age A_2. The reference ages A_1 and A_2 were set to 3 and 18 years, respectively, because these ages were frequently observed and captured nearly the entire age range of the Alaska skate. The remaining growth parameters L_1, L_2, and k were estimated within the model.

Spawner-recruit parameters

A Beverton-Holt function was used to describe the spawner-recruit relationship of the Alaska skate. Recruitment deviations were included in the model to account for variability between years but were constrained to a minimal level, consistent with an equilibrium life history strategy. The virgin level of recruitment (R_0) and the steepness (h) of the stock-recruitment function were freely estimated within the model, while the standard deviation of log recruitment (σ^R) was fixed at 0.1.

Initial fishing mortality

Initial fishing mortality was estimated within the base model for each of the two fisheries.

Model Evaluation

Alternative models

Because historical data on Alaska skates are sparse, we used only recent information in our base model. However we also wanted to explore the effects of including all available data and tracing the development of skate catch history in the BSAI. Due to the uncertainty involved in estimation of the Alaska skate proportion of the historic catch, two alternative models were created: one with a high catch scenario and one with a low catch scenario. Both alternatives include the earliest reported catches (1958) and EBS shelf survey data dating to 1982. Recent catch data (1992-2007) were identical to the base model in both alternatives.

Alternative model data

Catch data from 1954-1991 were obtained from the summary chapter of the 2006 BSAI SAFE report. We were not able to establish the provenance of all these data, but they appear to be a combination of domestic and foreign observer data as well as early U.S. and Japanese reports on commercial harvests. Due to the lack of detailed skate catch information, we had to make a number of assumptions in estimating Alaska skate catch. Prior to 1992, catches of all non-target species were reported in aggregate separately for the EBS and AI. Two catch histories were generated based on different assumptions regarding the proportion of skates in the reported non-target catch:

1) "High catch" model: For the "high catch" model, the historic proportion of all skates in the non-target catch was assumed to be the same as the 2003-2007 proportion of skates in BSAI non-target catches (EBS = 0.497, AI = 0.198). The species composition of the total skate catch was assumed to be equal to the species composition of EBS shelf and AI bottom trawl survey catches from 1999-2007 (Alaska skate = 95% and 27%, respectively).

2) "Low catch" model: The low catch history was designed to account for the large increase in total skate biomass during the 1980s according to EBS shelf survey estimates. The general approach was to use relative changes in survey biomass from 1982-1991 to correct the 2003-2007 total skate catch proportion used for all years in the "high catch" model. The average total skate survey biomass from 1982-1985 was compared to the average total skate survey biomass from 1991-2007. The resulting proportion (0.412) was applied to the total skate proportion in the 2003-2007 nontarget catch to estimate total skate catch from 1958-1985. From 1986 to 1991, there was a rapid increase in total skate survey biomass estimates. For each of these years, the survey biomass estimate for that year was divided by the average 1991-2007 biomass, and the resulting proportion was multiplied by the 2003-2007 total skate catch proportion. For 1991, the total skate proportion was assumed to be equal to the 2003-2007 value. Because we had no data indicating otherwise, we assumed that the proportion of total skates in the AI non-target catch was identical to the 2003-2007 value. As was the case for the "high catch" model, the proportion of Alaska skates in the total skate catch was assumed to be equal to the composition of EBS and AI bottom trawl survey catches from 1999-2007 (Alaska skate = 95% and 27%, respectively).

To allocate the total Alaska skate catch between longline and trawl gears, we assumed that the amount of skates captured by each gear was proportional to the relative proportion of Pacific cod longline catch to yellowfin sole trawl catch. These two fisheries are the dominant sources of Alaska skate catch in the BSAI. The actual longline/trawl ratio was known for catches from 1992-2006, and was used to create a correction factor that was applied to historical Pacific cod longline/yellowfin sole ratios to estimate longline and trawl catches from 1958-1991 (Table 17-13 and Figure 17-22). Estimates of Alaska skate biomass from the EBS shelf survey from 1982-1991 were included in both alternative models (Table 17-7).

Alternative model parameter changes

Independent and conditional parameters used in the alternative models were identical to the base model with the following exceptions: the recruitment steepness parameter (h) was fixed at the value estimated in the base model (0.48); σ^R was fixed at a higher level (0.3) to allow for greater variability in recruitment; initial fishing mortality and equilibrium catch were set equal to 0.

Model evaluation criteria

We evaluated each model based on the following criteria:

1) Model fit to survey biomass estimates.
2) Model fit to length compositions and length-at-age data.
3) Reasonable estimates of fishery selectivity parameters.
4) Reasonable estimates of virgin recruitment, recruitment variability and the Beverton-Holt steepness parameter.
5) Likelihood profile analysis of assumed values for M, Q, and σ^R.

Evaluation of the model and final model selection

Base model

1) The expected survey biomass produced by the base model provided a reasonable fit to the observed biomass (Figure 17-23). The model does predict a declining trend in survey biomass, whereas observed values seem to be increasing. However, in all but the three most recent years, model estimates were within the 95% confidence intervals of the observed biomass estimates. Declines in expected survey biomass, total BSAI Alaska skate biomass (Figure 17-24), and spawning biomass (Figure 17-25) are likely due to reduced recruitment during recent years.

Lower recruitment estimates may in turn be the result of the slight decline in the number of small skates observed in the EBS shelf survey from 2000-2007 (Figure 17-13).

2) The model provided adequate fits to the length composition data from the EBS shelf survey (Figure 17-26) and both fisheries (Figure 17-27). The model fit the observed length-at-age data reasonably well (Figure 17-28). Independent analysis (Matta 2006) suggests that Alaska skate growth is better described by a Gompertz model than by the LVB, which is a fixed feature of SS2. This discrepancy may have prevented the model from fitting the length-at-age data more closely.
3) Estimates of selectivity parameters (Table 17-11) and selectivity at length (Figure 17-29) for the longline fishery were reasonable. Longline fisheries selected larger skates, which is consistent with larger skates having greater ability to prey on large baited circle hooks. Prior to addition of 2007 survey length data, the estimated trawl selectivity suggested that small skates are fully selected by trawl fisheries but that larger skates are caught in relatively fewer numbers. We felt this was a realistic selectivity pattern for the following reasons: 1) flatfish trawl fisheries in the EBS are increasingly using halibut excluder devices, which may lower the capture probability of larger skates and 2) differences in the spatial distribution of trawl fisheries and large Alaska skates. The highest CPUEs in the yellowfin sole fishery occur over the middle shelf (Fritz et al. 1998). Alaska skates greater than 93 cm in length are concentrated over the outer shelf (Figure 17-30), while individuals between 30 and 93 cm are found over the middle shelf (Figure 17-31; Hoff 2007). Therefore, the reduced selectivity for large Alaska skates in the trawl fisheries may result from the fact that the largest skates are not spatially available to trawl fisheries. Addition of the 2007 survey length data resulted in a sharp spike in fishery selectivity and a higher probability of large skates being selected by the gear than expected given the distribution of adult Alaska skates. We therefore fixed the trawl fishery selectivity parameters at the values estimated prior to the data addition. The change in behavior of the model after adding the survey length composition data could be the result of disparities between fishery and survey data effective N, a phenomenon which we intend to investigate in future model iterations.
4) The base model estimate of unfished recruitment was consistent with the amount of spawning biomass and our limited knowledge of skate fecundity. We did not have skate-specific recruitment information with which to evaluate recruitment variability. We anticipated that skates, which are equilibrium life-history strategists, would have low levels of recruitment variability and fixed the values of σ^R accordingly. The estimated levels of recruitment variability (Figures 17-32 and 17-33) were higher than expected but still seem reasonable for this population. Similarly, we were unable to find information regarding reasonable steepness parameters for skates. However, the value of 0.44 estimated in the model is within the range of steepness estimates for teleost equilibrium strategists (Myers et al. 1999) and is similar to a fixed value of 0.4 used in a recent assessment of longnose skates (*Raja rhina*) off the west coast of the United States (Vladlena Gertseva, Oregon State University, personal communication, 2007).
5) To evaluate our independently estimated values for the parameters M, Q and σ^R, we created likelihood profiles by individually varying the fixed value of each parameter while monitoring the overall likelihood of the model and the effect on the Beverton-Holt steepness parameter (Figure 17-34). Varying M had the greatest effect of the three parameters on the objective function of the model, and our chosen value of 0.13 resulted in a relatively low likelihood. For lower values of M, the steepness parameter became too high to be realistically possible for an equilibrium strategist, while higher values of M produced increasingly worse model fits to the observed survey biomass. Varying Q and σ^R did not appear to have a strong effect on overall likelihood, and our chosen values for each of these parameters yielded reasonable steepness parameter values.

1958 models

1) The expected survey biomass produced by both 1958 models fit the observed values reasonably well, and the fit in recent years (1992 and later) was similar to the base model (Figure 17-35). The model overestimated survey biomass in the earliest years, likely because it was unable to account for the rapid increase in survey biomass during the late 1980s.
2) Fits to the length composition data were identical for both 1958 models and were similar to those from the base model.
3) Selectivity estimates were identical to the base model.
4) Both 1958 model estimates of unfished recruitment were similar to the base model estimates (Figure 17-36), although the “low catch” model produced the lowest R_0 value of all three models. Estimates of recruitment variability and the steepness parameter were problematic for the alternative models. To account for the steep rise in biomass observed in the shelf survey, extremely high recruitments were estimated during the early 1980s. Furthermore, these large recruitment events occurred at a time when spawning biomass was low (Figure 17-36). Therefore, in model runs where the steepness parameter was freely estimated within the model, a value of 1 was estimated (which corresponds to constant recruitment at all levels of spawning stock biomass). For the final 1958 model runs the steepness parameter was fixed so that it matched the base model, but the resulting estimates of recruitment variability were still unrealistically large. The “low catch” model estimated a lower unfished biomass than the “high catch” model (Figure 17-37), as well as lower levels of recruitment throughout the modeled time period.
5) Likelihood profile analysis was not performed for the 1958 models.

Final model selection

We chose to use the base model for the following reasons:

1) Our evaluation indicated that the base model was biologically realistic and provided reasonable fits to the observed data.
2) We felt that the 1958 models were unrealistic in their estimates of recruitment variability and the steepness parameter. This is likely due to the rapid increase in survey biomass during the late 1980s. The methods used in the EBS shelf survey have been standardized since 1982 and biomass estimates since that year are generally considered to be reliable. However, we are unable to explain the rapid increase in biomass observed in a species that, to the best of our knowledge, is an equilibrium strategist and therefore should have a low population growth rate. We feel that data prior to 1992 should not be included in Alaska skate assessment models until more information regarding this event becomes available.

Results

Definitions

Results shown here are from the base model only. Biomass is shown as total biomass (metric tons; t) of all Alaska skates in the population, and as female spawning biomass (t). Recruitment is reported as the number (in thousands of fish) of Alaska skates at age 0. As described above, this corresponds to the number of viable embryos deposited in egg cases. Fishing mortality is reported as the fully-selected, instantaneous fishing mortality rate.

Biomass time series

Time series of total biomass and spawning biomass base model estimates from 1992-2007 are reported in Table 17-14 and in Figures 17-24 and 17-25, respectively. These estimates suggest that total skate biomass has been declining in the BSAI since the mid-1990s and that spawning biomass has been declining since approximately the year 2000.

Recruitment

Time series of recruitment is reported in Table 17-14 and Figure 17-32, and the relationship between spawning biomass and recruitment is shown in Figure 17-33. The model estimated that recruitment was particularly high during the years 1998-2000 but has since declined. As discussed in the model evaluation section, we are unsure if this level of recruitment variability is realistic for an equilibrium strategist.

Exploitation and fishing mortality

A time series of exploitation (catch/total biomass) is given in Table 17-15. Figure 17-38 shows fishing mortality relative to spawning stock biomass, F_{OFL}, and maximum allowable F_{ABC}. These results indicate that current and historical catches of Alaska skates are below the maximum F_{ABC}.

Projections and Harvest Alternatives

Reference points and tier assignment

This assessment provides us with reliable estimates of B_0, $B_{40\%}$, and the fishing mortality rates corresponding to $F_{40\%}$ and $F_{35\%}$. Therefore, management recommendations are made under Tier 3 of the BSAI Groundfish Fishery Management Plan. Using Tier 3, ABC and OFL are set according to the following criteria:

3a) Stock status: $B/B_{40\%} > 1$
$F_{OFL} = F_{35\%}$
$F_{ABC} \leq F_{40\%}$
3b) Stock status: $0.05 < B/B_{40\%} < 1$
$F_{OFL} = F_{35\%}$ H $(B/B_{40\%} - 0.05) \times 1/0.95$
$F_{ABC} < F_{40\%}$ H $(B/B_{40\%} - 0.05) \times 1/0.95$
3c) Stock status: B/B40% < 0.05
$F_{OFL} = 0$
$F_{ABC} = 0$

Specification of OFL and maximum allowable ABC

Values for this section, including estimates of equilibrium catch, spawning biomass, and fishing mortality are given in Table 17-16. The 2008 estimate of spawning biomass for BSAI Alaska skates is 92,852 t. The estimate of B40% is 60,292 t, so B/B40% is 1.54 and 2008 Alaska skate harvest levels can be assigned according to subtier 3a. Therefore, F_{OFL} is 0.076 and maximum F_{ABC} is 0.066. The corresponding 2008 OFL is 28,854 t and maximum allowable ABC is 24,964 t. Specifications for 2009 are given in Table 17-16.

Tier 5 estimates of ABC for BSAI Alaska skates are assessment, described in further detail below, are 31,277 t using M=0.1 and 40,660 t using M=0.13. The Tier 3 estimate thus represents a 20.2% decrease from Tier 5 using M=0.10 and a 38.7% decrease from Tier 5 using M=0.13.

Recommended ABC for 2008

This assessment is the first exploration of Alaska skate population dynamics using an age-structured model and provides a more realistic analysis of the Alaska skate population in the BSAI than Tier 5. Because of this, and due to the sensitivity of elasmobranchs to fishing pressure, we recommend choosing the most conservative ABC of 24,964 t (Tier 3).

Harvest Scenarios

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). Projections of catch levels, spawning biomass, and fishing mortality to 2020 under each of these harvest scenarios are given in Tables 17-17 – 17-22.

For each scenario, the projections begin with the vector of 2007 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2008 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2007. 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 2008, are as follows ("*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} (Table 17-17). (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 2006 recommended in the assessment to the *max* F_{ABC} for 2006 (Table 17-17). (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} (Table 17-18). (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 2003-2007 average F (Table 17-19). (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 (Table 17-20). (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 follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, F is set equal to F_{OFL} (Table 17-21). (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in

2008 or 2) above ½ of its MSY level in 2008 and above its MSY level in 2018 under this scenario, then the stock is not overfished.)

Scenario 7: In 2008 and 2009, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL} (Table 17-22). (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2020 under this scenario, then the stock is not approaching an overfished condition.)

The estimated BMSY (here $B_{35\%}$) for Alaska skates is 52,755 t. Under scenario 6, Alaska skate biomass is projected to be 92,852 t in 2008 and 63,653 t in 2018. Therefore, the Alaska skate population in the BSAI is not overfished under the MSFCMA. For scenario 7, Alaska skate biomass is projected to be 60,739 t in 2020 and Alaska skates are not approaching an overfished condition.

ALASKA SKATE and OTHER SKATES – Tier 5 assessment

Data

Survey biomass

The biomass of the skate assemblage as a whole has shown an increasing trend from 1975-2007 (Table 17-23, Figure 17-39). Because skates as a group are found in nearly all habitats, the uncertainty (measured as the coefficient of variation, CV) in aggregate skate biomass estimates is rather low, but that for individual species is more variable (Table 17-2). Survey species identification became reliable in 1999. Unfortunately, due to taxonomic uncertainty, we cannot evaluate individual species trends within the complex for surveys prior to 1999. Recent surveys demonstrate the variable species composition of the skate complex within each of the three habitat areas, the EBS shelf, the EBS slope, and the Aleutian Islands (Figure 17-3). The Alaska skate (*B. parmifera*) is dominant and highly abundant on the EBS shelf, while in each of the other two habitat areas, the skate species composition is far more diverse, especially on the EBS slope (Table 17-2). The average survey biomass of the two proposed management groups, 'Alaska skate' and 'Other Skates', from 1999 – 2007 was used to generate specifications.

Analytic Approach and Results

Parameters estimated independently: M

As in previous years, M was estimated based on other life history parameters. Several methods were employed based on correlations of M with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Rikhter and Efanov 1976, Roff 1986). Natural mortality was estimated using life history parameters from California big skate (*Raja binoculata*) and longnose skate (*R. rhina*) (Zeiner and Wolf 1993), which are found in the GOA but are rare in the BSAI. We also estimated M for big and longnose skates from British Columbia and the Gulf of Alaska based on two new life history studies (McFarlane and King 2006, Gburski et al. 2007). These latest estimates of M have not been applied to this year's assessment since they have yet to undergo review by the SSC; however they have been included here to demonstrate their availability for future assessments. The new estimates of M are close to the estimate of M=0.10 derived from CA big and longnose skates, which has been accepted by the Plan Team and the SSC as a reasonable approximation of "aggregate skate" M for the Other Skates group. Considering the uncertainty inherent in applying this method to the multi-species Other Skates group, we elected to use the lowest estimate of M (M=0.10, Table 17-24), which results in conservative estimates of ABC and OFL under Tier 5 criteria. Until better information is available on the productivity of individual skate species in the BSAI Other Skates group, we recommend this strategy in the interim in order to promote skate conservation while still allowing for historical levels of incidental catch in target groundfish fisheries.

Alaska skate natural mortality was derived using the methods described above in conjunction with newly available species-specific life history parameters (Table 17-12). These methods are described in more detail in the Tier 3 Alaska skate assessment section. The lowest Alaska skate mortality rate of M=0.13 was applied to obtain estimates of ABC and OFL using Tier 5 methodology. The default multi-species estimate of M=0.10 was also applied to Alaska skate biomass estimates using Tier 5 for comparison.

Projections and Harvest Alternatives

Acceptable Biological Catch and Overfishing Limit

We recommend that a Tier 5 approach be applied to the Other Skate species complex if the catch remains incidental and no target fishery develops. Tier 5 is recommended because reliable estimates of biomass exists, and M =0.10 is considered a reasonable approximation of "aggregate skate" M by the Plan Team and SSC. We note that though the proxy M was applied to all species, it was based on relatively sensitive skate species. Therefore it is likely an underestimate of M for more productive species, which results in conservative specifications.

Tier 5 specifications for the Alaska skate are also shown here for comparison with the specifications generated from the single-species population model described earlier in this assessment. In addition to the default multi-species M=0.10 from last year's assessment, a new estimate of M=0.13 has been used to generate the Tier 5 ABC and OFL. This new estimate of M, based on Alaska skate life history parameters, has been reviewed and accepted by the Plan Team and the SSC as a reasonable approximation of natural mortality for this species. Biomass estimates for both the Alaska skate and the Other Skates group were used from years when research survey species identification is considered most reliable (1999-2007).

Tier 6 is not recommended because the catch history for skates is not considered reliable (reported as "Other species"), and average catch for untargeted species is likely to constrain target fisheries if used to specify harvest limits. For the Tier 5 estimate, we recommend using a 9 year average of skate biomass so that we may include multiple estimates from each of the trawl surveys, while capturing recent biomass levels.

	Alaska skate			Other Skates		
Survey Year	EBS shelf	EBS slope	AI	EBS shelf	EBS slope	AI
1999	315,536			32,941		
2000	300,954		9,801	24,338		19,518
2001	402,909			17,405		
2002	347,873	35,932	10,662	18,441	33,344	23,752
2003	354,244			32,095		
2004	402,354	4,248	12,727	14,205	28,909	40,344
2005	461,067			20,127		
2006	424,511		13,484	18,045		40,726
2007	457,941			17,083		
average	**385,265**	**20,090**	**11,669**	**21,631**	**31,127**	**31,085**

Alaska skate ABC

Applying the new Alaska skate-specific M estimate of 0.13 to the 9 year average of bottom trawl survey biomass estimates, we calculate an ABC of 0.75 * 0.13 * (EBS shelf biomass of 385,265 t + EBS slope biomass of 20,090 t + AI biomass of 11,669 t) = 0.0975 * 417,024 t = **40,660 t**.

Applying the default multi-species M estimate of 0.10 to the 9 year average of bottom trawl survey biomass estimates, we calculate an ABC of 0.75 * 0.10 * (EBS shelf biomass of 385,265 t + EBS slope biomass of 20,090 t + AI biomass of 11,669 t) = 0.075 * 417,024 t = **31,277 t**.

Alaska skate OFL

Applying the new Alaska skate-specific M estimate of 0.13 to the 9 year average of bottom trawl survey biomass estimates, we calculate an OFL of 0.13 * (EBS shelf biomass of 385,265 t + EBS slope biomass of 20,090 t + AI biomass of 11,669 t) = 0.13 * 417,024 t = **54,213 t**.

Applying the default multi-species M estimate of 0.10 to the 9 year average of bottom trawl survey biomass estimates, we calculate an OFL of 0.10 * (EBS shelf biomass of 385,265 t + EBS slope biomass of 20,090 t + AI biomass of 11,669 t) = 0.1* 417,024 = **41,702 t**.

Other Skates ABC

Applying the M estimate of 0.10 to the 9 year average of bottom trawl survey biomass estimates, we calculate an ABC of 0.75 * 0.10 * (EBS shelf biomass of 21,631 t + EBS slope biomass of 31,127 t + AI biomass of 31,085 t) = 0.075 * 83,843 t = **6,288 t**.

Other Skates OFL

Applying the M estimate of 0.10 to the 9 year average of bottom trawl survey biomass estimates, we calculate an OFL of 0.10 * (EBS shelf biomass of 21,631 t + EBS slope biomass of 31,127 t + AI biomass of 31,085 t) = 0.1 * 83,843 t = **8,384 t**.

In the event the SSC chooses Tier 5 criteria for the Alaska skate, we strongly recommend using last year's default estimate of M=0.10 to generate specifications. Increasing M from 0.10 to 0.13 results in a substantial increase (32%, or approximately 10,000 t) from last year's ABC. Because skates are managed with the rest of the Other species complex under a single TAC, such an increase would reduce protection to all the species within this complex, and could encourage the development of directed fisheries. Because we do not yet fully understand skate population dynamics or the effects of directed fishing on species within the Other species complex, we feel it is prudent to use the more conservative estimate of M until such information becomes available.

Assemblage analysis and recommendations

Because skates represent a potentially valuable fishery resource as well as a potentially sensitive species group, we recommend that they be managed separately from the BSAI Other species complex. There is a reliable biomass time series for the skate assemblage as a whole in both the EBS and AI, and recently (since 1999) there are also reliable estimates of biomass for each species within the assemblage.

We further recommend splitting the Alaska skate (*Bathyraja parmifera*) from the BSAI skate assemblage to form two management groups: Alaska skate and 'Other Skates'. The purpose of separate recommendations is to provide increased protection to rare or endemic species in the EBS slope and AI habitat areas, since the Alaska skate constitutes the bulk of the skate biomass in the EBS shelf habitat area. We have shown that the distribution of species differs greatly by habitat areas within the BSAI, and that overall catch is not necessarily in proportion to BSAI-wide biomass due to the distribution of fishing effort. Because it would be difficult to manage skates by habitat area, managing Alaska skates and the Other Skates complex separately represents a reasonable compromise which increases protection to the species within each ecosystem but maintains a level of management simplicity appropriate to nontarget species complexes. In the event that target fisheries develop for individual skate species in the Other Skates complex, we would recommend that target skate species be further separated from the complex and managed individually. Furthermore, directed fishing for skates in the BSAI should only be allowed when sufficient life history information becomes available to make reasonable species-specific estimates of productivity.

Ecosystem Considerations

This section focuses on the Alaska skate in both the EBS and AI, with all other species found in each area summarized within in the group "Other Skates." We also include supplemental information on the other biomass dominant species in the AI, the Aleutian and whiteblotched skates. This level of aggregation is necessary due to current data constraints, but improved species-specific information will be incorporated as it becomes available.

Skates are predators in the BSAI FMP area. Some species are piscivorous while others specialize in benthic invertebrates; additionally, at least three species, deepsea skate, roughtail skate, and longnose skate, are benthophagic during the juvenile stage but become piscivorous as they grow larger (Ebert 2003, Robinson 2006) (Table 17-1). Each skate species would occupy a slightly different position in EBS and AI food webs based upon its feeding habits, but in general skates as a group are predators at a relatively high trophic level. For simplicity, we show the food webs for all skate species combined in each system (Figure 17-40; EBS in upper panel, AI in lower panel). In the EBS food web, the skate biomass and therefore the general skate food web position is dominated by the Alaska skate, which eats primarily pollock (as do most other piscivorous animals in the EBS). The food web indicates that aside from sperm whales, most of the "predators" of EBS skates are fisheries, and that cod and halibut are both predators and prey of skates. The AI food web shows skates with different predators and prey than in the EBS, but still at the same moderately high trophic level. Relative to EBS skates, AI skates display more diet diversity (because the species complex is more diverse than in the Alaska skate-dominated EBS), and have more non-fishery predators including sharks and sea lions. These food webs were derived from mass balance ecosystem models assembling information on the food habits, biomass, productivity and consumption for all major living components in each system (Aydin et al. in review).

The density and mortality patterns for skates also differ greatly between the EBS and AI ecosystems. The biomass density of Alaska skates is much higher in the EBS than in the AI (Figure 17-42 upper left panel) and we now know they are likely separate species between the areas as well. The density of Alaska skates in the EBS also far exceeds that of all other *Bathyraja* species in any area (Figure 17-42 upper right panel), but the density of other *Bathyraja* skates is highest in the AI. One simple way to evaluate ecosystem (predation) effects relative to fishing effects is to measure the proportions of overall mortality attributable to each source. The lower panels of Figure 17-42 distinguish predation from fishing mortality, and further distinguish these measured sources of mortality from sources that are not explained within the ecosystem models, which are based on early 1990s fishing and food habits information. While there are many uncertainties in estimating these mortality rates, the results suggest that (early 1990s) fishing mortality exceeded predation mortality for Alaska skates and for Other Skates in the EBS and AI (and for Other Skates in the GOA as well). Furthermore, predation mortality appeared to be higher for AI skates than for EBS skates, both for Alaska and Other Skate species in the early 1990s, suggesting that skates experience higher overall mortality in the AI relative to the EBS. One source of uncertainty in these results is that all skate species in all areas were assumed to have the same total mortality rate, which is an oversimplification, but one which is consistent with the assumptions regarding natural mortality rate (the same for all skate species) in this stock assessment. We expect to improve on these default assumptions as data on productivity and catch for the skate species in each area continue to improve.

In terms of annual tons removed, it is instructive to compare fishery catches with predator consumption of skates. We estimate that fisheries were annually removing about 13,000 and 1,000 tons of skates from the EBS and AI, respectively on average during the early 1990s (Fritz 1996, 1997). While estimates of predator consumption of skates are perhaps more uncertain than catch estimates, the ecosystem models incorporate uncertainty in partitioning estimated consumption of skates between their major predators in each system. The predators with the highest overall consumption of Alaska skates in the EBS are sperm whales, which account for less than 2% of total skate mortality and consumed between 500 and 2,500 tons of skates annually in the early 1990s. Consumption of EBS Alaska skates by Pacific halibut and cod are too small to be reliably estimated (Figure 17-42, left panels). Similarly, sperm whales account for less than 2% of Other Skate mortality in the EBS, but are still the primary predator of Other Skates there, consuming an estimated 50 to 400 tons annually. Pacific halibut consume very small amounts of Other Skates in the EBS, according to early 1990s information integrated in ecosystem models (Figure 17-42, right panels). The predators with the highest consumption of Alaska skates in the AI are also sperm whales, which account for less than 2% of total skate mortality and consumed between 20 and 120 tons of skates annually in the early 1990s. Pinnipeds (Steller sea lions) and sharks also contributed to Alaska skate mortality in the AI, averaging less than 50 tons annually (Figure 17-43, left panels). Similarly, sperm whales account for less than 2% of Other Skate mortality in the AI, but are still the primary predator of Other Skates there, consuming an estimated 20 to 150 tons annually. Pinnipeds and sharks consume very small amounts of Other Skates in the AI, according to early 1990s information (Figure 17-43, right panels). Gerald Hoff's research on skate nursery areas suggests that gastropod predation on skate egg cases may account for a significant portion of mortality during the embryonic stage, and Pacific cod and Pacific halibut consume substantial numbers of newly hatched juvenile skates within nursery areas. These sources of mortality may be included in future stock assessments.

Diets of skates are derived from food habits collections taken in conjunction with EBS and AI trawl surveys. Skate food habits information is more complete for the EBS than for the AI, but we present the best available data for both systems here. Over 40% of EBS Alaska skate diet measured in the early 1990s was adult pollock, and another 15% of the diet was fishery offal, suggesting that Alaska skates are opportunistic piscivores (Figure 17-44, upper left panel). Eelpouts, rock soles, sandlance, arrowtooth flounder, salmon, and sculpins made up another 25-30% of Alaska skates' diet, and invertebrate prey made up the remainder of their diet. This diet composition combined with estimated consumption rates and the high biomass of Alaska skates in the EBS results in an annual consumption estimate of 200,000 to 350,000 tons of pollock annually (Figure 17-44, lower left panel). EBS Other Skates also consume pollock (45% of combined diets), but their lower biomass results in consumption estimates ranging from 20,000 to 70,000 tons of pollock annually (Figure 17-44, right panels). Other Skates tend to consume more invertebrates than Alaska skates in the EBS, so estimates of benthic epifaunal consumption due to Other Skates range up to 50,000 tons annually, higher than those for Alaska skates despite the disparity in biomass between the groups (Figure 17-44, lower panels). Because Alaska skates and all Other Skates are distributed differently in the EBS, with Alaska skates dominating the shallow shelf areas and the more diverse species complex located on the outer shelf and slope, we might expect different ecosystem relationships for skates in these habitats based on differences in food habits among the species. Similarly, in the AI the unique skate complex has different diet compositions and consumption estimates from those estimated for EBS skates. The skate in the AI formerly known as the Alaska skate is opportunistically piscivorous like its EBS relative, feeding on the common commercial forage fish, Atka mackerel (65% of diet) and pollock (14% of diet), as well as fishery offal (7% of diet; Figure 17-45 upper left panel). Diets of Other Skates in the AI are more dominated by benthic invertebrates, especially shrimp (pandalid and non-pandalid total 42% of diet), but include more pelagic prey such as juvenile pollock, adult Atka mackerel, adult pollock and squids (totaling 45% of diet; Figure 17-45 upper right panel). Estimated annual consumption of Atka mackerel by AI (former) Alaska skates in the early 1990s ranged from 7,000 to 15,000 tons, while pollock consumption was below 5,000 tons (Figure 17-45 lower left panel). Shrimp consumption by AI Other Skates was estimated to range from 4,000 to 15,000 tons annually in the early 1990s, and consumption of pollock ranged from 2,000 to 10,000 tons (Figure 17-45 lower right panel). Atka mackerel consumption by AI Other Skates was estimated to be below 5,000 tons annually. The diet composition estimated for AI Other Skates is likely dominated by the biomass dominant species in that system, whiteblotched skate and Aleutian skate. The diet compositions of both Aleutian and whiteblotched skates in the AI appear to be fairly diverse (Figure 17-46), and are described in further detail in Yang (2007) along with the diets of big skate, Bering skate, Alaska skate, roughtail skate, and mud skate in the AI. In the future, we hope to use diet compositions to make separate consumption estimates for whiteblotched and Aleutian skates along with (former) Alaska skates in the AI.

Examining the trophic relationships of EBS and AI skates provides a context for assessing fishery interactions beyond the direct effect of bycatch mortality. In both areas, the biomass-dominant species of skates feed on commercially important fish species, so it is important for fisheries management to maintain the health of pollock and Atka mackerel stocks in particular to maintain the forage base for skates (as well as for other predators and for human commercial interests).

Data gaps and research priorities

Aggregate skate and Alaska skate catches have been estimated using several different methods with a number of inherent assumptions. We used species composition from recent surveys to partition the Alaska skate catch; however there are two caveats involved with this approach: 1) we assume species composition has remained constant since 1958, and 2) we assume that survey species composition is representative of the catch species composition. Aggregate skate catch records can mask shifts in species composition, and fishing gear may be more selective for larger-bodied species. Species identification by fishery observers has vastly improved in recent years; however it is still difficult to make accurate identifications in the longline fishery, as many skates are dropped off the line without being brought on board. Mounted video camera systems may be a cost-effective way to determine the species composition of the catch in the future.

In the Alaska skate model, we assumed a catch rate with 100% mortality. In reality, skate mortality is dependent upon the time spent out of water, the type of gear, and handling practices after capture. From fishery observer data, approximately 30% of skates are retained; however we currently have no information regarding the survival of skates that are discarded at sea.

Very few biomass indices are available from the Bering Sea slope survey. The Bering Sea slope habitat area has very high skate species diversity, yet there are only two years of survey data from this area where species identification can be considered reliable (2002 and 2004). Continuation of the Bering Sea slope survey, at least in alternate years, would help to identify overall trends in skate abundance as well as potential shifts in the relative species composition there.

We have initiated a tagging program to gather information regarding movement, distribution patterns, and growth of the Alaska skate. We expect to deploy approximately 4,000 tags during RACE surveys in summer 2008 and 2009, and an additional 1,000 tags during other surveys or research cruises.

Fecundity is a very difficult quantity to measure in skates, as individuals of some species may reproduce throughout the year and thus the number of mature or maturing eggs present in the ovary may represent only a fraction of the annual reproductive output. Matta (2006) estimated the average fecundity of the Alaska skate to range between 21 and 37 eggs per female per year, based on the assumed relationship between reproductive potential and M (Gunderson 1997). However, due to the uncertainty involved with this parameter, fecundity estimates were not included in the stock assessment model. Fecundity estimates for other skate species range from 48 to 150 young per year (Holden et al. 1971; Holden 1975; Luer & Gilbert 1985; Ellis & Shackley 1995), and it is conceivable that the Alaska skate also has very low annual fecundity. Additional work, such as laboratory rearing experiments, is needed to validate these estimates.

Skate habitat is only beginning to be described in detail. Adults appear capable of significant mobility in response to general habitat changes, but any effects on the small scale nursery habitats crucial to reproduction could have disproportionate population effects. Eggs are mostly limited to isolated nursery grounds, and juveniles use different habitats than adults. Changes in these habitats have not been monitored historically, so assessments of habitat quality and its trends are not currently available. We recommend continued study of skate nursery areas to evaluate their importance to population production.

Because skates are at a relatively high trophic level in the EBS and AI, predation mortality is less significant than fishing mortality for adult skates. Therefore, the assessment of skate population dynamics and response to fishing should be continued and improved as fishing represents the largest explained source of mortality in the EBS and AI (especially since this mortality is not from targeted fishing, but from incidental catch). Highest priority research should continue to focus on direct fishing effects on skate populations. The most important component of this research is to fully evaluate the productive capacity of skate populations, including information on age and growth, maturity, fecundity, and habitat associations. This research has been initiated for major skate species in the EBS and AI, and some results have already become available. Such research should be fully funded to completion.

Juvenile skates and skate egg cases are likely to much more vulnerable to predation and disturbance than adults. Gerald Hoff's (AFSC) work on skate nursery areas, described in the life history section of this assessment, suggests the egg case and neonate life history stages are susceptible to predation by snails and some groundfish. Differences between life history stages in terms of predation and effects of trawling on nursery areas have not been examined in population or ecosystem models.

The PSRC (MLML) has recently received funding from the North Pacific Research Board (NPRB) to examine the feeding habits of Aleutian, Bering, big, and longnose skates. Simon Brown, a graduate student, is currently working on this project. Specific objectives are to: 1) determine the diets of Alaskan skate species through analysis of stomach contents, 2) examine temporal, ontogenetic, and intergender differences in diet for each species, 3) investigate aspects of foraging habitat and trophic relationships for each species, and 4) compare interspecific diets of these Alaskan skate species to determine degree of dietary overlap. The results of this study will provide basic biological information on skates for inclusion in multi-species and predator/prey models.

We do not see any conflict at present between commercial fishing and skate foraging on pollock or Atka mackerel, but we do recommend continued monitoring of skate populations and food habits at appropriate spatial scales to ensure that these trophic relationships remain intact as fishing for these commercial forage species continues and evolves.

Ecosystem Effects on Stock and Fishery Effects on the Ecosystem: Summary

In the following table, we summarize ecosystem considerations for BSAI skates and the entire groundfish fishery where they are caught incidentally. Because there is no "skate fishery" in the EBS or AI at present, we attempt to evaluate the ecosystem effects of skate bycatch from the combined groundfish fisheries operating in these areas in the second portion of the summary table. The observation column represents the best attempt to summarize the past, present, and foreseeable future trends. The interpretation column provides details on how ecosystem trends might affect the stock (ecosystem effects on the stock) or how the fishery trend affects the ecosystem (fishery effects on the ecosystem). The evaluation column indicates whether the trend is of *no concern, probably no concern, possible concern, definite concern,* or *unknown.*

Ecosystem effects on BSAI Skates ***(evaluating level of concern for skate populations)***

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Pollock	Increasing to steady population currently at a high biomass level	Adequate forage available for piscivorous skates	No concern
Atka mackerel	Cyclically varying population with slight upward trend overall 1977-2005	Adequate forage available for piscivorous skates	No concern
Shrimp/ Benthic invertebrates	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Predator population trends			
Sperm whales	Populations recovering from whaling?	Possibly higher mortality on skates? But still a very small proportion of mortality	No concern
Steller sea lions	Declined from 1960s, low but level recently	Lower mortality on skates?	No concern
Sharks	Population trends unknown	Unknown	Unknown
Changes in habitat quality			
Benthic ranging from shallow shelf to deep slope, isolated nursery areas in specific locations	Skate habitat is only beginning to be described in detail. Adults appear adaptable and mobile in response to habitat changes. Eggs are limited to isolated nursery grounds and juveniles use different habitats than adults. Changes in these habitats have not been monitored historically, so assessments of habitat quality and its trends are not currently available.	Continue study on small nursery areas to evaluate importance to population production	Possible concern if nursery grounds are disturbed or degraded.

Groundfish fishery effects on ecosystem via skate bycatch *(evaluating level of concern for ecosystem)*			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Skate catch	Varies from 12,000 to 23,000 tons annually	Largest portion of total mortality for skates	Possible concern
Forage availability	Skates have few predators, and skates are small proportion of diets for their predators	Fishery removal of skates has a small effect on predators	Probably no concern
Fishery concentration in space and time			
	Skate bycatch is spread throughout FMP areas, although higher proportion of skate bycatch occurs on outer continental shelf and upper slope	Potential impact to skate populations if fishery disturbs nursery or other important habitat, but small effect on skate predators	Possible concern for skates, probably no concern for skate predators
Fishery effects on amount of large size target fish			
	Survey length compositions (2000-2007) suggest that large size classes of Alaska skates appear to be stable	Fishery removals do not appear to have an effect on size structure	Probably no concern
Fishery contribution to discards and offal production			
	Skate discard a relatively high proportion of skate catch, some incidentally caught skates are retained and processed	Unclear whether discard of skates has ecosystem effect	Unknown
Fishery effects on age-at-maturity and fecundity			
	Skate age at maturity and fecundity are just now being described; fishery effects on them difficult to determine due to lack of unfished population to compare with	Unknown	Unknown

Summary

Recommendations	Alaska skate	Alaska skate	Alaska skate	Other Skates
M	0.13	0.10	0.13	0.10
Tier	3	5	5	5
Projected Total Biomass or 9 Year Avg Biomass	490,958	417,024	417,024	83,843
F_{OFL}	0.076	0.10	0.13	0.10
Max F_{ABC}	0.066	0.075	0.0975	0.075
Recommended F_{ABC}	0.066	0.075	0.0975	0.075
OFL	28,854	41,702	54,213	8,384
Max ABC	24,964	31,277	40,660	6,288
Recommended ABC	24,964	31,277	40,660	6,288
Projected Total Biomass or 9 Year Avg Biomass	483,291	417,024	417,024	83,843
F_{OFL}	0.076	0.10	0.13	0.10
Max F_{ABC}	0.066	0.075	0.0975	0.0975
Recommended F_{ABC}	0.066	0.075	0.0975	0.0975
OFL	28,399	41,702	54,213	8,384
Max ABC	24,570	31,277	40,660	6,288
Recommended ABC	24,570	31,277	40,660	6,288

Acknowledgements

Many thanks to the following for their valuable contributions to this document: Bob Lauth, Mark Wilkins, and others in the AFSC RACE program for providing survey biomass estimates, the North Pacific Groundfish Observer Program for their hard work in the field and compiling data, and the Alaska Regional Office for making nontarget species catch estimates available. Jim Ianelli provided the projection model. Rick Methot, Grant Thompson, Anne Hollowed, Vladlena Gertseva, and Martin Dorn provided invaluable advice on how to tackle creating a brand new assessment using SS2. Sarah Gaichas provided a helpful review of an earlier draft. Thank you!!

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Tables

Table 17-1. Life history and depth distribution information available for BSAI and GOA skate species, from Stevenson (2004) unless otherwise noted.

Species	Common name	Max obs. length (TL cm)	Max obs. age	Age, length Mature (50%)	Feeding mode [2]	N embryos/ egg case [1]	Depth range (m) [9]
Bathyraja abyssicola	deepsea skate	135 (M) [10] 157 (F) [11]	?	110 cm (M) [11] 145 cm (F) [13]	benthophagic; predatory [11]	1 [13]	362-2904
Bathyraja aleutica	Aleutian skate	150 (M) 154 (F) [12]	14 [6]	121 cm (M) 133 cm (F) [12]	predatory	1	15-1602
Bathyraja interrupta	Bering skate (complex?)	83 (M) 82 (F) [12]	19 [6]	67 cm (M) 70 cm (F) [12]	benthophagic	1	26-1050
Bathyraja lindbergi	Commander skate	97 (M) 97 (F) [12]	?	78 cm (M) 85 cm (F) [12]	?	1	126-1193
Bathyraja maculata	whiteblotched skate	120	?	94 cm (M) 99 cm (F) [12]	predatory	1	73-1193
Bathyraja mariposa [3]	butterfly skate	76	?	?	?	1	90-448
Bathyraja minispinosa	whitebrow skate	83[10]	?	70 cm (M) 66 cm (F) [12]	benthophagic	1	150-1420
Bathyraja parmifera	Alaska skate	118 (M) 119 (F) [4]	15 (M) 17 (F) [4]	9 yrs, 92cm (M) 10 yrs, 93cm(F) [4]	predatory	1	17-392
Bathyraja sp. cf. *parmifera*	“Leopard” parmifera	133 (M) 139 (F)	?	?	predatory	?	48-396
Bathyraja taranetzi	mud skate	67 (M) 77 (F) [12]	?	56 cm (M) 63 cm (F) [12]	predatory [13]	1	58-1054
Bathyraja trachura	roughtail skate	91 (M) [14] 89 (F) [11]	20 (M) 17 (F) [14]	13 yrs, 76 cm (M) 14 yrs, 74 cm (F)[14, 12]	benthophagic; predatory [11]	1	213-2550
Bathyraja violacea	Okhotsk skate	73	?	?	benthophagic	1	124-510
Amblyraja badia	roughshoulder skate	95 (M) 99 (F) [11]	?	93 cm (M) [11]	predatory [11]	1 [13]	1061-2322
Raja binoculata	big skate	244	15 [5]	6-8 yrs, 72-90 cm [7]	predatory [8]	1-7	16-402
Raja rhina	longnose skate	180	25 [5]	7-10 yrs, 65-83 cm [7]	benthophagic; predatory [15]	1	9-1069

[1] Eschemeyer 1983. [2] Orlov 1998 & 1999 (Benthophagic eats mainly amphipods, worms. Predatory diet primarily fish, cephalopods). [3] Stevenson et al. 2004. [4] Matta 2006. [5] Gburski et al. 2007. [6] Gburski unpub data. [7] McFarlane & King 2006. [8] Wakefield 1984. [9] Stevenson et al. 2006. [10] Mecklenberg et al. 2002. [11] Ebert 2003. [12] Ebert 2005. [13] Ebert unpub data. [14] Davis 2006. [15] Robinson 2006.

Table 17-2. Species composition of the EBS and AI skate complexes from the most recent AFSC bottom trawl surveys.

Skate species	Common name	2007 EBS shelf bio (t)	cv	2004 EBS slope bio (t)	cv	2006 Aleutians bio (t)	cv
Bathyraja abyssicola	deepsea	0		164	0.73	0	
Bathyraja aleutica	Aleutian	2,718	0.43	14,987	0.14	6,684	0.23
Bathyraja interrupta	Bering	9,327	0.14	1,953	0.11	186	0.55
Bathyraja lindbergi	Commander	0		4,194	0.15	0	
Bathyraja maculata	whiteblotched	3,234	0.92	3,450	0.16	29,712	0.19
Bathyraja minispinosa	whitebrow	0		1,755	0.20	0	
Bathyraja parmifera	Alaska	457,941	0.07	4,248	0.33	13,484	0.19
Bathyraja taranetzi	mud	0		702	0.20	2,970	0.28
Bathyraja trachura	roughtail	0		1,677	0.12	0	
Bathyraja violacea	Okhotsk	0		8	1.00	0	
Raja binoculata	big	1,804	0.76	0		568	0.72
Raja rhina	longnose	0		0		0	
Rajidae unid	Unidentified skate species	0		19	0.54	605	0.41
Total skate complex		**475,024**	**0.07**	**33,156**	**0.08**	**54,210**	**0.12**

Table 17-3. Time series of BSAI Other species ABC, TAC, OFL and catch (t), with skate catch proportion.

Year	Other species ABC	Other species TAC	Other species OFL	Other species catch	BSAI skate catch	Skate % of Other species catch
1991	28,700	15,000		17,199		
1992	27,200	20,000	27,200	33,075	16,962	51%
1993		22,610		23,851	12,226	51%
1994	27,500	26,390	141,000	24,555	14,223	58%
1995	27,600	20,000	136,000	22,213	14,892	67%
1996	27,600	20,125	137,000	21,440	12,643	59%
1997	25,800	25,800		25,176	17,747	70%
1998	25,800	25,800	134,000	25,531	19,318	76%
1999	32,860	32,860	129,000	20,562	14,080	68%
2000	31,360	31,360	71,500	26,108	18,877	72%
2001	33,600	26,500	69,000	27,178	20,570	76%
2002	39,100	30,825	78,900	28,619	21,279	74%
2003	43,300	32,309	81,100	26,150	19,419	74%
2004	46,810	27,205	81,150	29,637	22,462	76%
2005	53,860	29,000	87,920	29,505	22,982	78%
2006	58,882	29,000	89,404	26,798	19,992	75%
2007	68,800	37,355	91,700	*22,786	*15,680	*69%

Sources: Other species ABC, TAC, OFL and 1992-2002 Other species catch from AKRO website.
BSAI skate catch 1992-1996 from Fritz 1996, 1997, 1997-2002 from Gaichas et al. 2004.
2003-2007 Other species and BSAI skate catch from AKRO CAS. *2007 data current as of 10/5/2007.

Table 17-4. Estimated catch (t) of all skate species combined by target fishery, gear, and area, 1997-2002. Source: Gaichas AFSC.

Target fishery	**gear**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Arrowtooth	hook n line		0.65	9.72	1.31		0.49
	trawl	1.62	117.64	17.74	43.02	89.98	81.55
Arrowtooth Total		1.62	118.29	27.46	44.33	89.98	82.04
Atka mackerel	trawl	110.51	130.81	126.66	71.50	80.57	73.30
Flatheadsole	trawl	777.22	1,867.59	1,215.15	1,655.80	1,752.36	1,530.37
Other	hook n line		10.42	26.07	52.48	70.43	31.17
	trawl						8.82
Other Total			10.42	26.07	52.48	70.43	39.98
OtherFlats	trawl	39.18	103.15	69.22	115.16	20.09	58.48
Pacific cod	hook n line	13,298.81	13,534.64	9,651.09	12,975.65	14,116.58	14,059.10
	pot	1.50	0.01	0.11	0.06	0.10	0.00
	trawl	715.23	770.48	984.30	1,053.86	631.91	1,400.41
Pacific cod Total		14,015.53	14,305.12	10,635.50	14,029.56	14,748.59	15,459.51
Pollock	trawl	349.73	405.67	375.87	598.19	627.58	807.04
Rock sole	trawl	679.20	558.69	322.21	334.28	820.60	836.61
Rockfish	hook n line	110.27	6.73	0.69	1.70	4.42	0.84
	trawl	30.05	39.94	53.61	50.53	47.67	78.14
Rockfish Total		140.32	46.67	54.30	52.23	52.09	78.99
Sablefish	hook n line	266.00	110.10	109.54	115.86	194.11	233.13
	pot			0.09	0.01	0.06	0.01
	trawl		0.06			1.24	
Sablefish Total		266.00	110.16	109.63	115.87	195.41	233.14
Turbot	hook n line	140.82	280.84	319.92	317.36	187.07	120.80
	pot			1.22			
	trawl	16.13	18.67	17.34	23.92	16.66	7.76
Turbot Total		156.95	299.51	338.48	341.28	203.73	128.57
Unknown	hook n line	0.11	2.00	1.16	0.95	0.21	
	trawl		1.09		0.01	0.11	
Unknown Total		0.11	3.09	1.16	0.95	0.32	
Yellowfinsole	trawl	1,210.99	1,358.70	778.11	1,464.90	1,908.69	1,950.67
Grand Total		17,747.37	19,317.86	14,079.84	18,876.53	20,570.46	21,278.69

FMP area	**area**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
AI	541	569.98	640.25	462.61	501.96	540.77	288.88
	542	200.87	369.17	239.96	608.31	422.64	217.74
	543	86.30	119.02	99.79	698.20	1,546.14	188.84
AI Total		857.15	1,128.45	802.36	1,808.47	2,509.56	695.46
EBS	509	1,920.87	2,317.12	2,033.62	2,830.27	3,092.09	3,112.51
	512	0.92		14.33		91.68	132.82
	513	2,572.53	2,605.18	1,993.53	2,641.56	2,726.15	4,036.76
	514	134.61	40.86	203.65	101.55	83.42	223.02
	516	74.26	73.35	199.06	122.64	249.95	336.13
	517	3,499.07	4,820.64	3,514.42	4,910.51	4,378.18	4,394.10
	518	49.00	82.65	80.14	52.09	101.80	65.00
	519	42.69	106.07	57.86	83.01	96.52	68.93
	521	7,066.94	7,205.81	4,420.95	5,724.41	6,517.25	7,327.22
	523	548.85	455.37	404.81	284.01	324.73	314.50
	524	980.48	482.36	355.11	318.01	399.14	572.23
EBS Total		16,890.22	18,189.41	13,277.48	17,068.06	18,060.90	20,583.23
BSAI Total		17,747.37	19,317.86	14,079.84	18,876.53	20,570.46	21,278.69

Table 17-5. Estimated catch (t) of all skate species combined by target fishery and reporting area 2003-2007. Source: AKRO CAS. *2007 data complete as of October 5, 2007.

Region	Target	2003	2004	2005	2006	2007
EBS	Atka mackerel	20	35	22	8	26
	Cod	14,954	18,000	18,975	14,459	10,492
	Flatfish	3,085	2,613	2,546	3,219	3,287
	Pollock	471	843	731	1,306	1,039
	Rockfish	11	6	4	3	4
	Sablefish	2	2	2	13	10
	Other	220	91	25	27	52
EBS Total		18,764	21,591	22,305	19,034	14,910
AI	Atka mackerel	74	108	118	133	86
	Cod	200	486	406	417	464
	Flatfish	254	247	100	188	111
	Pollock	0	0	0	<1	<1
	Rockfish	61	16	26	22	69
	Sablefish	55	8	24	108	27
	Other	11	6	3	89	13
AI Total		655	871	677	958	770
BSAI Total		19,419	22,462	22,982	19,992	15,680

Region	Reporting Area	2003	2004	2005	2006	2007
EBS	508	0	<1	0	0	0
	509	2,009	2,170	3,226	3,335	3,455
	512	25	205	15	0	0
	513	2,785	2,883	4,007	2,663	2,080
	514	281	67	196	221	402
	516	132	417	239	252	393
	517	3,038	3,046	3,656	2,389	1,356
	518	25	7	3	8	1
	519	199	139	103	65	82
	521	8,948	10,310	8,467	8,334	5,799
	523	307	323	244	279	301
	524	1,016	2,025	2,149	1,490	1,041
EBS Total		18,764	21,591	22,305	19,034	14,910
AI	541	302	472	472	562	293
	542	234	260	124	329	313
	543	118	139	82	67	164
AI Total		655	871	677	958	770
BSAI Total		19,419	22,462	22,982	19,992	15,680

Table 17-6. Observed skate catch and percent retained by species, and by region, 2003-2007. *2007 reported as of October 15, 2007 (not a complete year). Source: North Pacific Groundfish Observer Program database.

	2003		2004		2005		2006		2007	
Species	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained
Alaska	1,179	49%	4,373	36%	4,125	39%	4,956	36%	4,076	32%
Aleutian	71	28%	264	36%	304	31%	154	43%	119	28%
Bathyraja UnID	58	77%	77	8%	6,319	37%	4,586	29%	3,233	23%
Bering	43	27%	233	12%	197	10%	128	17%	79	21%
Big	26	60%	131	27%	165	19%	179	27%	84	46%
Commander	2	1%	15	18%	26	5%	16	5%	21	16%
Longnose	1	32%	15	42%	5	44%	2	48%		0%
Mud			29	7%	22	4%	6	20%	13	7%
Raja UnID					10	4%				0%
Roughtail			5	8%	2	2%	5	12%	2	3%
Skate UnID	13,024	38%	8,822	27%	3,853	28%	2,819	26%	510	14%
Whiteblotched	9	1%	153	21%	58	24%	92	28%	39	28%
Whitebrow			5	31%	7	7%	3	22%	2	21%
Other	2	1%	0	2%	0	100%	0	67%	2	14%
Total	**14,416**	**39%**	**14,123**	**30%**	**15,092**	**34%**	**12,947**	**31%**	**8,181**	**27%**

	2003		2004		2005		2006		2007	
Region	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained	Obs Catch (t)	% Retained
AI	437	18%	590	21%	463	17%	690	21%	406	34%
EBS	13,978	39%	13,533	30%	14,629	35%	12,258	32%	7,775	27%
Total	14,416	39%	14,123	30%	15,092	34%	12,947	31%	8,181	27%

Table 17-7. EBS shelf bottom trawl survey estimates of Alaska skate (*Bathyraja parmifera*) biomass (metric tons). Estimates and CVs above the dotted line (prior to 1999) were partitioned from aggregate skate biomass using species composition data from 1999-2007; estimates below the dotted line were obtained directly from trawl survey data. Years listed in bold (1992-2007) below the solid line were included in the base model.

Year	Biomass (mt)	s
1982	155,361	0.10
1983	152,752	0.10
1984	177,036	0.10
1985	141,621	0.10
1986	237,936	0.10
1987	328,250	0.10
1988	386,540	0.10
1989	384,423	0.10
1990	505,457	0.10
1991	424,235	0.10
1992	369,546	0.10
1993	354,952	0.10
1994	392,043	0.10
1995	370,722	0.10
1996	382,069	0.10
1997	370,244	0.10
1998	335,181	0.10
1999	315,536	0.16
2000	300,954	0.06
2001	402,909	0.06
2002	347,873	0.07
2003	354,244	0.05
2004	402,354	0.05
2005	461,067	0.05
2006	424,511	0.05
2007	457,941	0.07

Table 17-8. Alaska skate EBS shelf survey length compositions, 2000-2007. Bin number is the lower limit of each 5 cm length interval.

	Year							
Bin	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
20	0.0159	0.0182	0.0142	0.0113	0.0052	0.0087	0.0094	0.0096
25	0.0523	0.0559	0.0422	0.0436	0.0235	0.0272	0.0250	0.0196
30	0.0636	0.0739	0.0575	0.0514	0.0413	0.0360	0.0355	0.0307
35	0.0579	0.0627	0.0680	0.0638	0.0411	0.0512	0.0421	0.0465
40	0.0659	0.0600	0.0680	0.0613	0.0648	0.0628	0.0530	0.0605
45	0.0565	0.0612	0.0665	0.0645	0.0663	0.0732	0.0645	0.0710
50	0.0715	0.0559	0.0751	0.0570	0.0786	0.0693	0.0662	0.0690
55	0.0631	0.0556	0.0616	0.0468	0.0696	0.0708	0.0672	0.0649
60	0.0692	0.0606	0.0560	0.0510	0.0565	0.0761	0.0678	0.0661
65	0.0505	0.0572	0.0575	0.0475	0.0589	0.0645	0.0710	0.0758
70	0.0444	0.0538	0.0571	0.0535	0.0572	0.0540	0.0653	0.0658
75	0.0402	0.0507	0.0549	0.0535	0.0634	0.0564	0.0651	0.0635
80	0.0467	0.0362	0.0344	0.0556	0.0534	0.0486	0.0532	0.0522
85	0.0407	0.0371	0.0388	0.0499	0.0530	0.0543	0.0565	0.0536
90	0.0472	0.0587	0.0594	0.0602	0.0596	0.0632	0.0657	0.0657
95	0.0911	0.0893	0.0818	0.1059	0.0971	0.0754	0.0849	0.0763
100	0.0804	0.0800	0.0676	0.0762	0.0758	0.0702	0.0689	0.0696
105	0.0355	0.0260	0.0310	0.0411	0.0297	0.0325	0.0326	0.0300
110	0.0070	0.0065	0.0071	0.0060	0.0033	0.0046	0.0060	0.0080
115	0.0000	0.0000	0.0011	0.0000	0.0007	0.0011	0.0002	0.0016
120	0.0000	0.0000	0.0004	0.0000	0.0002	0.0000	0.0000	0.0000
125	0.0005	0.0006	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000
Sample Size	2,140	3,236	2,678	2,823	4,210	4,589	5,208	6,898

Table 17-9. Partitioned Alaska skate catch estimates (metric tons) based on observed aggregate skate catch data and survey species composition. Total Alaska skate BSAI catch estimates for each fishery (right-most column) were used in the SS2 base model.

Year	EBS shelf Longline	EBS shelf Trawl	EBS slope Longline	EBS slope Trawl	AI Longline	AI Trawl	BSAI Longline	BSAI Trawl
1992	12,239	2,698	70	25	166	92	12,475	2,815
1993	8,822	1,945	50	18	119	67	8,992	2,029
1994	10,263	2,262	59	21	139	77	10,461	2,360
1995	10,746	2,369	61	22	145	81	10,953	2,471
1996	9,123	2,011	52	18	123	69	9,299	2,098
1997	12,907	2,845	74	26	150	84	13,131	2,955
1998	13,900	3,064	79	28	198	110	14,177	3,202
1999	9,703	2,139	58	20	141	78	9,901	2,237
2000	12,744	2,809	75	26	388	216	13,207	3,052
2001	13,973	3,080	79	28	440	245	14,491	3,353
2002	15,776	3,477	119	42	138	77	16,033	3,596
2003	13,718	3,218	92	23	102	77	13,912	3,318
2004	16,591	3,892	27	23	148	61	16,766	3,975
2005	17,673	3,366	123	14	115	70	17,910	3,450
2006	14,736	3,248	83	29	153	85	14,972	3,362
2007	11,601	2,557	65	23	135	75	11,801	2,655

Table 17-10. Alaska skate length compositions from the EBS 2007 longline and trawl fisheries. Bin number is the lower limit of each 5 cm length interval.

Bin	2007 longline	2007 trawl
20	0.0000	0.0115
25	0.0000	0.0279
30	0.0000	0.0427
35	0.0000	0.0427
40	0.0026	0.0706
45	0.0062	0.0903
50	0.0191	0.0952
55	0.0433	0.0624
60	0.0860	0.0788
65	0.0989	0.0624
70	0.1144	0.0706
75	0.0963	0.0608
80	0.0902	0.0460
85	0.0840	0.0525
90	0.0871	0.0361
95	0.1020	0.0608
100	0.0948	0.0493
105	0.0438	0.0213
110	0.0196	0.0099
115	0.0103	0.0066
120	0.0015	0.0016
125	0.0000	0.0000
Sample Size	1,941	609

Table 17-11. Final parameter values of the base model. Where parameters were estimated freely within the model, minimum and maximum bounds and estimation phase are shown.

Parameter	Value	Min	Max	Fixed?	Phase
Growth and Natural Mortality					
natural mortality (M)	0.13			X	
length at A1 (L1)	25.80	10	30		4
length at A2 (L2)	98.95	70	120		4
von Bertalanffy coefficient (k)	0.15	0.05	0.2		4
CV of L1	0.19	0	0.5		3
CV of L2	-1.47	-3	1		3
Length-Weight Relationship					
coefficient (a)	4.01E-06			X	
exponent (b)	3.15			X	
Length at Maturity					
length at 50% maturity (L_{50})	93.28			X	
slope (b)	-0.55			X	
Weight-Fecundity Relationship					
coefficient (a)	0.5			X	
exponent (b)	0			X	
Stock-Recruit Relationship					
ln virgin recruitment level (R0)	10.55	5	15		1
steepness (h)	0.44	0.2	1		3
SD of R0 (σ^R)	0.10			X	
EBS shelf survey catchability					
ln catchability (ln Q)	-0.179			X	
Longline fishery length selectivity					
peak (p1)	67.6	7.6	126.2		2
top (p2)	2.6	-6.0	4.0		3
ascending width (p3)	5.0	-1.0	9.0		3
descending width (p4)	5.3	-1.0	9.0		3
selectivity at first size bin (p5)	-5.0	-5.0	9.0		2
selectivity at last size bin (p6)	9.0			X	
Trawl fishery length selectivity					
peak (p1)	49.3			X	
top (p2)	-6.0			X	
ascending width (p3)	6.4			X	
descending width (p4)	4.9			X	
selectivity at first size bin (p5)	-5.0			X	
selectivity at last size bin (p6)	0.3			X	
EBS shelf survey length selectivity					
peak (p1)	106.9			X	
top (p2)	-0.6			X	
ascending width (p3)	9.0			X	
descending width (p4)	6.5			X	
selectivity at first size bin (p5)	0.2			X	
selectivity at last size bin (p6)	9.0			X	
Initial fishing mortality					
longline fishery F	0.025	0.0010	1		1
trawl fishery F	0.008	0.0001	1		1

Table 17-12. Estimates of M based on Alaska skate life history parameters from Matta (2006). "Age mature" (T_{mat}) was given a range to estimate M by the Rikhter and Efanov method to account for uncertainty in this parameter.

Sex	**Hoenig**	**T_{mat}**	**Rikhter & Efanov**	**Alverson & Carney**	**Charnov**	**Roff**	**Jensen k**	**Jensen T_{50}**
males	0.28			0.37	0.22	**0.13**	0.19	0.18
females	0.25			0.35	0.16	0.15	0.14	0.17
both		8	0.19					
		9	0.16					
		10	**0.13**					

Table 17-13. Supplemental catch data (t) added to the base model data for use in the alternative models. Data are based on non-target catch estimates in the summary chapter of the 2006 BSAI SAFE report.

	low catch			high catch		
year	longline	trawl	**total**	longline	trawl	**total**
1958	3	25	29	8	61	69
1959	9	65	74	21	158	180
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	19	127	147	44	307	351
1965	78	395	473	152	938	1,089
1966	57	386	443	131	934	1,065
1967	394	914	1,309	540	1,986	2,525
1968	819	3,950	4,769	1,552	9,349	10,901
1969	349	1,851	2,200	696	4,411	5,107
1970	721	2,825	3,546	1,229	6,569	7,797
1971	416	2,369	2,784	864	5,672	6,536
1972	1,022	2,298	3,320	1,383	4,964	6,347
1973	1,443	9,644	11,087	3,297	23,307	26,604
1974	1,734	10,509	12,243	3,735	25,258	28,994
1975	1,559	9,553	11,112	3,380	22,976	26,357
1976	849	4,614	5,463	1,718	11,012	12,729
1977	1,388	6,461	7,849	2,581	15,247	17,828
1978	1,856	10,780	12,636	3,900	25,840	29,741
1979	1,344	6,889	8,233	2,632	16,377	19,009
1980	2,165	5,268	7,434	4,622	12,438	17,060
1981	2,019	5,305	7,324	4,548	12,685	17,234
1982	1,080	2,736	3,817	2,372	6,504	8,876
1983	894	2,311	3,205	1,991	5,513	7,504
1984	480	1,265	1,744	1,083	3,026	4,109
1985	641	1,706	2,347	1,457	4,087	5,545
1986	841	2,332	3,173	1,314	3,714	5,028
1987	931	2,623	3,553	1,073	3,038	4,111
1988	1,480	4,399	5,880	1,458	4,333	5,791
1989	600	1,788	2,388	594	1,771	2,365
1990	916	2,693	3,609	695	2,031	2,726
1991	6,308	1,386	7,694	6,313	1,387	7,699

Table 17-14. Time series of total biomass (metric tons), spawning biomass (metric tons) and the number of recruits (thousands of fish) predicted by the base model.

Year	Total Biomass (t)	Spawning Biomass (t)	Recruits (1000s)
1992	549,082	107,758	25,105
1993	551,076	108,401	29,581
1994	554,318	110,247	34,400
1995	552,719	112,097	31,827
1996	547,637	114,263	29,219
1997	542,526	117,102	36,810
1998	531,871	118,860	42,818
1999	519,799	119,817	38,683
2000	513,218	121,201	42,040
2001	503,761	120,495	30,861
2002	494,891	118,322	34,432
2003	486,325	114,773	30,448
2004	482,114	110,991	22,830
2005	475,167	106,303	31,116
2006	467,804	101,886	30,531
2007	462,909	98,399	30,050

Table 17-15. Time series of exploitation (catch/total biomass) as estimated by the base model.

Year	Longline Fishery	Trawl Fishery	Total
1992	0.024	0.008	0.032
1993	0.017	0.006	0.023
1994	0.020	0.007	0.027
1995	0.021	0.007	0.028
1996	0.018	0.006	0.024
1997	0.026	0.009	0.034
1998	0.028	0.010	0.038
1999	0.020	0.007	0.027
2000	0.028	0.010	0.037
2001	0.031	0.011	0.042
2002	0.035	0.012	0.047
2003	0.031	0.011	0.042
2004	0.038	0.013	0.051
2005	0.041	0.011	0.052
2006	0.034	0.011	0.046
2007	0.027	0.009	0.036

Table 17-16. Summary of major results of the base model and management recommendations for Alaska skates in the BSAI.

Tier	3a
Reference mortality rates	
M	0.13
$F_{35\%}$	0.076
$F_{40\%}$	0.066
Equilibrium spawning biomass (t)	
$B_{35\%}$	52,755
$B_{40\%}$	60,292
$B_{100\%}$	150,729
Projected biomass for 2008 (t)	
Spawning (at max F_{ABC})	92,852
Total	490,958
ABC for 2008	
F_{ABC} (maximum permissible)	0.066
F_{ABC} (recommended)	0.066
ABC (t; maximum permissible)	24,964
ABC (t; recommended)	24,964
Overfishing level for 2008	
F_{OFL}	0.076
OFL (t)	28,854
Projections for 2009	
Spawning biomass (t; at max F_{ABC})	90,133
Total biomass (t)	483,291
ABC (t; maximum permissible)	24,570
OFL (t)	28,399

Table 17-17. Projections of catch (t), spawning biomass (t), and fishing mortality under harvest scenarios 1 and 2 (F = max FABC).

Catch Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	18,422	18,422	18,422	18,422	0
2009	24,523	24,568	24,570	24,626	32
2010	23,638	23,756	23,764	23,914	85
2011	22,749	23,003	23,017	23,317	175
2012	21,956	22,362	22,379	22,835	277
2013	21,298	21,825	21,841	22,476	371
2014	20,749	21,367	21,385	22,165	449
2015	20,235	20,988	20,996	21,874	510
2016	19,809	20,667	20,669	21,654	557
2017	19,460	20,380	20,394	21,399	596
2018	19,207	20,141	20,164	21,199	631
2019	18,952	19,932	19,970	21,110	663
2020	18,751	19,749	19,806	21,029	691

Spawning Biomass Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	92,851	92,852	92,852	92,853	1
2009	90,131	90,133	90,133	90,136	1
2010	87,301	87,303	87,303	87,305	1
2011	85,063	85,065	85,065	85,067	1
2012	83,181	83,183	83,183	83,186	1
2013	81,377	81,389	81,389	81,404	8
2014	79,442	79,497	79,498	79,563	37
2015	77,245	77,407	77,415	77,614	113
2016	74,772	75,145	75,168	75,607	258
2017	72,174	72,873	72,909	73,716	481
2018	69,632	70,745	70,785	72,065	759
2019	67,377	68,848	68,916	70,735	1,058
2020	65,386	67,294	67,343	69,668	1,343

Fishing Mortality Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0.048	0.048	0.048	0.048	0.000
2009	0.066	0.066	0.066	0.066	0.000
2010	0.066	0.066	0.066	0.066	0.000
2011	0.066	0.066	0.066	0.066	0.000
2012	0.066	0.066	0.066	0.066	0.000
2013	0.066	0.066	0.066	0.066	0.000
2014	0.066	0.066	0.066	0.066	0.000
2015	0.066	0.066	0.066	0.066	0.000
2016	0.066	0.066	0.066	0.066	0.000
2017	0.066	0.066	0.066	0.066	0.000
2018	0.066	0.066	0.066	0.066	0.000
2019	0.066	0.066	0.066	0.066	0.000
2020	0.066	0.066	0.066	0.066	0.000

Table 17-18. Projections of catch (t), spawning biomass (t), and fishing mortality under harvest scenario 3 (F = 50% of max F_{ABC}).

Catch Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	18,422	18,422	18,422	18,422	0
2009	7,349	7,363	7,363	7,380	9
2010	7,370	7,405	7,408	7,453	26
2011	7,367	7,445	7,449	7,540	54
2012	7,369	7,495	7,501	7,647	87
2013	7,385	7,556	7,561	7,765	120
2014	7,412	7,616	7,623	7,880	149
2015	7,424	7,682	7,685	7,987	174
2016	7,444	7,746	7,744	8,084	194
2017	7,472	7,799	7,801	8,163	211
2018	7,514	7,846	7,854	8,235	227
2019	7,531	7,893	7,903	8,302	241
2020	7,558	7,926	7,946	8,394	254

Spawning Biomass Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	92,851	92,852	92,852	92,853	1
2009	91,710	91,712	91,712	91,714	1
2010	92,609	92,611	92,611	92,614	1
2011	94,073	94,075	94,075	94,078	1
2012	95,900	95,902	95,903	95,905	1
2013	97,793	97,807	97,808	97,824	9
2014	99,484	99,548	99,550	99,626	43
2015	100,744	100,942	100,953	101,195	138
2016	101,471	101,934	101,968	102,530	327
2017	101,742	102,664	102,714	103,770	633
2018	101,775	103,268	103,331	105,069	1,034
2019	101,774	103,892	103,953	106,494	1,491
2020	101,779	104,574	104,640	108,007	1,950

Fishing Mortality Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0.048	0.048	0.048	0.048	0.000
2009	0.019	0.019	0.019	0.019	0.000
2010	0.019	0.019	0.019	0.019	0.000
2011	0.019	0.019	0.019	0.019	0.000
2012	0.019	0.019	0.019	0.019	0.000
2013	0.019	0.019	0.019	0.019	0.000
2014	0.019	0.019	0.019	0.019	0.000
2015	0.019	0.019	0.019	0.019	0.000
2016	0.019	0.019	0.019	0.019	0.000
2017	0.019	0.019	0.019	0.019	0.000
2018	0.019	0.019	0.019	0.019	0.000
2019	0.019	0.019	0.019	0.019	0.000
2020	0.019	0.019	0.019	0.019	0.000

Table 17-19. Projections of catch (t), spawning biomass (t), and fishing mortality under harvest scenario 4 (F = 2003-2007 average F).

Catch Projections					
Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	18,422	18,422	18,422	18,422	0
2009	17,741	17,774	17,775	17,815	23
2010	17,373	17,459	17,464	17,573	62
2011	16,975	17,161	17,171	17,389	128
2012	16,618	16,915	16,929	17,267	205
2013	16,329	16,722	16,735	17,207	277
2014	16,096	16,562	16,575	17,156	338
2015	15,859	16,436	16,442	17,116	388
2016	15,668	16,336	16,333	17,098	427
2017	15,510	16,234	16,243	17,024	460
2018	15,429	16,148	16,170	16,981	490
2019	15,310	16,080	16,109	16,971	517
2020	15,230	16,010	16,057	17,006	541
Spawning Biomass Projections					
Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	92,851	92,852	92,852	92,853	1
2009	90,759	90,761	90,761	90,763	1
2010	89,385	89,387	89,387	89,389	1
2011	88,555	88,557	88,557	88,560	1
2012	88,049	88,050	88,051	88,053	1
2013	87,578	87,591	87,591	87,607	9
2014	86,915	86,973	86,975	87,044	39
2015	85,895	86,070	86,079	86,294	123
2016	84,474	84,878	84,908	85,391	284
2017	82,784	83,563	83,606	84,501	537
2018	81,025	82,279	82,326	83,772	859
2019	79,430	81,126	81,198	83,288	1,213
2020	77,996	80,233	80,277	82,980	1,558
Fishing Mortality Projections					
Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0.048	0.048	0.048	0.048	0.000
2009	0.047	0.047	0.047	0.047	0.000
2010	0.047	0.047	0.047	0.047	0.000
2011	0.047	0.047	0.047	0.047	0.000
2012	0.047	0.047	0.047	0.047	0.000
2013	0.047	0.047	0.047	0.047	0.000
2014	0.047	0.047	0.047	0.047	0.000
2015	0.047	0.047	0.047	0.047	0.000
2016	0.047	0.047	0.047	0.047	0.000
2017	0.047	0.047	0.047	0.047	0.000
2018	0.047	0.047	0.047	0.047	0.000
2019	0.047	0.047	0.047	0.047	0.000
2020	0.047	0.047	0.047	0.047	0.000

Table 17-20. Projections of catch (t), spawning biomass (t), and fishing mortality under harvest scenario 5 ($F = 0$).

Catch Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0

Spawning Biomass Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	92,851	92,852	92,852	92,853	1
2009	92,374	92,376	92,377	92,379	1
2010	94,912	94,914	94,914	94,916	1
2011	98,098	98,100	98,100	98,103	1
2012	101,750	101,752	101,752	101,755	2
2013	105,565	105,579	105,580	105,598	10
2014	109,247	109,316	109,318	109,399	46
2015	112,520	112,735	112,747	113,009	150
2016	115,226	115,735	115,771	116,396	362
2017	117,386	118,425	118,478	119,655	710
2018	119,208	120,906	120,988	122,963	1,177
2019	120,882	123,351	123,424	126,350	1,720
2020	122,497	125,742	125,836	129,829	2,280

Fishing Mortality Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0.000	0.000	0.000	0.000	0.000
2009	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.000	0.000	0.000	0.000
2011	0.000	0.000	0.000	0.000	0.000
2012	0.000	0.000	0.000	0.000	0.000
2013	0.000	0.000	0.000	0.000	0.000
2014	0.000	0.000	0.000	0.000	0.000
2015	0.000	0.000	0.000	0.000	0.000
2016	0.000	0.000	0.000	0.000	0.000
2017	0.000	0.000	0.000	0.000	0.000
2018	0.000	0.000	0.000	0.000	0.000
2019	0.000	0.000	0.000	0.000	0.000
2020	0.000	0.000	0.000	0.000	0.000

Table 17-21. Projections of catch (t), spawning biomass (t), and fishing mortality under harvest scenario 6 ($F = F_{OFL}$).

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
Catch Projections					
2008	28,839	28,854	28,855	28,872	10
2009	27,675	27,727	27,729	27,793	36
2010	26,462	26,598	26,607	26,779	98
2011	25,280	25,571	25,587	25,928	200
2012	24,239	24,700	24,721	25,241	316
2013	23,384	23,981	23,998	24,717	420
2014	22,670	23,364	23,390	24,270	506
2015	22,023	22,868	22,877	23,865	573
2016	21,492	22,439	22,449	23,548	623
2017	21,063	22,076	22,093	23,209	664
2018	20,730	21,767	21,797	22,932	701
2019	20,417	21,501	21,543	22,813	745
2020	19,648	21,097	21,111	22,648	926
Spawning Biomass Projections					
Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	91,879	91,879	91,879	91,879	0
2009	87,536	87,536	87,536	87,536	0
2010	83,986	83,986	83,986	83,986	0
2011	81,062	81,062	81,062	81,062	0
2012	78,528	78,528	78,528	78,528	0
2013	76,115	76,125	76,126	76,138	7
2014	73,638	73,689	73,690	73,751	34
2015	70,984	71,136	71,145	71,332	107
2016	68,151	68,505	68,526	68,938	243
2017	65,299	65,952	65,984	66,737	450
2018	62,582	63,620	63,653	64,842	705
2019	60,220	61,568	61,635	63,310	975
2020	58,238	59,916	59,976	62,076	1,209
Fishing Mortality Projections					
Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0.077	0.077	0.077	0.077	0.000
2009	0.077	0.077	0.077	0.077	0.000
2010	0.077	0.077	0.077	0.077	0.000
2011	0.077	0.077	0.077	0.077	0.000
2012	0.077	0.077	0.077	0.077	0.000
2013	0.077	0.077	0.077	0.077	0.000
2014	0.077	0.077	0.077	0.077	0.000
2015	0.077	0.077	0.077	0.077	0.000
2016	0.077	0.077	0.077	0.077	0.000
2017	0.077	0.077	0.077	0.077	0.000
2018	0.077	0.077	0.077	0.077	0.000
2019	0.076	0.077	0.076	0.077	0.000
2020	0.074	0.076	0.076	0.077	0.001

Table 17-22. Projections of catch (t), spawning biomass (t), and fishing mortality under harvest scenario 7 ($F = F_{ABC}$ in 2007-2008 and $F = F_{OFL}$ thereafter).

Catch Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	24,951	24,963	24,964	24,979	9
2009	24,160	24,205	24,207	24,262	31
2010	26,933	27,069	27,078	27,251	98
2011	25,708	26,000	26,016	26,359	201
2012	24,623	25,085	25,107	25,628	317
2013	23,724	24,322	24,340	25,060	421
2014	22,970	23,663	23,689	24,571	507
2015	22,280	23,127	23,136	24,124	574
2016	21,714	22,663	22,672	23,772	624
2017	21,252	22,267	22,284	23,402	664
2018	20,892	21,931	21,960	23,097	701
2019	20,565	21,638	21,687	22,953	735
2020	20,017	21,333	21,357	22,802	854

Spawning Biomass Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	92,244	92,244	92,244	92,244	0
2009	88,722	88,722	88,722	88,722	0
2010	85,597	85,597	85,597	85,597	0
2011	82,616	82,616	82,616	82,616	0
2012	80,029	80,029	80,029	80,029	0
2013	77,562	77,572	77,573	77,585	7
2014	75,023	75,074	75,075	75,136	35
2015	72,293	72,445	72,454	72,642	107
2016	69,370	69,725	69,746	70,160	244
2017	66,413	67,069	67,101	67,857	452
2018	63,583	64,624	64,658	65,851	707
2019	61,104	62,457	62,524	64,205	979
2020	58,977	60,680	60,739	62,859	1,223

Fishing Mortality Projections

Year	Lower 90% CI	Median	Mean	Upper 90% CI	SD
2008	0.066	0.066	0.066	0.066	0.000
2009	0.066	0.066	0.066	0.066	0.000
2010	0.077	0.077	0.077	0.077	0.000
2011	0.077	0.077	0.077	0.077	0.000
2012	0.077	0.077	0.077	0.077	0.000
2013	0.077	0.077	0.077	0.077	0.000
2014	0.077	0.077	0.077	0.077	0.000
2015	0.077	0.077	0.077	0.077	0.000
2016	0.077	0.077	0.077	0.077	0.000
2017	0.077	0.077	0.077	0.077	0.000
2018	0.077	0.077	0.077	0.077	0.000
2019	0.077	0.077	0.077	0.077	0.000
2020	0.075	0.077	0.076	0.077	0.001

Table 17-23. Total skate biomass (metric tons) with coefficient of variation (cv) from bottom trawl surveys of the Eastern Bering Sea (EBS) shelf, EBS slope, and Aleutian Islands (AI), 1975-2007.

Year	**EBS shelf**		**EBS slope**		**AI**	
	biomass	**cv**	**biomass**	**cv**	**biomass**	**cv**
1975	24,349	0.19				
1976						
1977						
1978						
1979	58,147	0.14	3,056	0.26		
1980					4,257	0.25
1981			2,743	0.12		
1982	164,084	0.10	2,723	0.10		
1983	161,329	0.09			9,683	0.12
1984	186,976	0.09				
1985	149,573	0.11	3,329	0.10		
1986	251,296	0.15			15,436	0.19
1987	346,679	0.10				
1988	408,242	0.11	3,271	0.21		
1989	406,007	0.08				
1990	533,837	0.11				
1991	448,054	0.09	4,031	0.25	14,967	0.17
1992	390,294	0.09				
1993	374,882	0.07				
1994	414,054	0.08			25,014	0.10
1995	391,537	0.08				
1996	403,521	0.06				
1997	391,032	0.07			28,922	0.14
1998	354,000	0.05				
1999	348,477	0.16				
2000	325,292	0.06			29,320	0.09
2001	420,313	0.06				
2002	366,315	0.07	69,275	0.50	34,413	0.11
2003	386,339	0.05				
2004	416,559	0.05	33,156	0.08	53,071	0.16
2005	481,194	0.05				
2006	442,556	0.05			54,210	0.12
2007	475,024	0.07				

Table 17-24. Estimates of M for the Other Skates group based on *Raja* sp. life history parameters. "Age mature" (T_{mat}) was given a range for M estimates by the Rikhter and Efanov method to account for uncertainty in this parameter. Study areas are indicated as CA (California), GOA (Gulf of Alaska), and BC (British Columbia. Life history parameter sources: Zeiner and Wolf 1993, Gburski et al. 2007, McFarlane and King 2006.

Species	Area	Sex	Hoenig	T_{mat}	Rikhter & Efanov	Alverson & Carney	Charnov	Roff
Big skate	CA	*males*	0.38					
	CA	*females*	0.35					
	CA	*both*		8	0.19			
	CA			9	0.16			
	CA			10	0.13			
	CA			11	0.12			
	CA			12	**0.10**			
	GOA	*males*	0.28			0.33	0.28	
	GOA	*females*	0.30			0.45	0.15	
	BC	*males*	0.17			0.25	0.10	0.34
	BC	*females*	0.16			0.25	0.08	0.27
	BC	*both*		5	0.32			
	BC			6	0.26			
	BC			7	0.22			
	BC			8	0.19			
Longnose skate	CA	*males*	0.32			0.31	0.44	0.23
	CA	*females*	0.35			0.45	0.29	0.03
	CA	*both*		7	0.22		0.31	
	CA			8	0.19			
	CA			9	0.16			
	CA			10	0.13			
	GOA	*males*	0.17			0.24	0.11	
	GOA	*females*	0.17			0.28	0.07	
	BC	*males*	0.18			0.25	0.13	0.21
	BC	*females*	0.16			0.22	0.11	0.12
	BC	*both*		6	0.26			
	BC			7	0.22			
	BC			8	0.19			
	BC			9	0.16			
	BC			10	0.13			

Figures

Figure 17-1. Skate diversity on the Bering Sea slope: five species of skate captured in a single trawl haul on the NMFS Bering sea slope survey, 2002. Species pictured include whitebrow skate (*B. minispinosa*), mud skate (*B. taranetzi*), whiteblotched skate (*B. maculata*), Aleutian skate (*B. aleutica*), and Commander skate (*B. lindbergi*). Photo credit: Gerald Hoff.

The following maps show the range of each skate species encountered in the BSAI FMP area. These maps were created primarily using survey data, although observer records were included whenever positive species identification was possible (through voucher specimens or photographs).

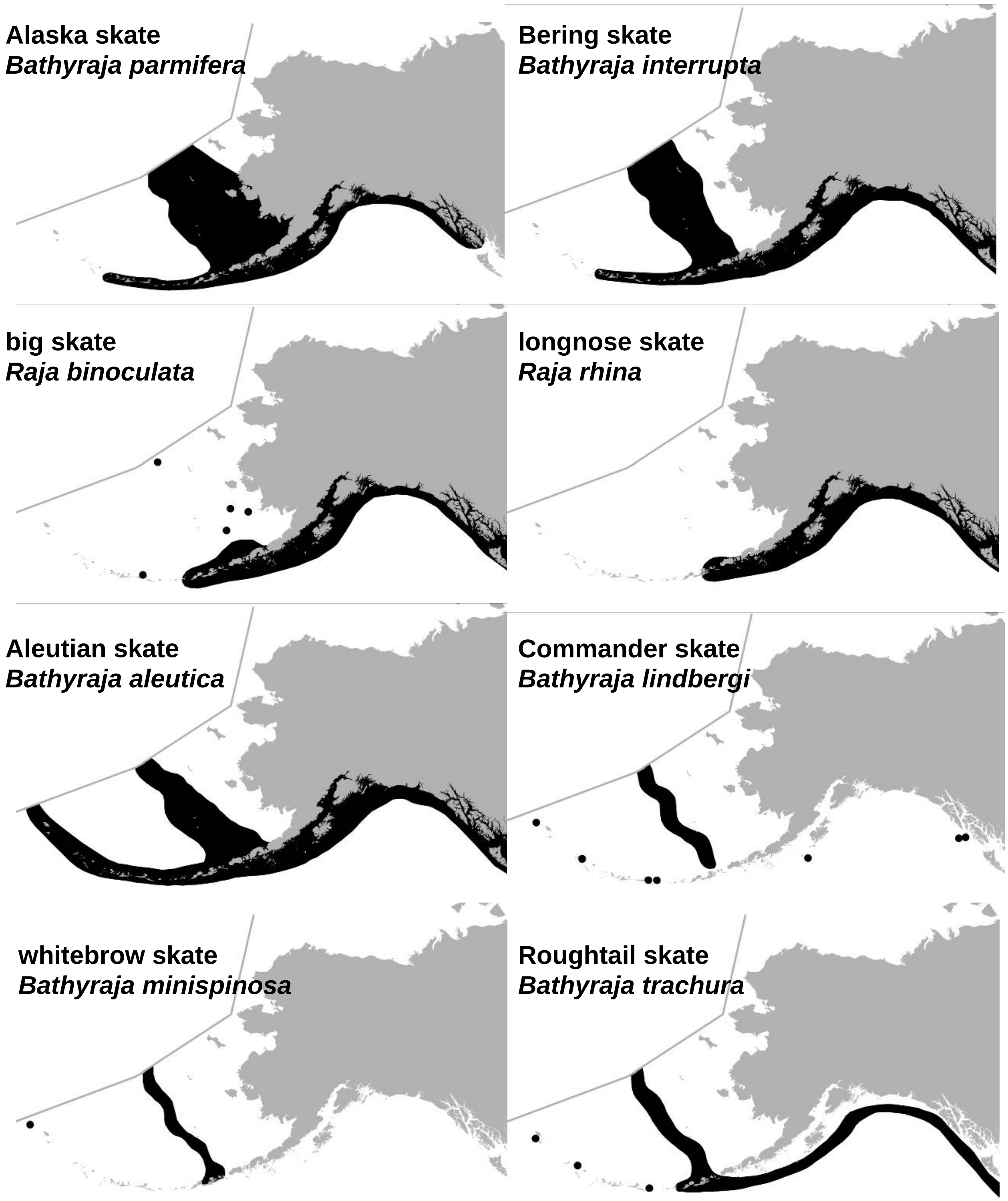


Figure 17-2. Distribution of skate species in Alaskan waters. (Source: Stevenson et al. 2007)

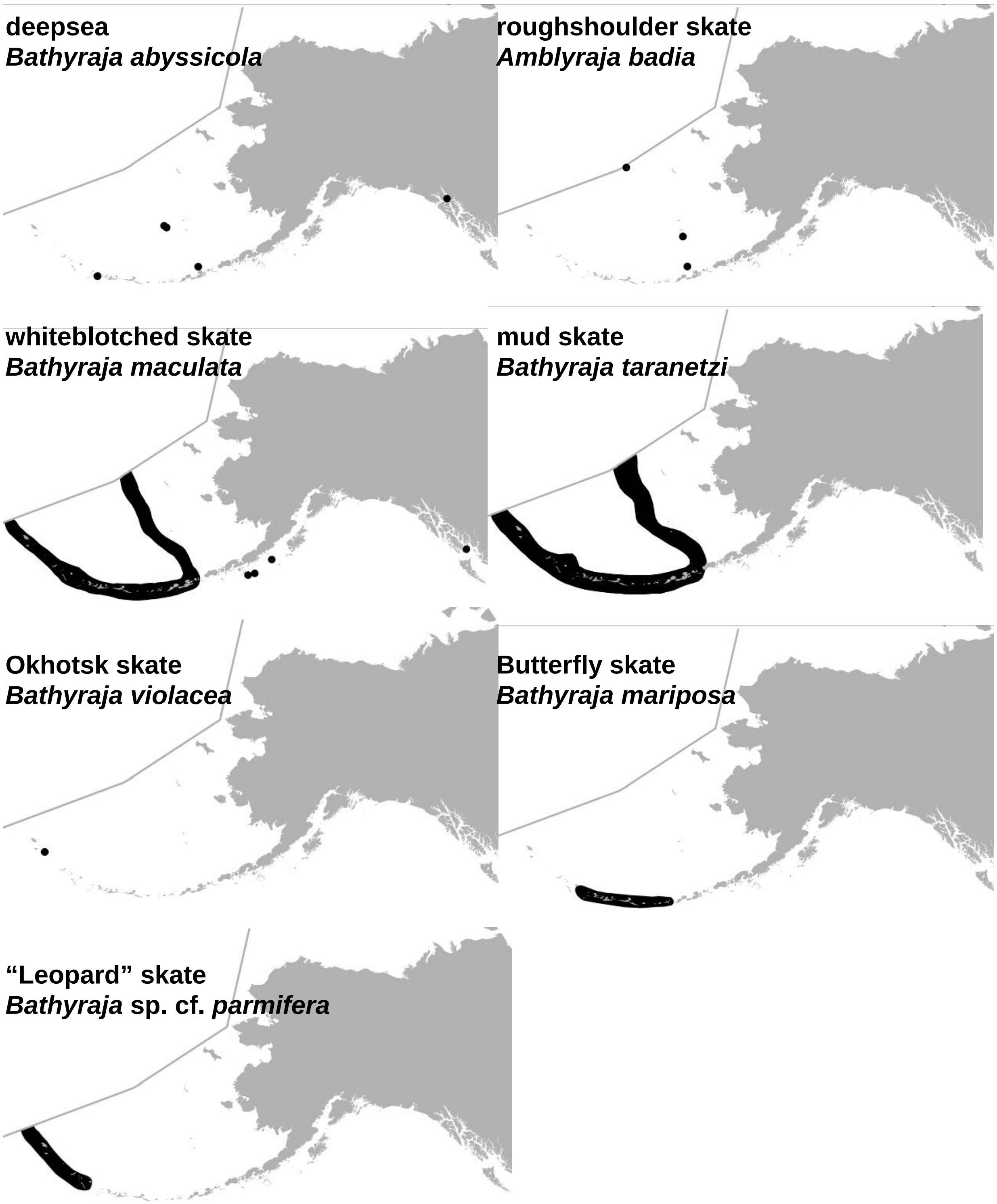


Figure 17-2(continued). Distribution of skate species in Alaskan waters (Source: Stevenson et al. 2007).

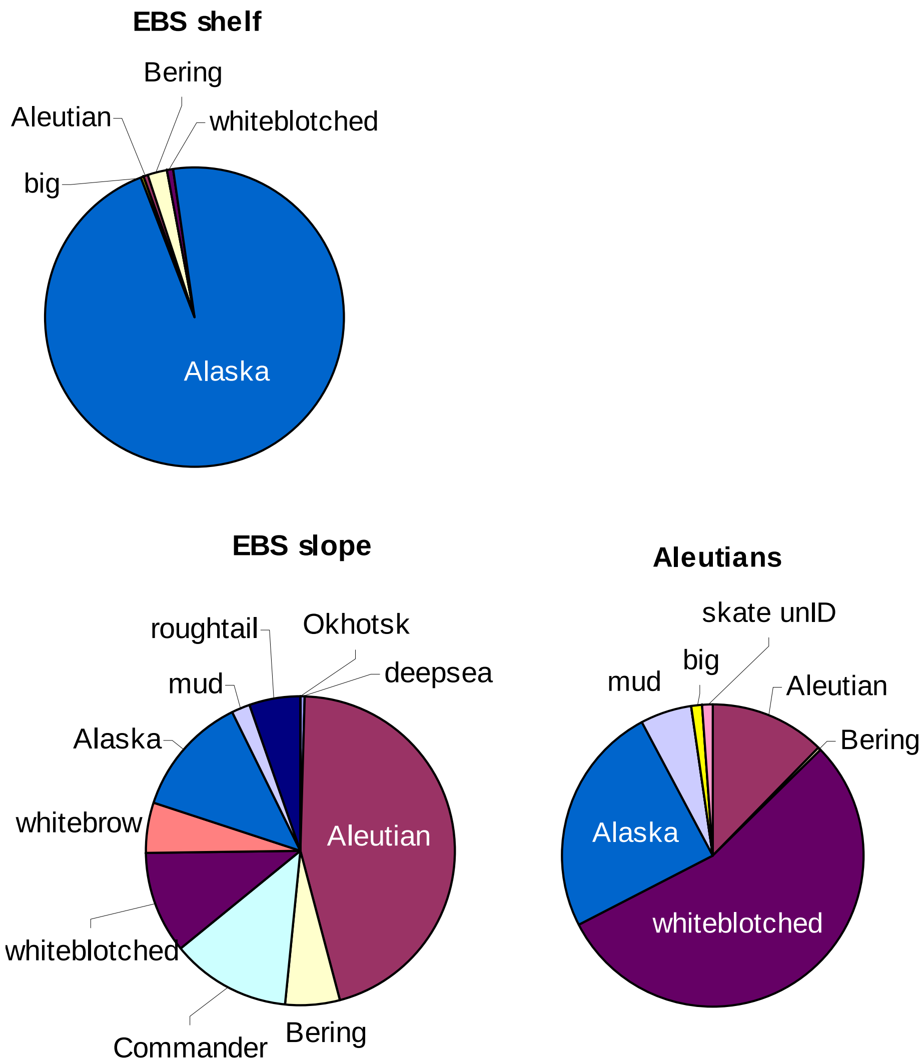


Figure 17-3. Skate species composition (by weight) by habitat area, EBS shelf (top), EBS slope (bottom left), and AI (bottom right). EBS shelf data are from 2007 bottom trawl survey; AI data are from 2006 bottom trawl survey; EBS slope data are from 2004 bottom trawl survey.

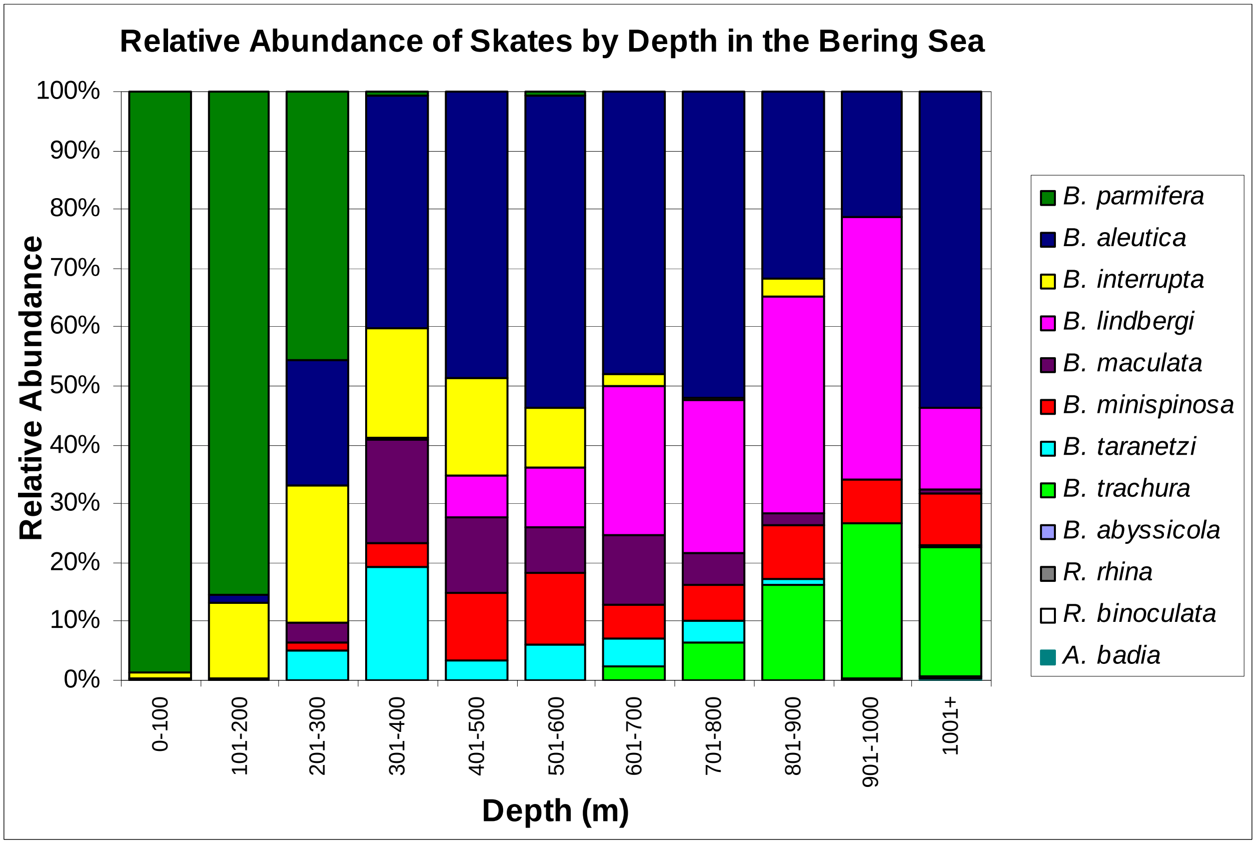


Figure 17-4. Relative abundance of skate species in the EBS by depth. (Source: Stevenson et al. 2006.)

The following CPUE maps were created using data from RACE Bering Sea Groundfish Surveys, 2001-2004. The data shown is the average CPUE (kg/ha) for each station, and the scale changes appropriately for each species.

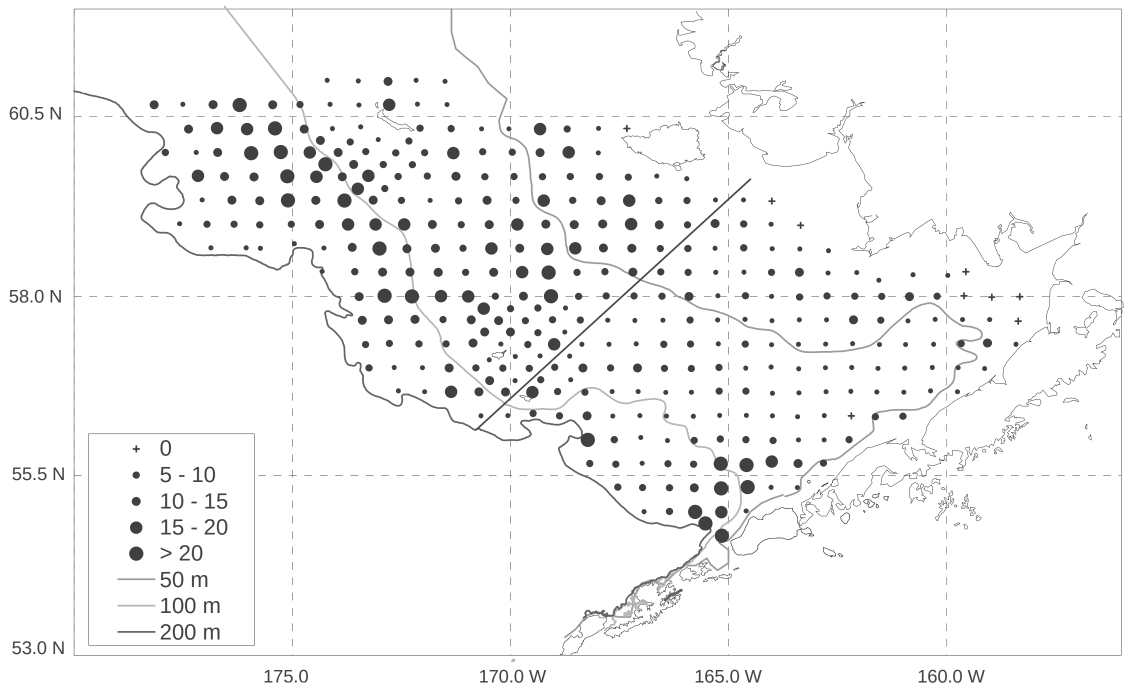


Figure 17-5. Average survey CPUE, Alaska skate (*Bathyraja parmifera*), 2001-2004.

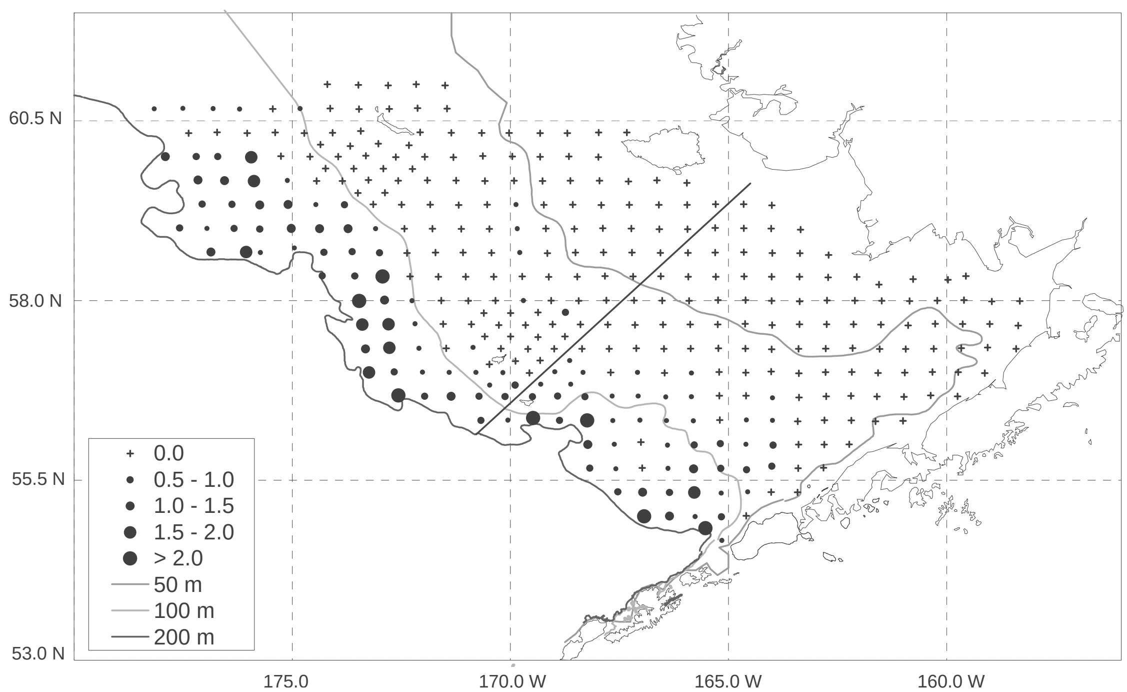


Figure 17-6. Average survey CPUE, Bering skate (*Bathyraja interrupta*), 2001-2004.

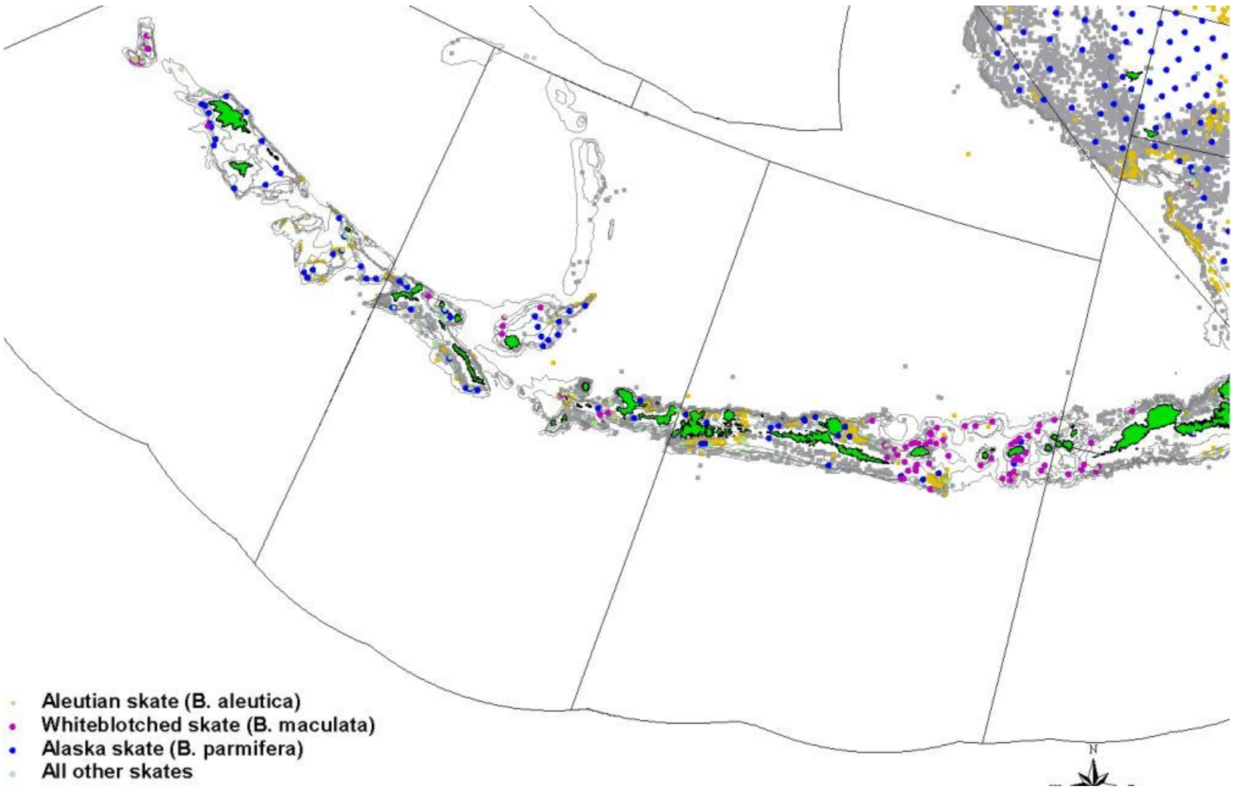


Figure 17-7. Skate distribution in the AI from NMFS bottom trawl surveys. Specimens of *B. parmifera* in the western AI have now been described as a new species (see below).

Figure 17-8. Skate diversity in the Aleutians: a new species, the leopard skate, from the Aleutian Islands (left) formerly thought to be the same species as the extremely common Alaska skate, *B. parmifera* (from the EBS, right). Photo credits: leopard skate, Richard MacIntosh; Alaska skate, Beth Matta.

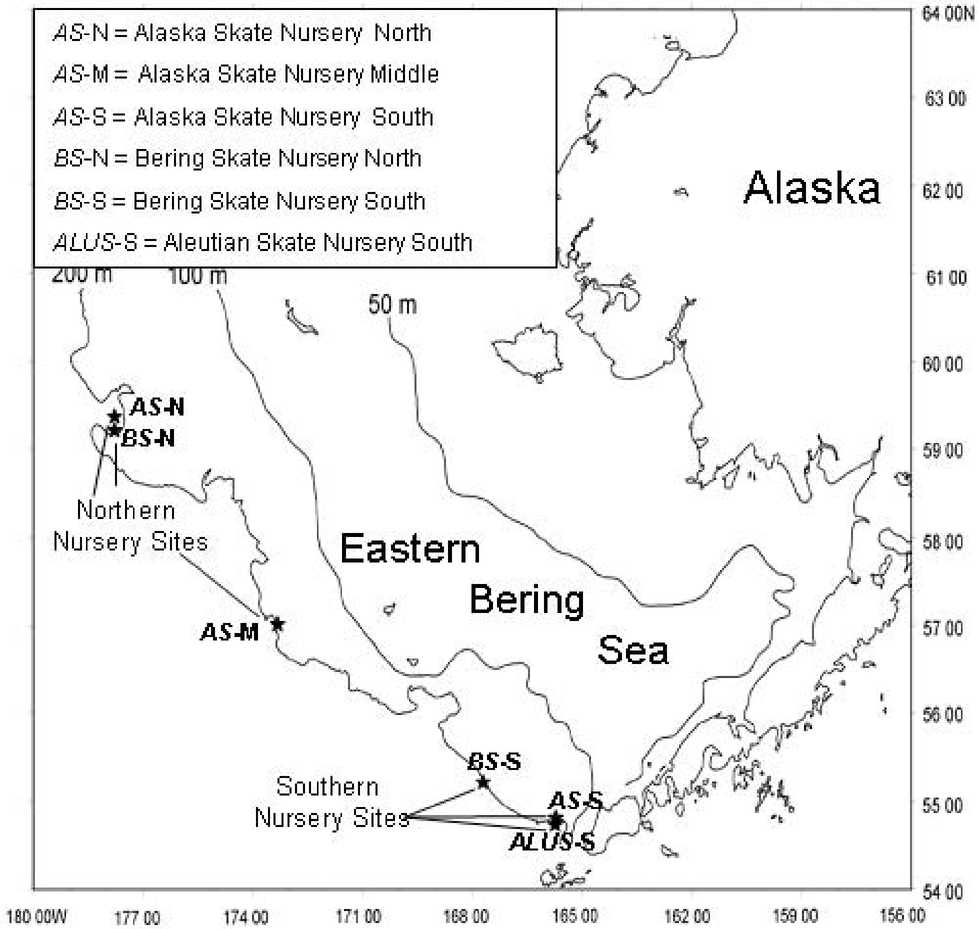


Figure 17-9. Map of the eastern Bering Sea with the six known skate nursery site locations and designations as a northern or southern nursery site. (See the legend for nursery site designation.) Source: Gerald Hoff, AFSC, unpublished data.

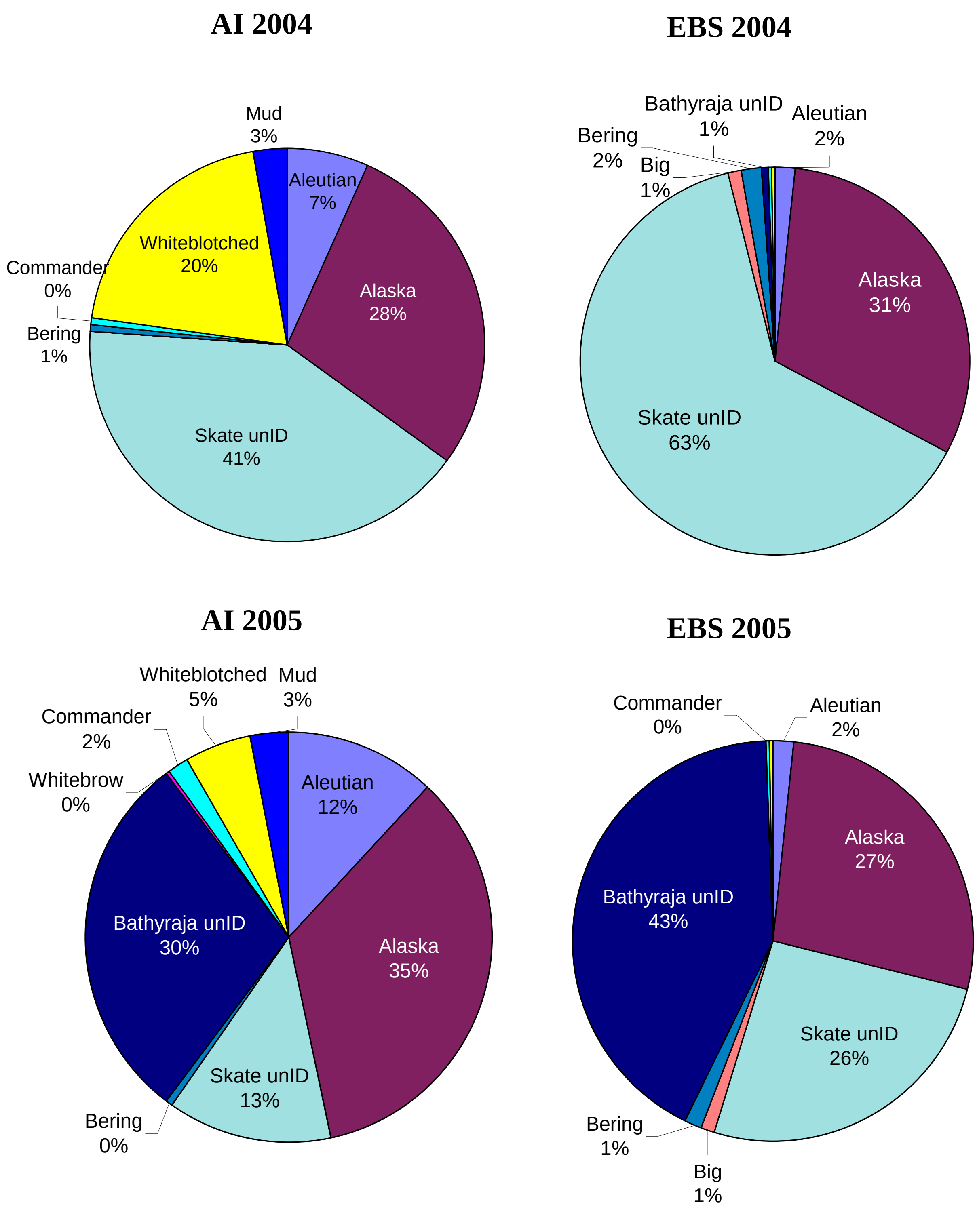


Figure 17-10. Identification of observed incidentally caught skates in AI (left) and EBS (right) groundfish fisheries, 2004 (top) and 2005 (bottom). Source: North Pacific Groundfish Observer Program database.

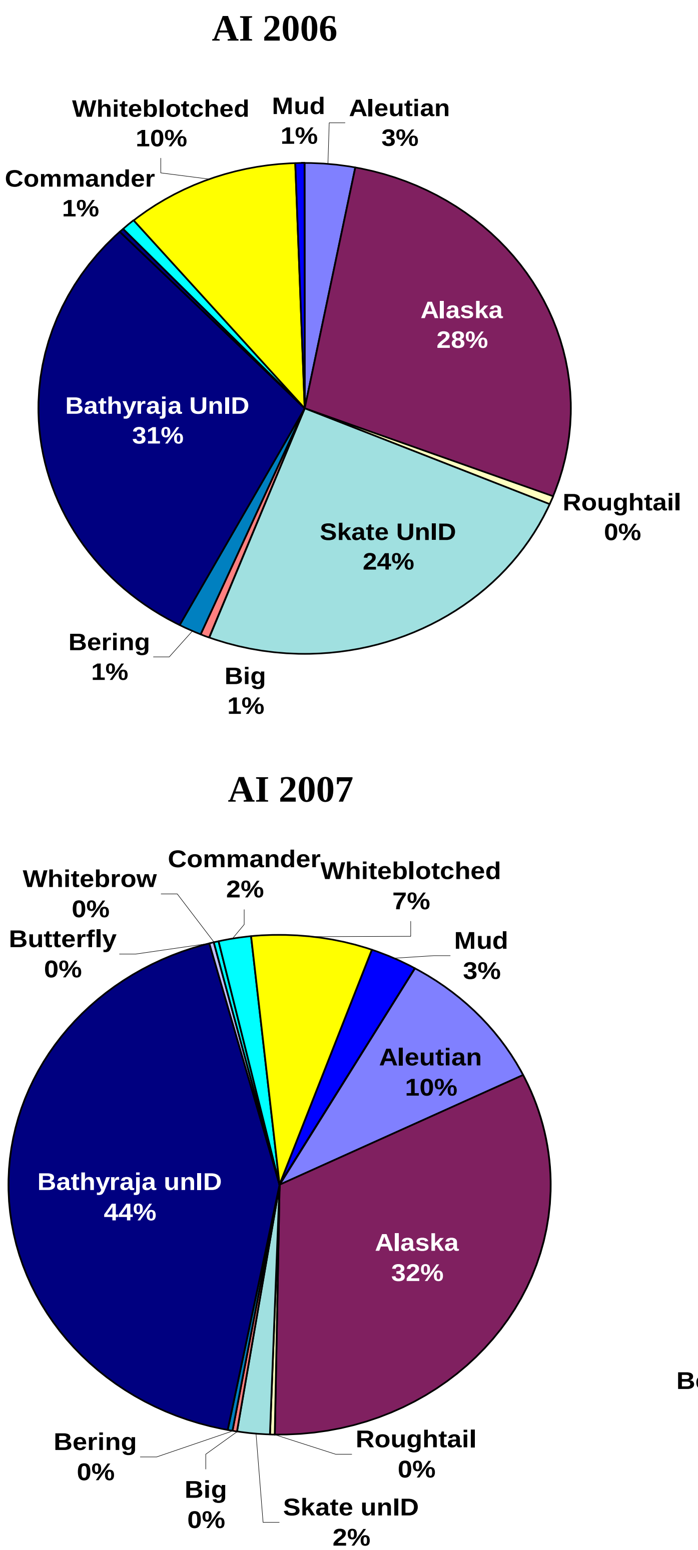


Figure 17-10 (continued). Identification of observed incidentally caught skates in AI (left) and EBS (right) groundfish fisheries, 2006 (top) and 2007 (bottom). Source: North Pacific Groundfish Observer Program database. 2007 data are reported through October 15, 2007.

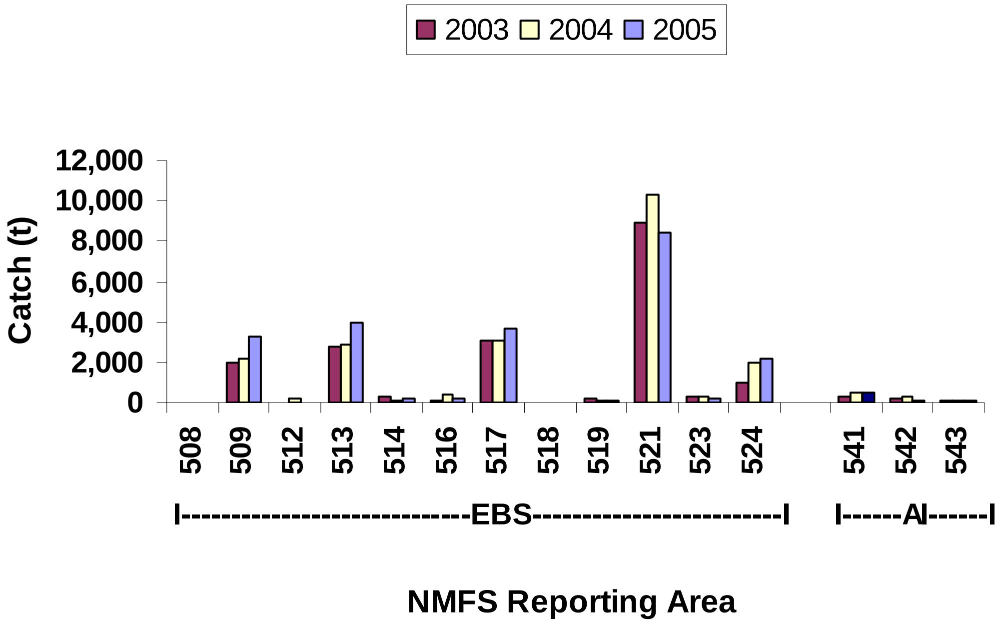
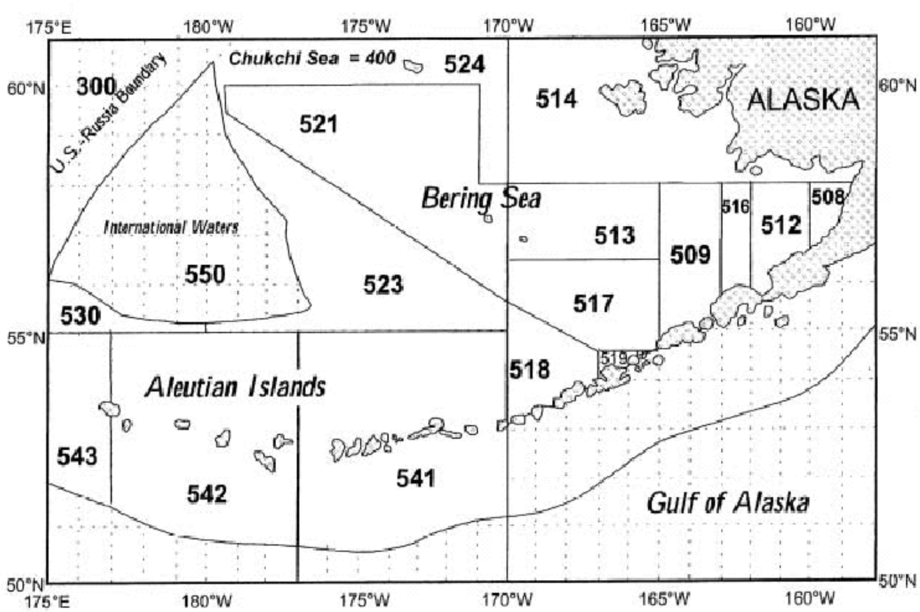


Figure 17-11. Total skate catch (all species combined) by FMP reporting area for both the EBS and the AI, 2003-2005. Source: AKRO CAS.

BSAI Statistical and Reporting Areas



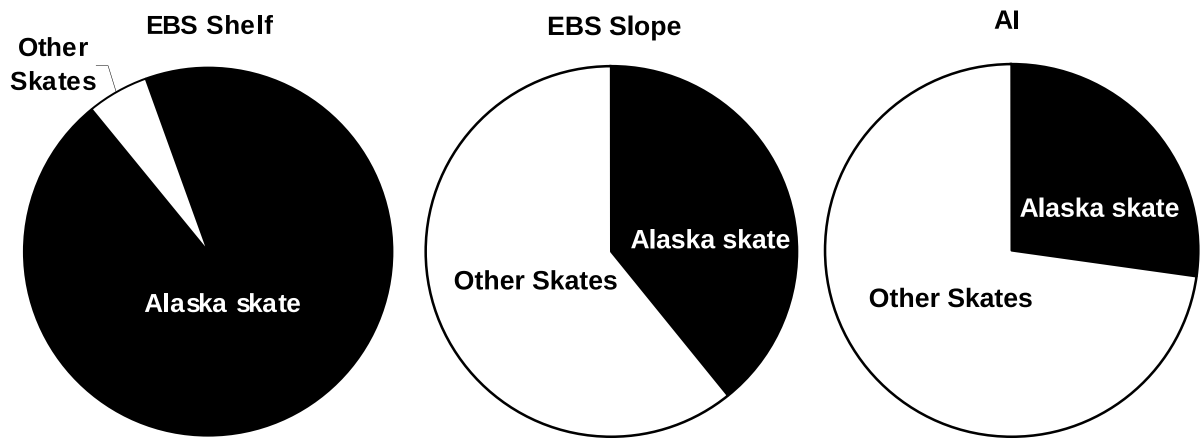


Figure 17-12. Relative proportion of Alaska skates and Other Skates in each habitat area. Graphs represent weighted averages from 1999-2007 trawl survey biomass estimates. These data were used to reconstruct catch data and pre-1999 survey biomass estimates for the Alaska skate.

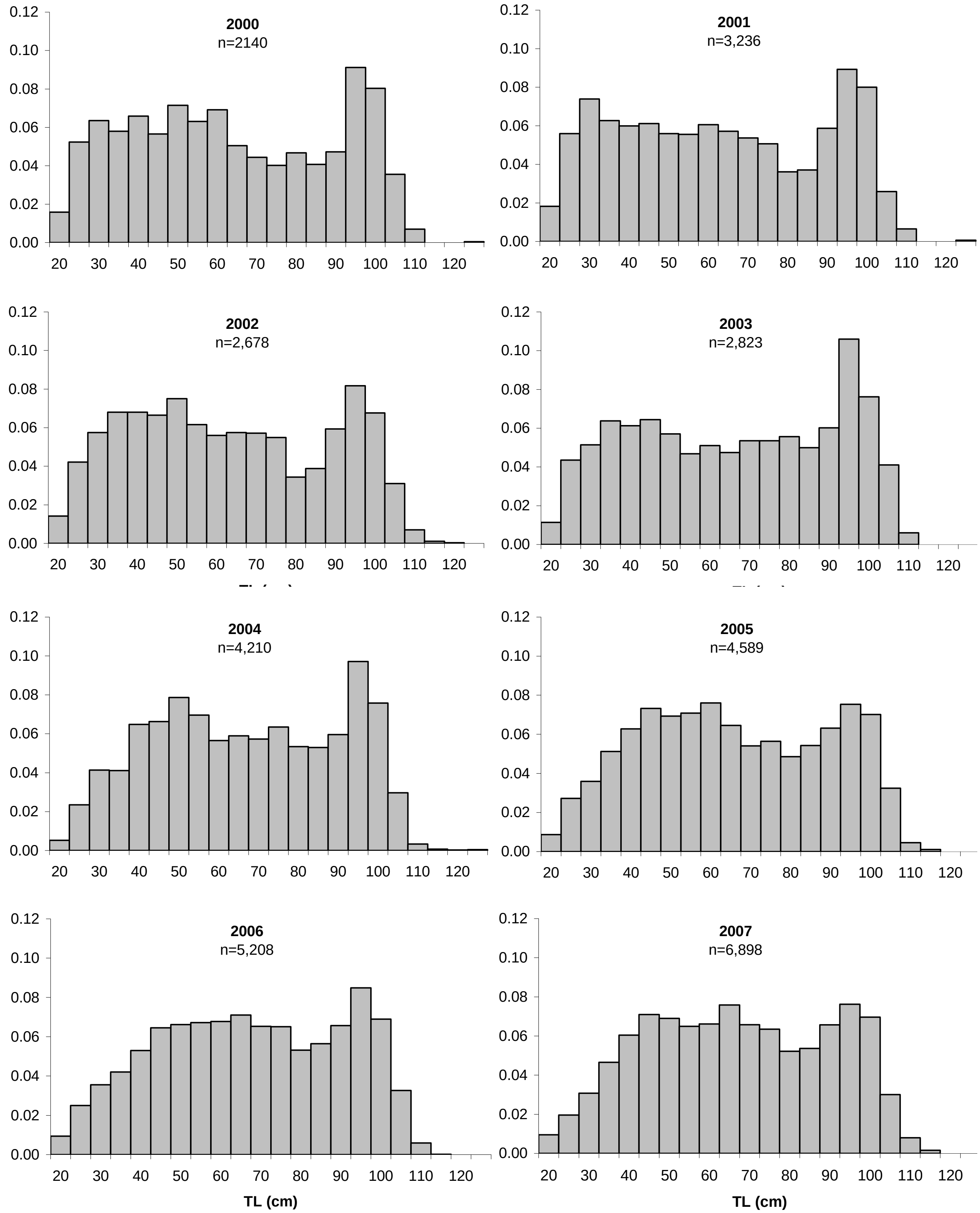


Figure 17-13. Alaska skate length compositions from EBS shelf trawl surveys 2000-2007.

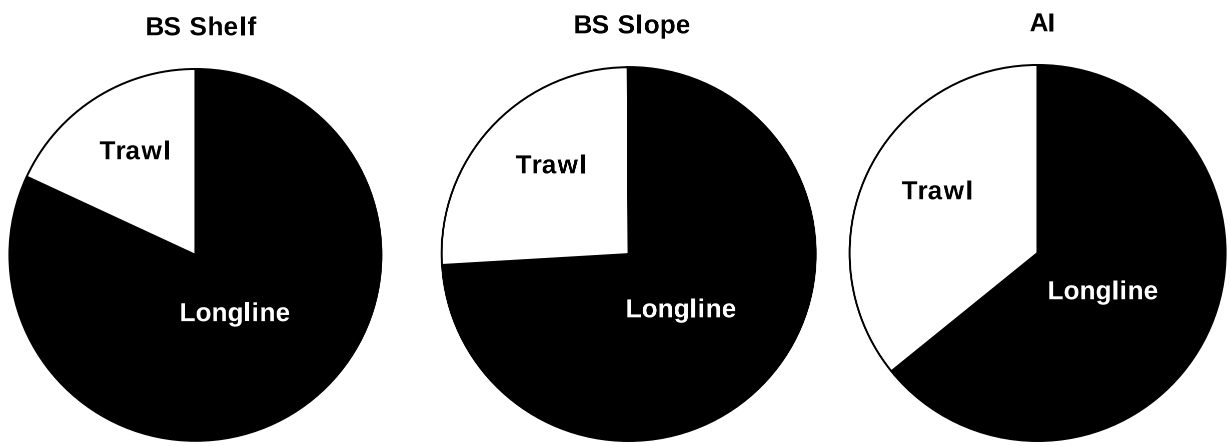


Figure 17-14. Average proportion of catch by major gear type in each habitat area (2003-2005).

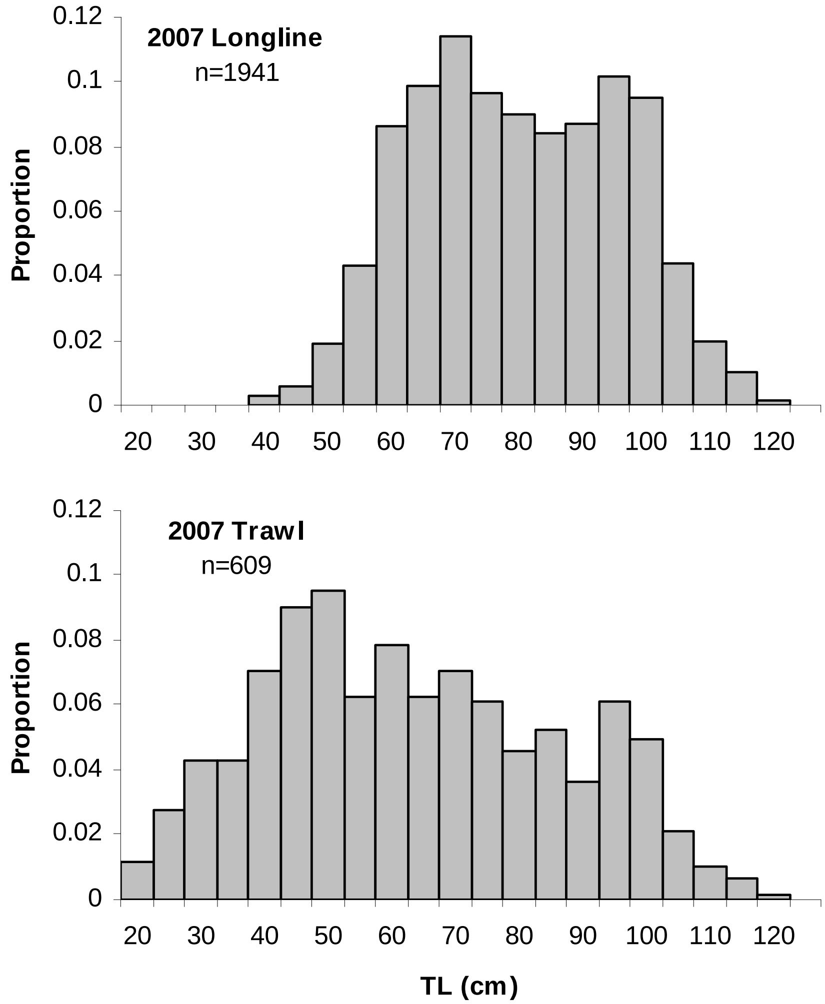


Figure 17-15. Alaska skate length compositions from the 2007 longline fishery (top) and trawl fishery (bottom) operating in the Eastern Bering Sea.

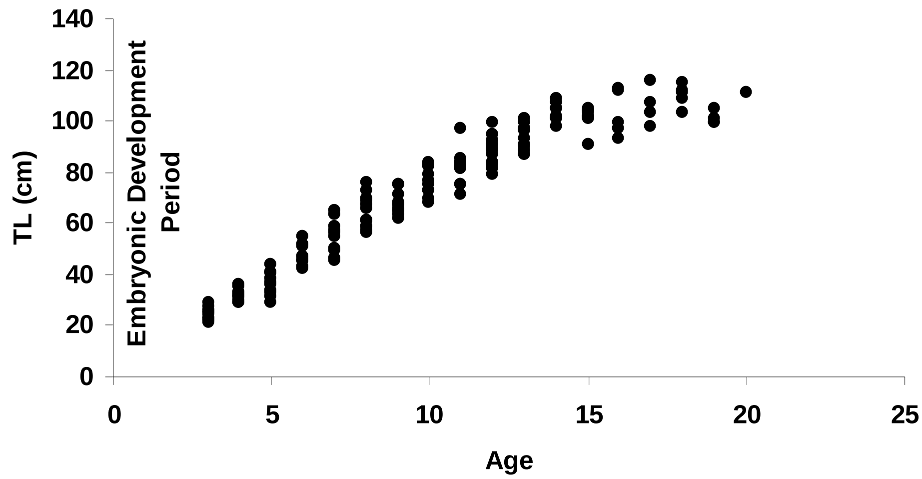


Figure 17-16. Observed size at age data from Alaska skates collected in the 2003 EBS shelf trawl survey, sexes combined (n=182). The three year embryonic development period included in the base model is represented by the shaded area.

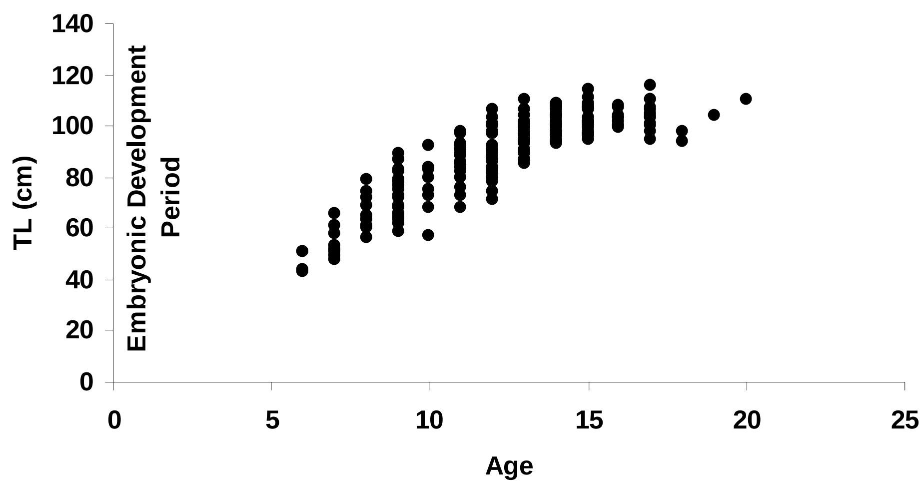


Figure 17-17. Observed size at age data from Alaska skates collected in the 2005 longline fishery, sexes combined (n=208). The three year embryonic development period included in the base model is represented by the shaded area.

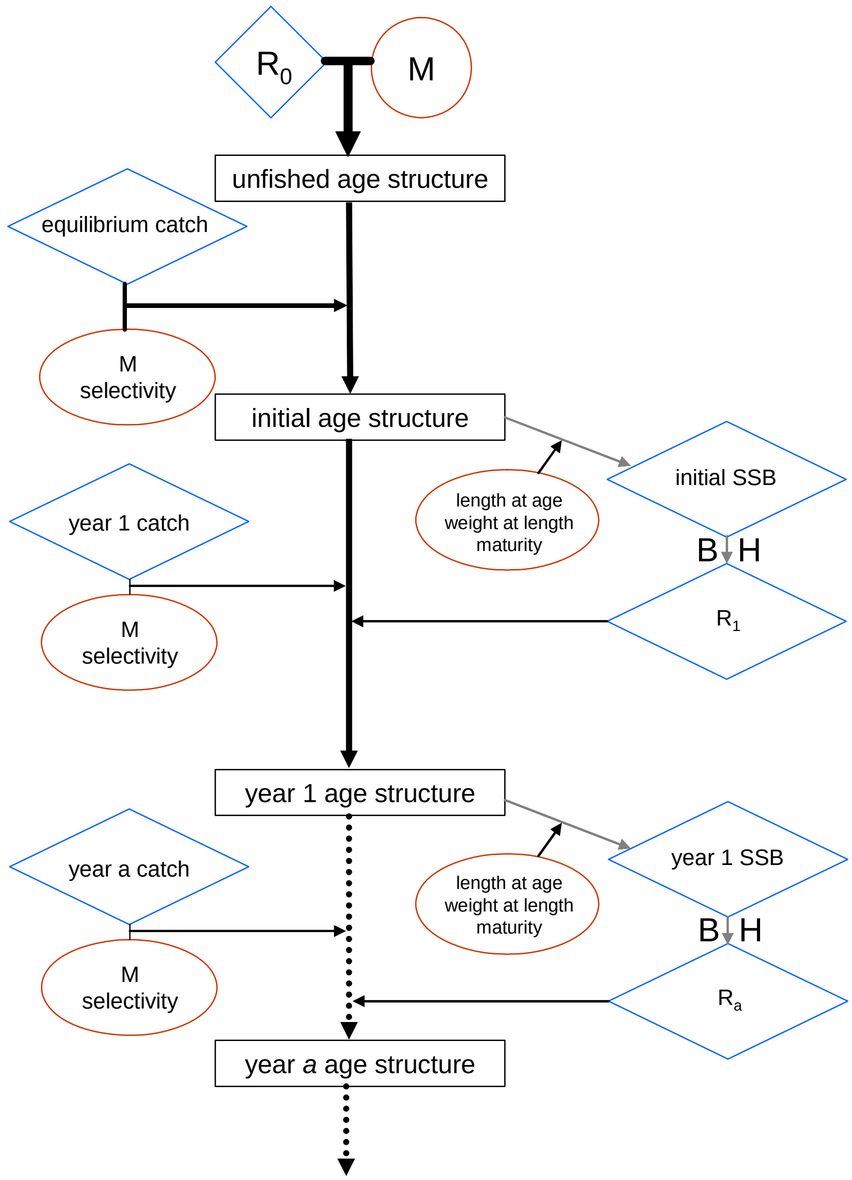


Figure 17-18. Simplified schematic depiction of population dynamics model used in the Alaska skate assessment. Blue diamonds indicate physical quantities, red circles indicate rates. R_a = recruitment in year a, M = natural mortality, SSB = spawning biomass, BH indicates that a Beverton-Holt stock-recruit relationship is applied to SSB to estimate recruitment.

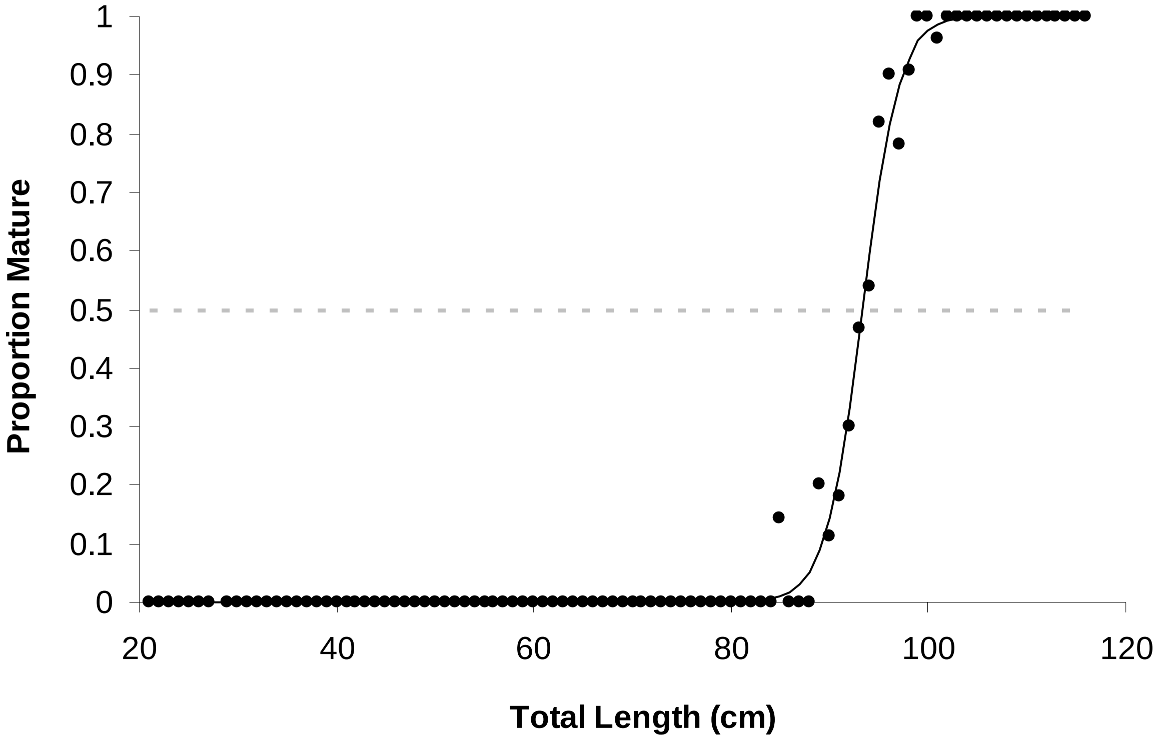


Figure 17-19. Female Alaska skate maturity-at-length data shown with fitted logistic curve from Matta (2006) (n=642).

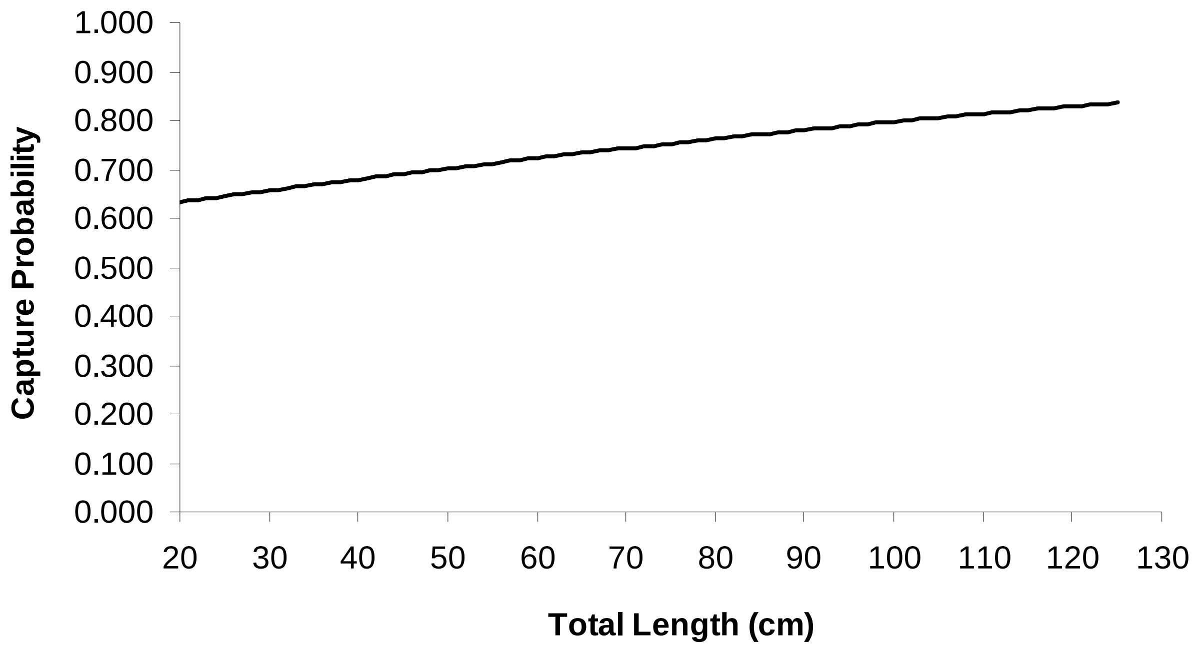


Figure 17-20. Length-based capture probability for skates (*Bathyraja* spp.) in the EBS shelf bottom trawl survey, based on data from Kotwicki and Weinberg (2005).

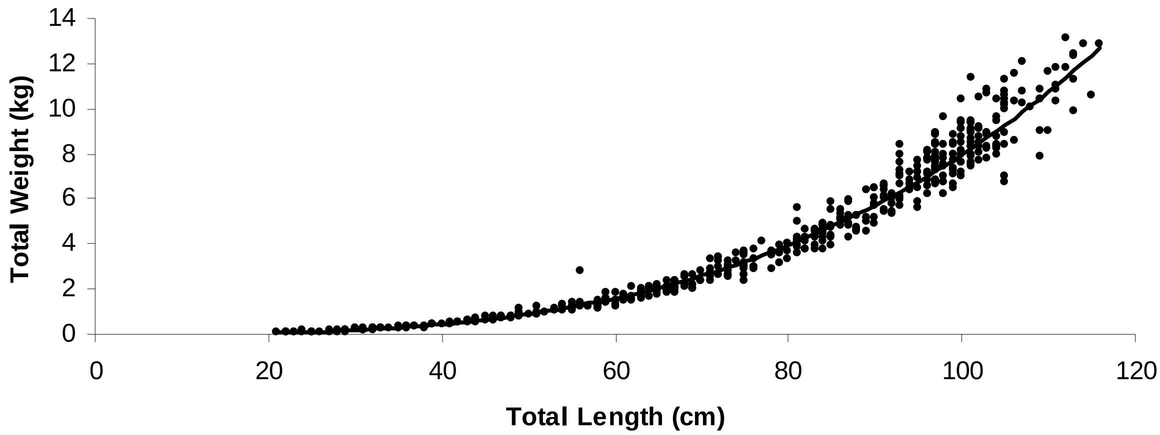


Figure 17-21. The relationship between total length (TL) and total body weight (W) for the Alaska skate, both sexes combined (n=526).

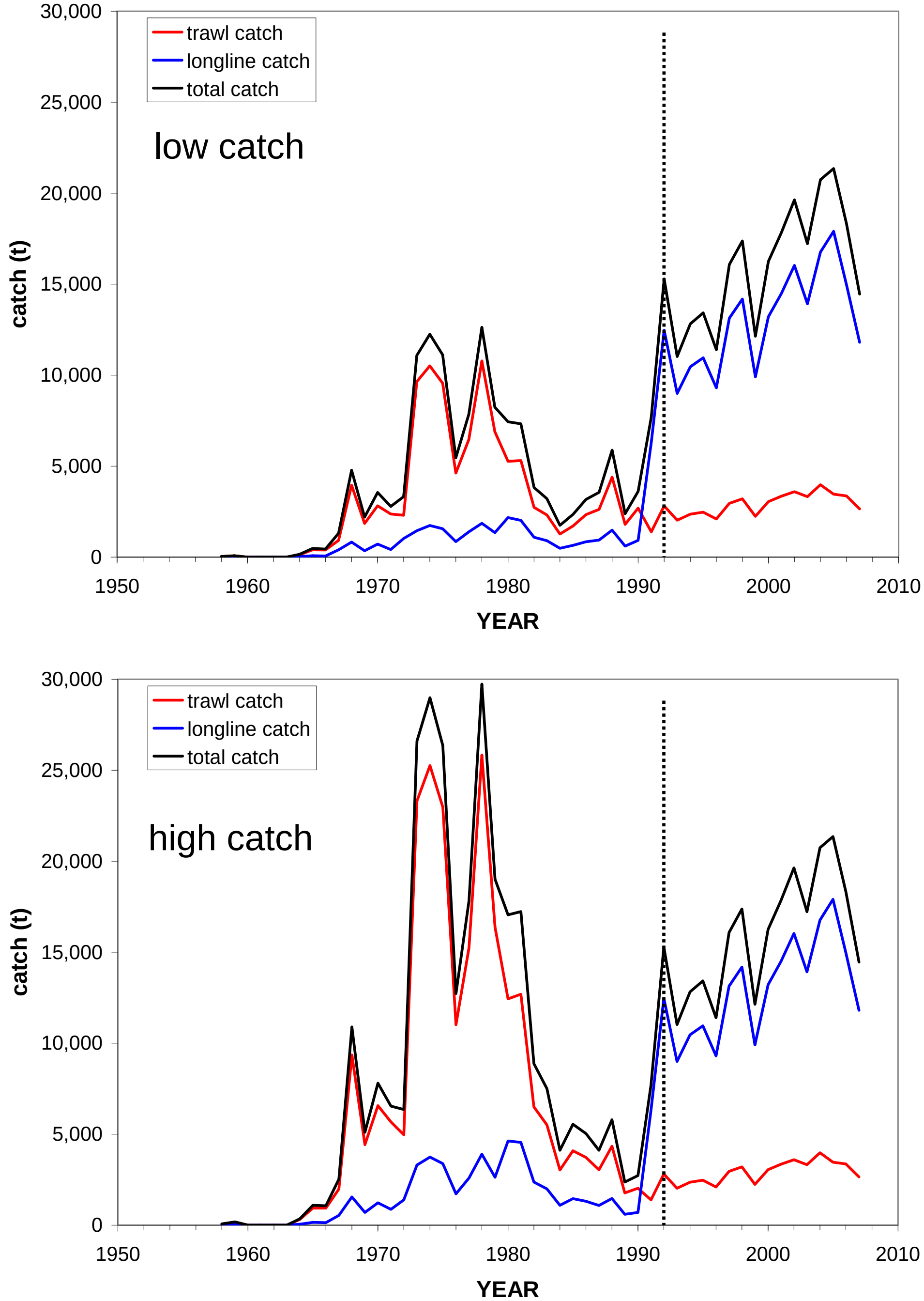


Figure 17-22. Estimated trawl, longline, and total catch of Alaska skates (t) in the BSAI used in the "low catch" and "high catch" alternative models. Non-target catch data from 1958-1991 were obtained from summary chapter of the 2006 BSAI SAFE report; data from 1992-2007 were obtained from the Blend system and AKRO CAS. Vertical line indicates the starting point of the base model as well as the division between catch data sources.

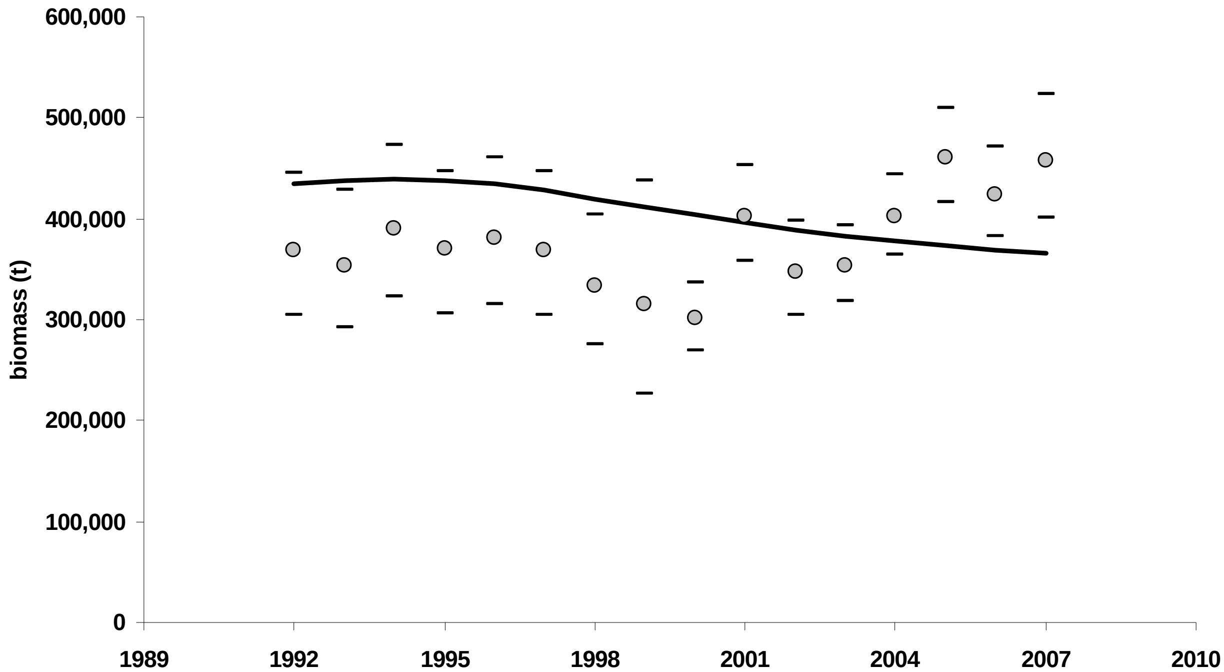


Figure 17-23. Observed biomass (circles) from EBS shelf surveys 1992-2007, with approximate confidence intervals (± 2 SE), and predicted survey biomass from the base model (black line).

Figure 17-24. Time series of total biomass (t) estimated in the base model.

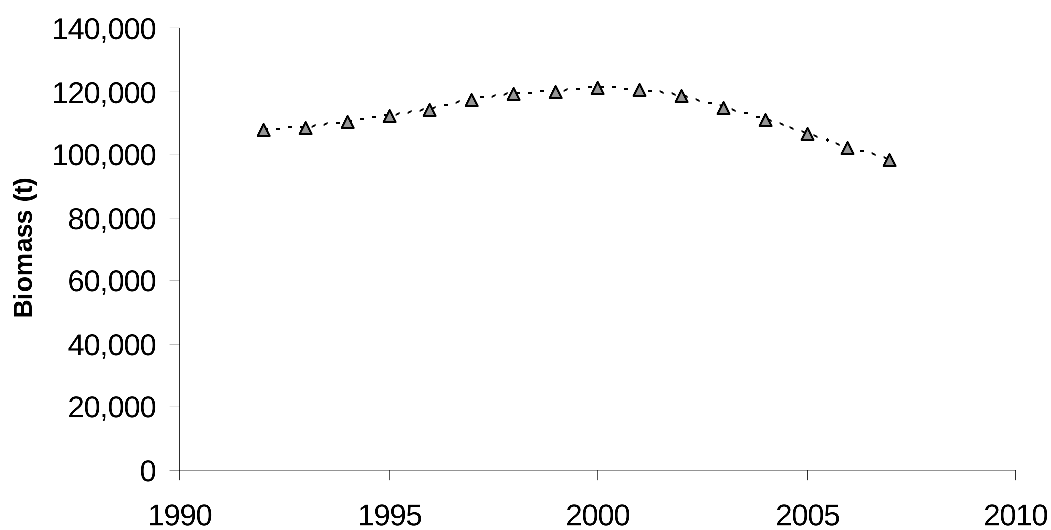


Figure 17-25. Time series of female spawning biomass (t) estimated in the base model.

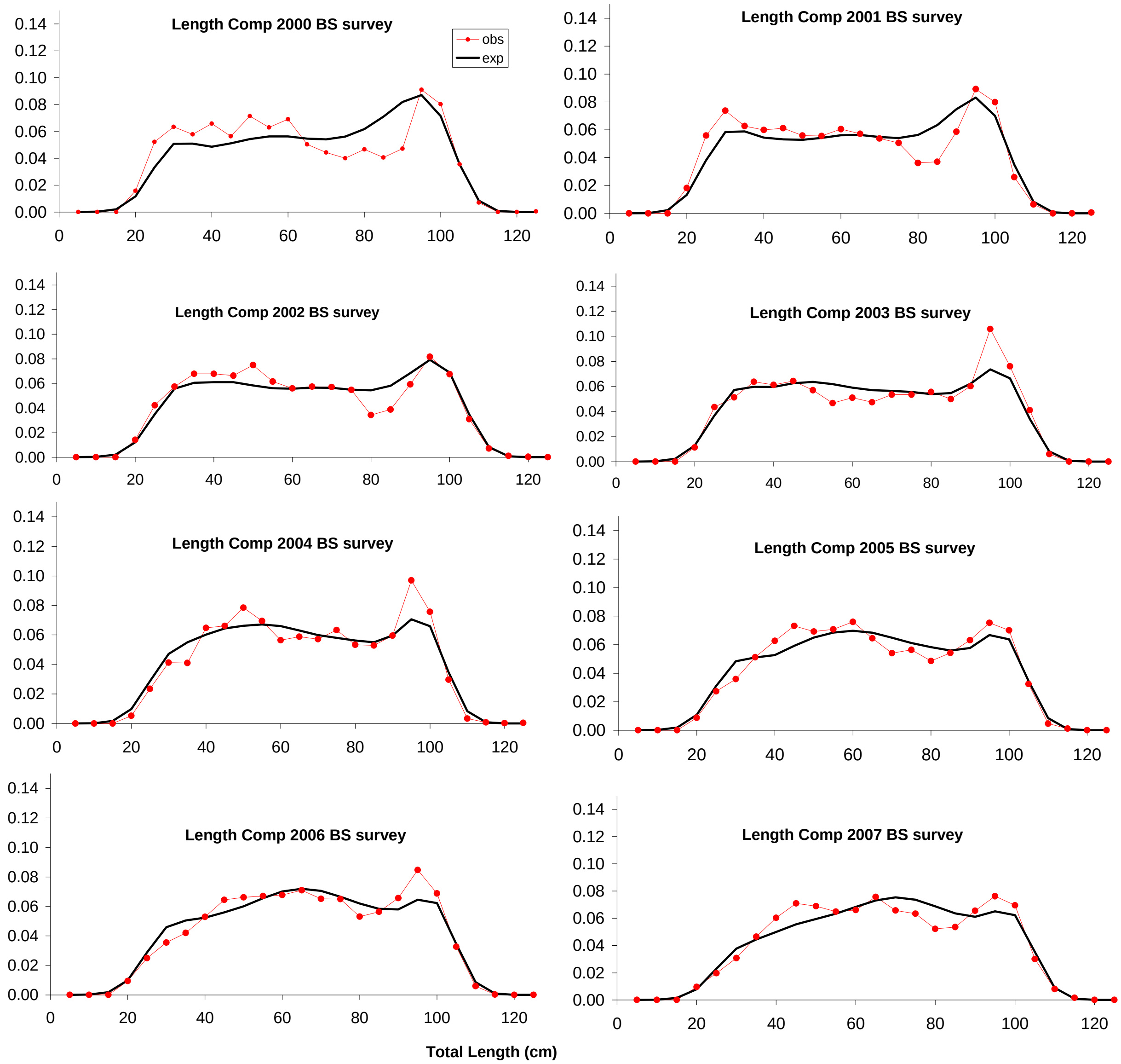


Figure 17-26. Observed length compositions from EBS shelf trawl survey data (red circles) and model predictions (black lines).

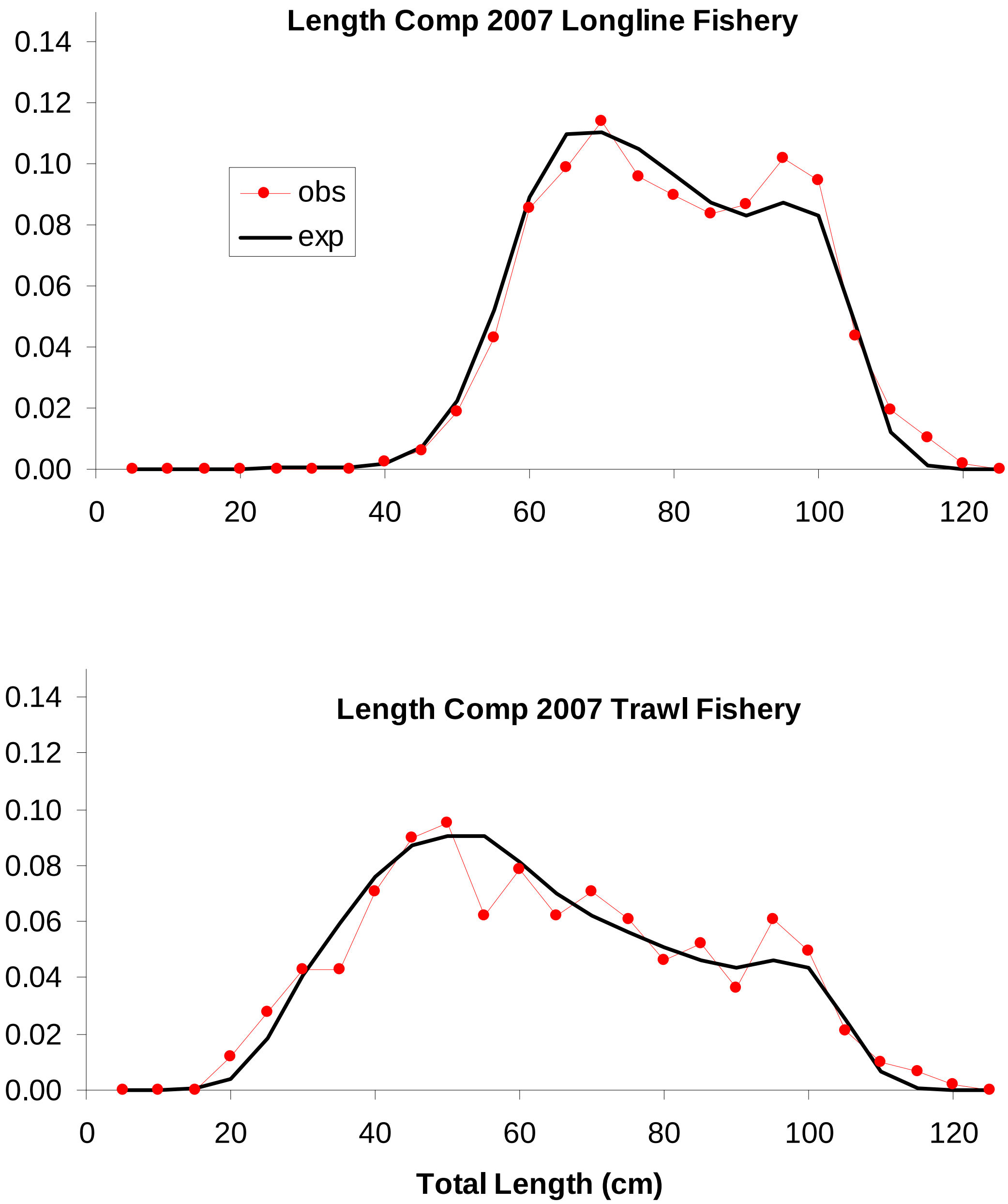


Figure 17-27. Observed length compositions from the 2007 longline (top) and trawl (bottom) fisheries, with model predictions.

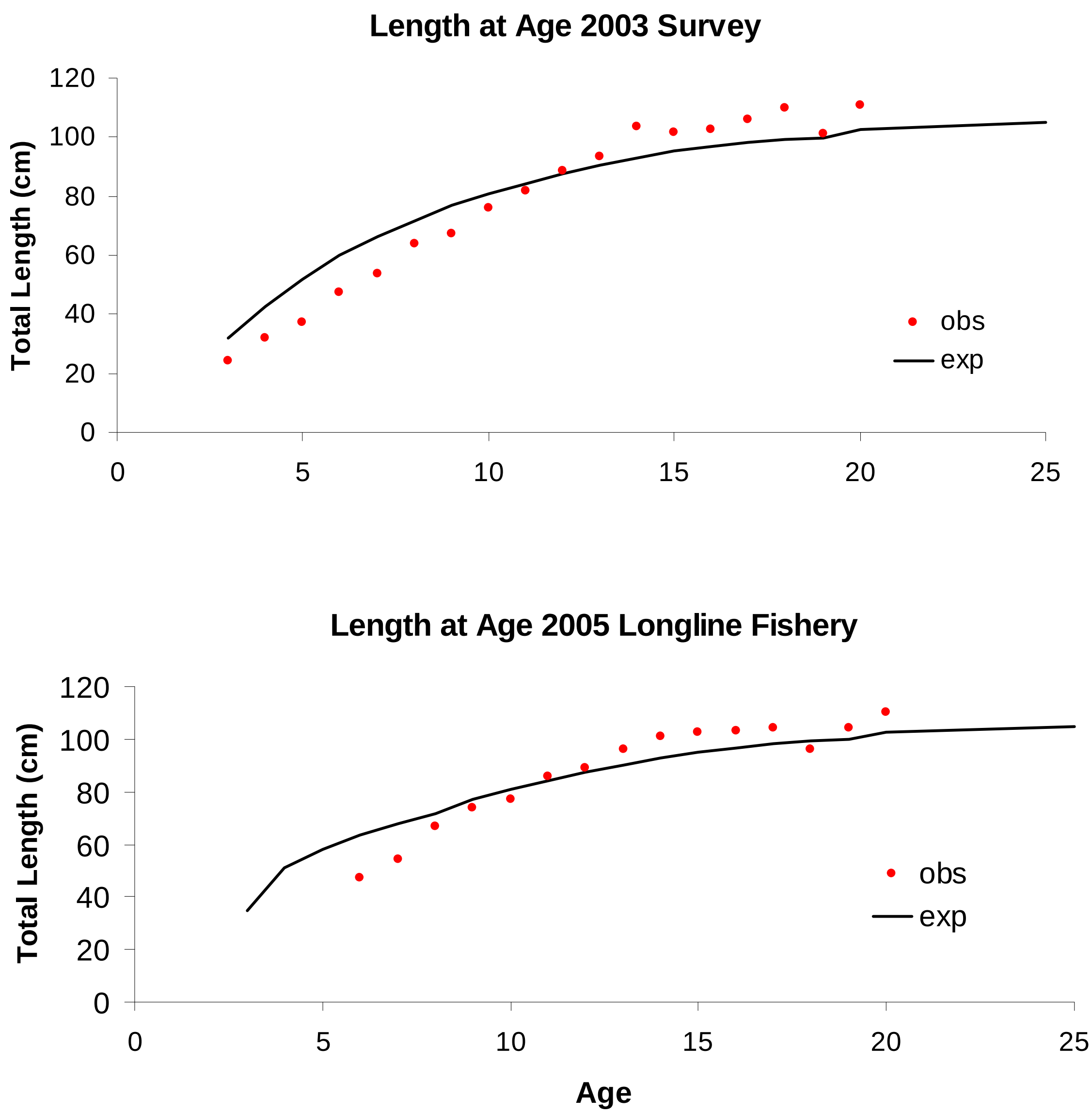


Figure 17-28. Observed length-at-age (cm) from the 2003 EBS shelf survey (top) and 2005 longline fishery (bottom), with model predictions.

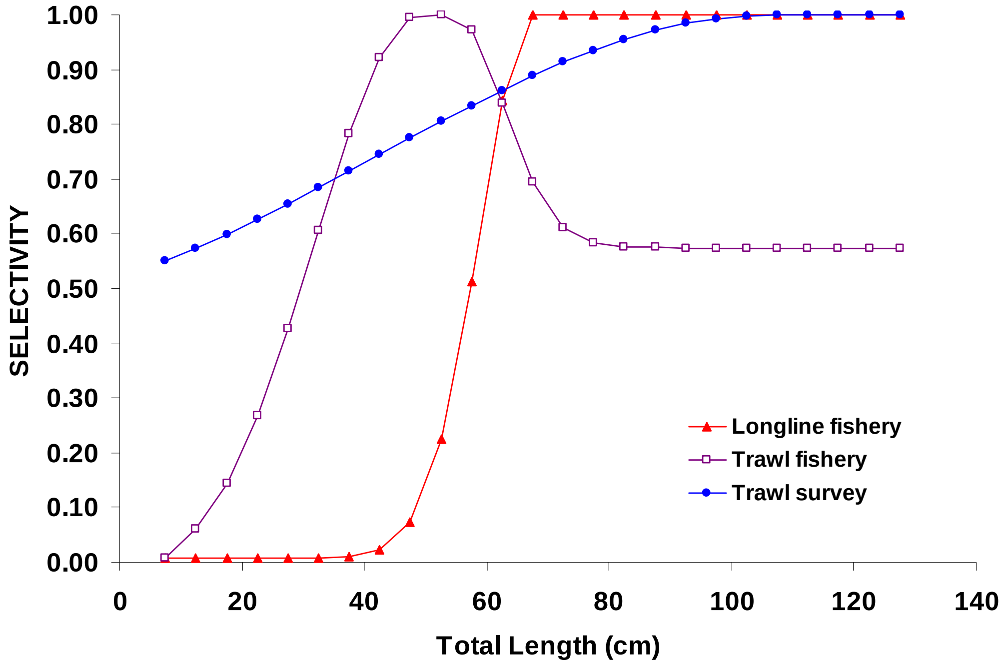


Figure 17-29. Length selectivities of the longline fishery, trawl fishery, and EBS shelf trawl survey.

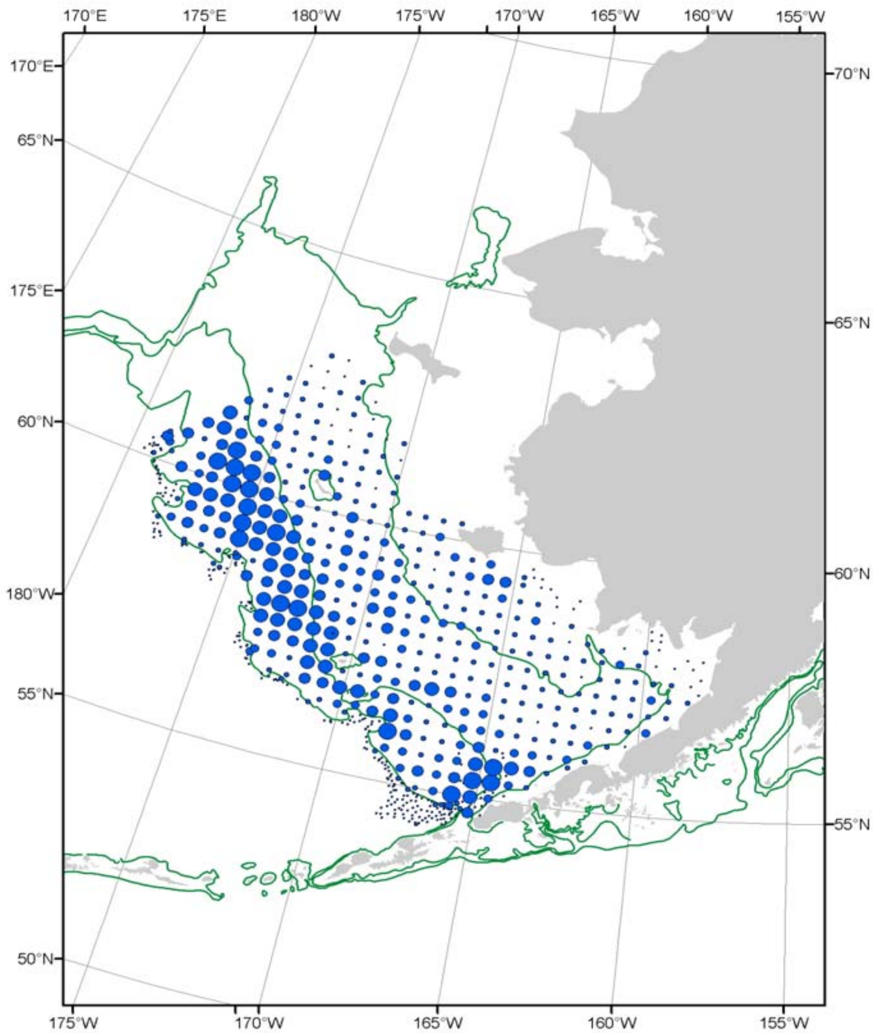


Figure 17-30. Distribution of mature Alaska skates (total length > 92.9 cm) in the EBS shelf trawl survey, 2000-2006. Figure is from Hoff 2007.

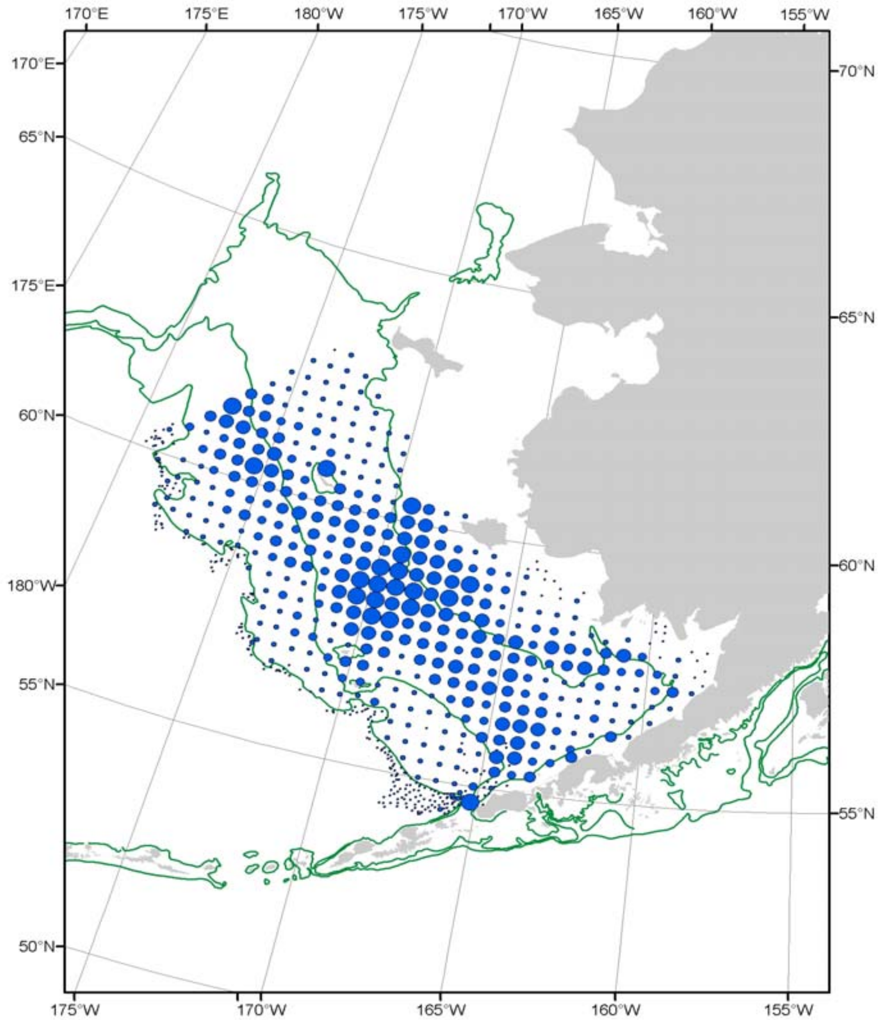


Figure 17-31. Distribution of immature Alaska skates (total length = 30.0 to 92.9 cm) in the EBS shelf trawl survey, 2000-2006. Figure is from Hoff 2007.

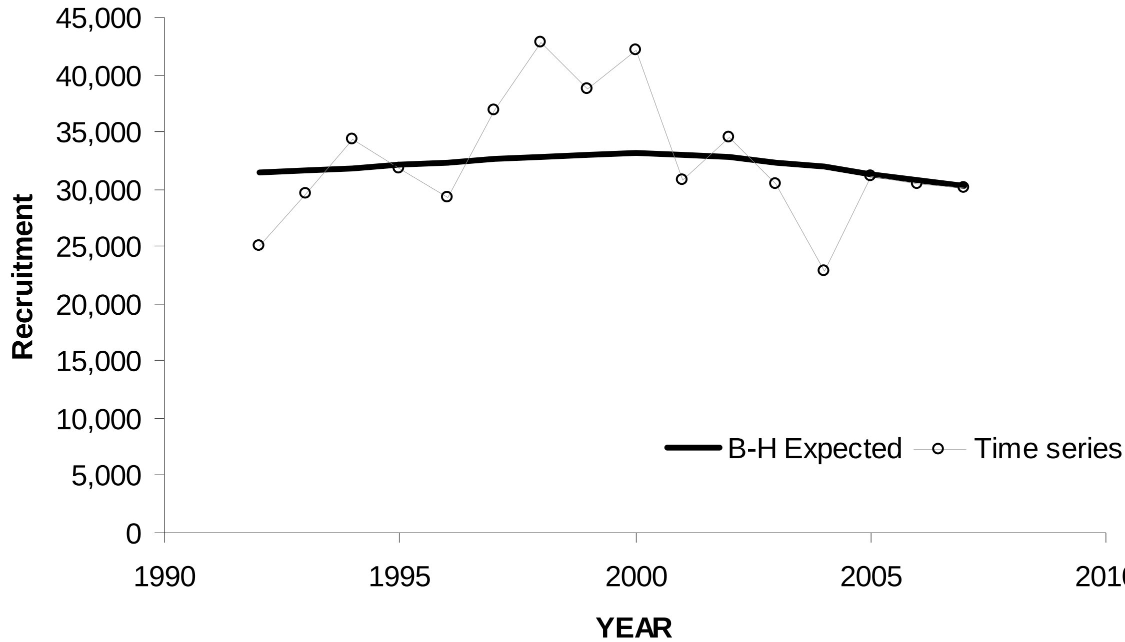


Figure 17-32. Time series of expected recruitment (in thousands of age 0 fish), with the time series of individual year class estimates predicted by the model and the expected Beverton-Holt stock-recruit relationship.

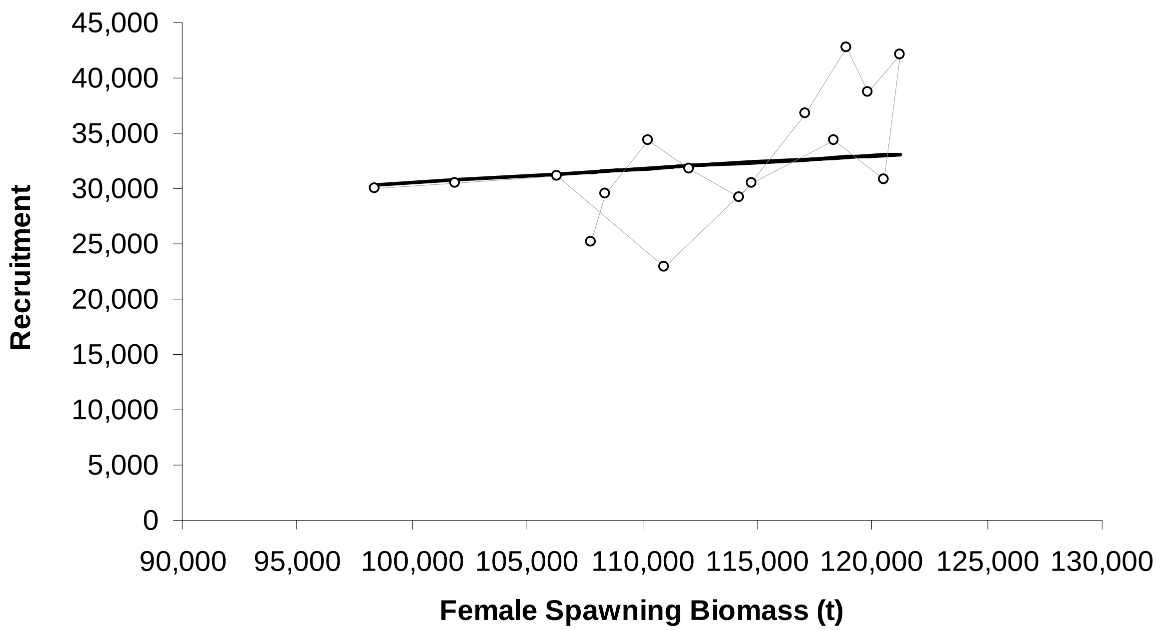


Figure 17-33. Relationship between the number of age 0 recruits (in thousands of fish) and female spawning biomass (t). Time series of individual year class estimates from SS2 is shown with a Beverton-Holt stock-recruit relationship.

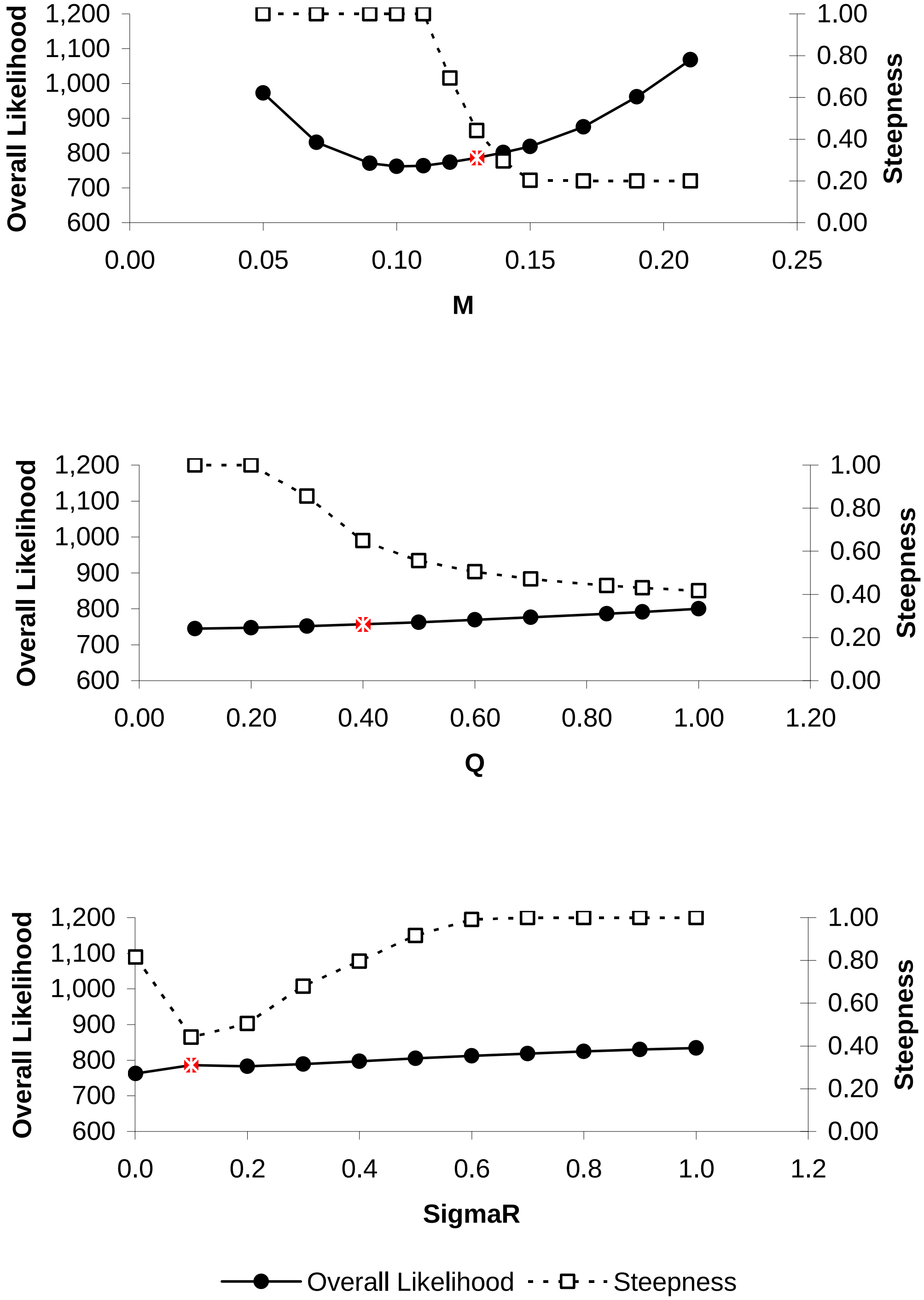


Figure 17-34. Likelihood profile analysis for the base model parameters M (top), Q (center), and σ^R (bottom). The effects of varying each parameter independently upon the overall likelihood of the model and upon the Beverton-Holt steepness parameter are depicted. Red squares show the final fixed values for each parameter.

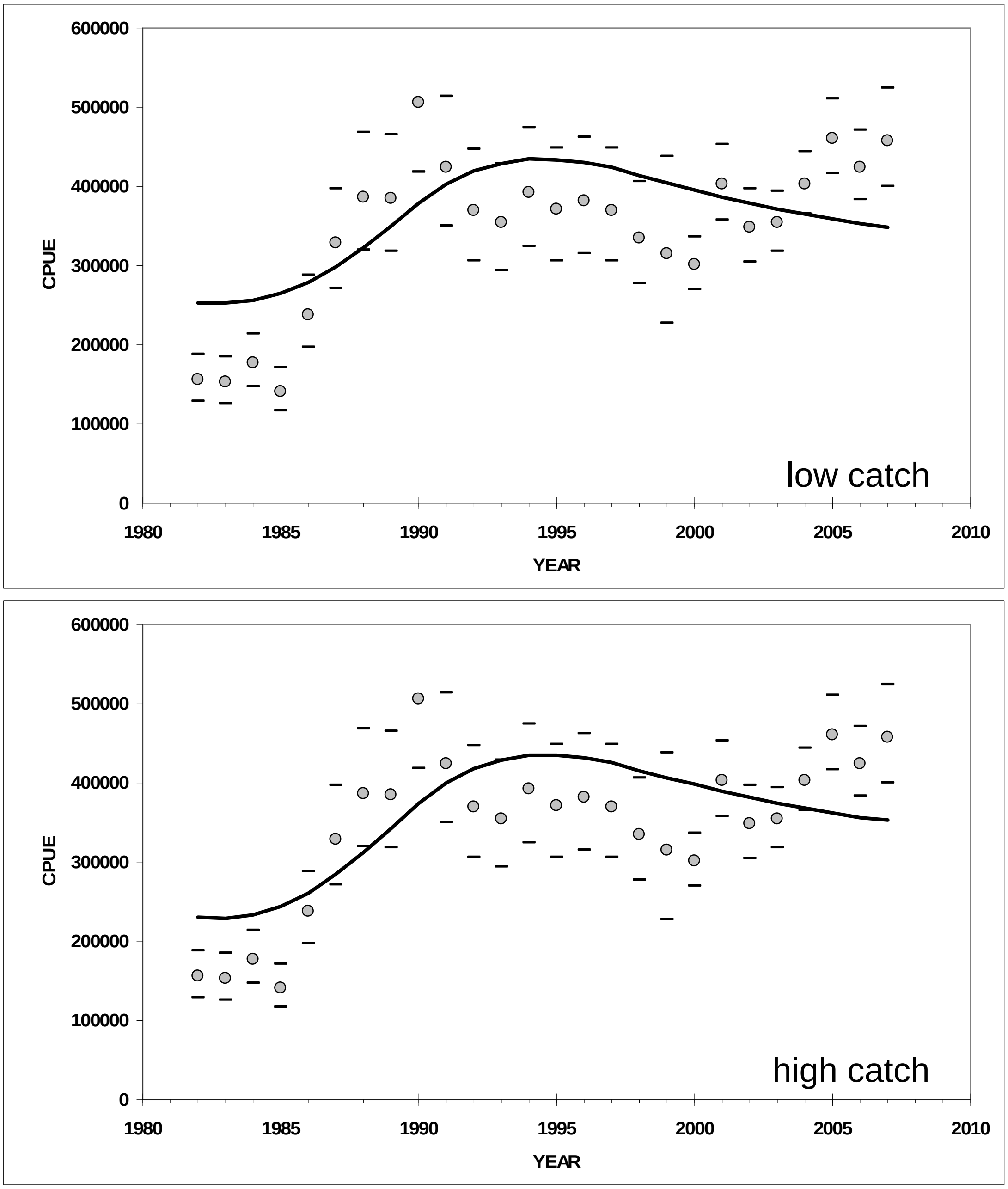
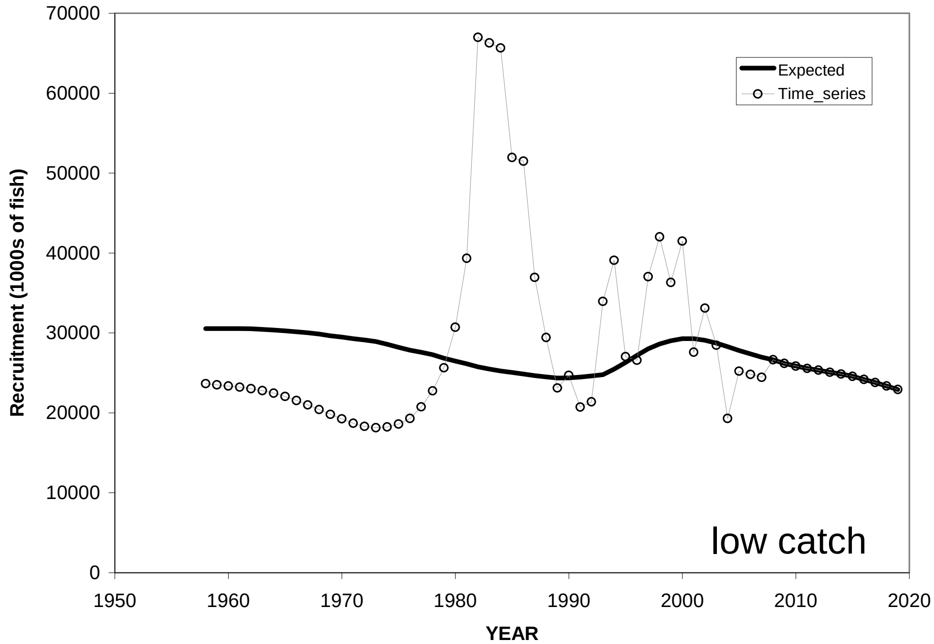


Figure 17-35. Observed and expected EBS shelf survey biomass of Alaska skates for “low catch” and “high catch” alternative models. Observed survey biomass estimates (t) from 1982 to 2007are shown as grey circles; expected shelf survey biomass (t) shown as black lines. Dashes indicate approximate 95% confidence intervals for the observed biomass estimates.



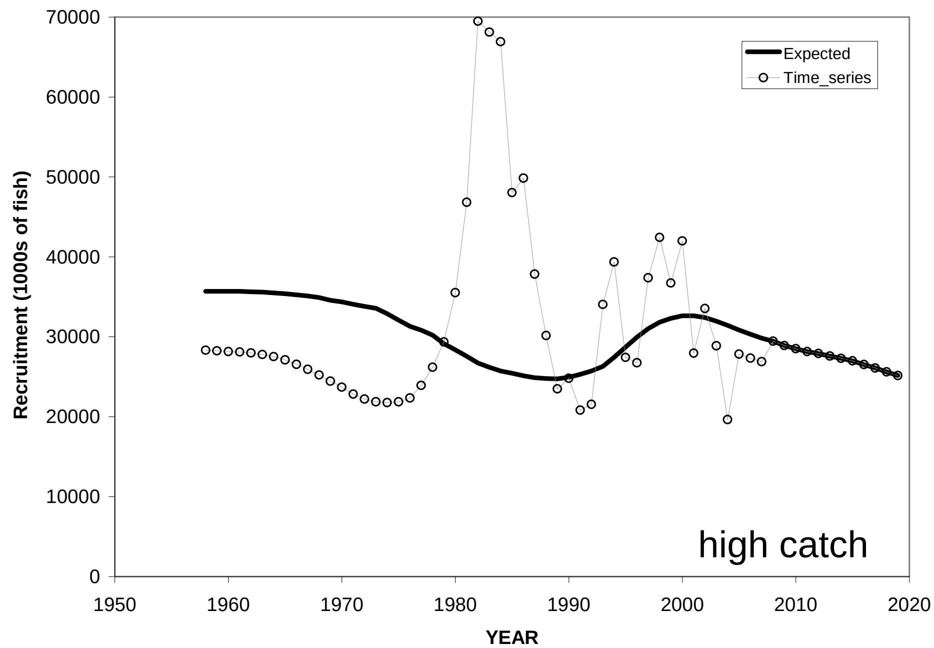


Figure 17-36. Relationship between the number of age 0 recruits (thousands of fish) and female spawning biomass (t) estimated by the “low catch” and “high catch” alternative models. Annual recruitment estimates from the 1958 models (open circles) are shown with the estimated Beverton-Holt stock-recruit relationship.

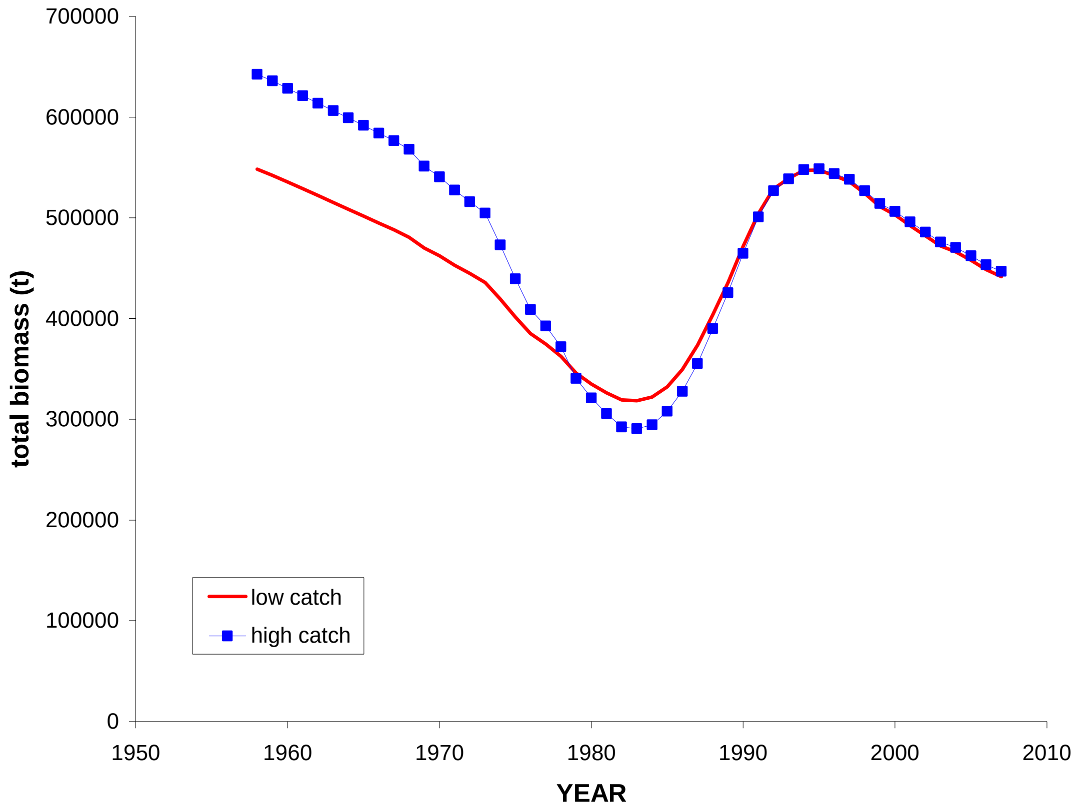


Figure 17-37. Total Alaska skate biomass estimates (t) from the "low catch" (red line) and "high catch" (blue line with squares) models.

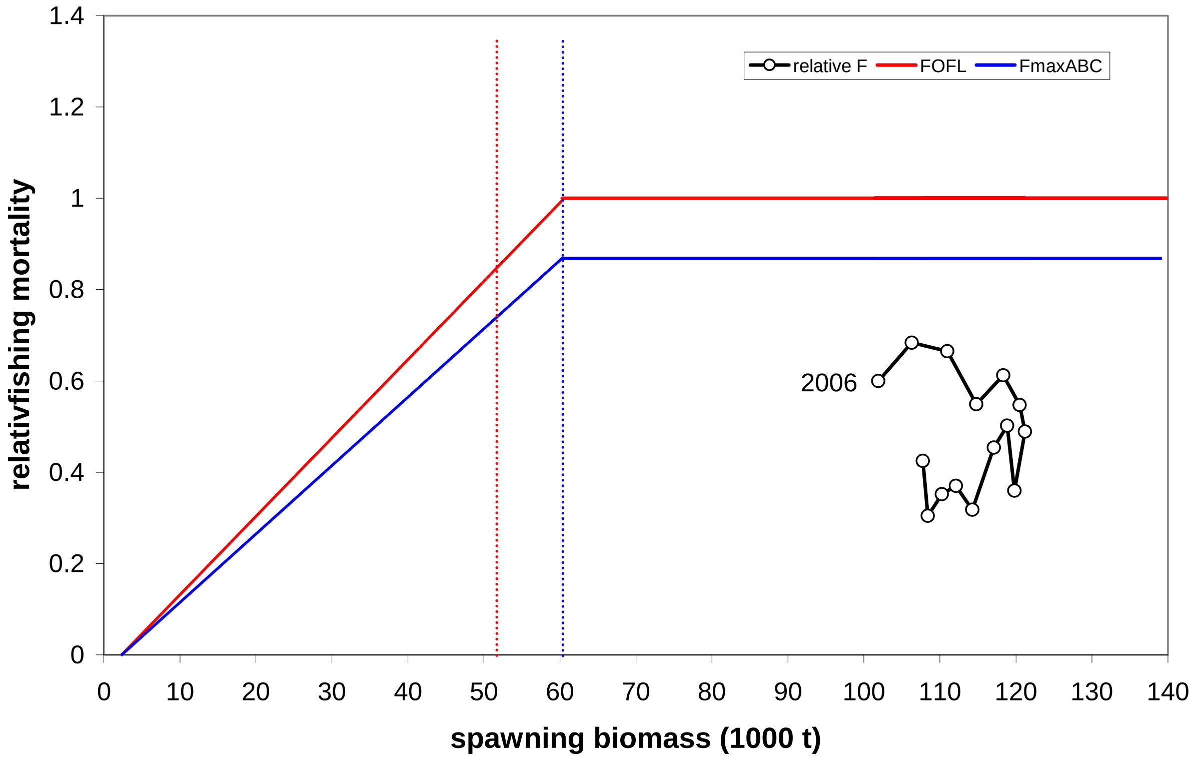


Figure 17-38. Relative fishing mortality ($F/F_{35\%}$) versus estimated spawning biomass for Alaska skates from 1992-2006. Black line with circles indicates observed fishing mortality rates; solid red line indicates F_{OFL}; solid blue line indicates F_{maxABC}. Dashed vertical red line indicates $B_{35\%}$; dashed vertical blue line indicates $B_{40\%}$.

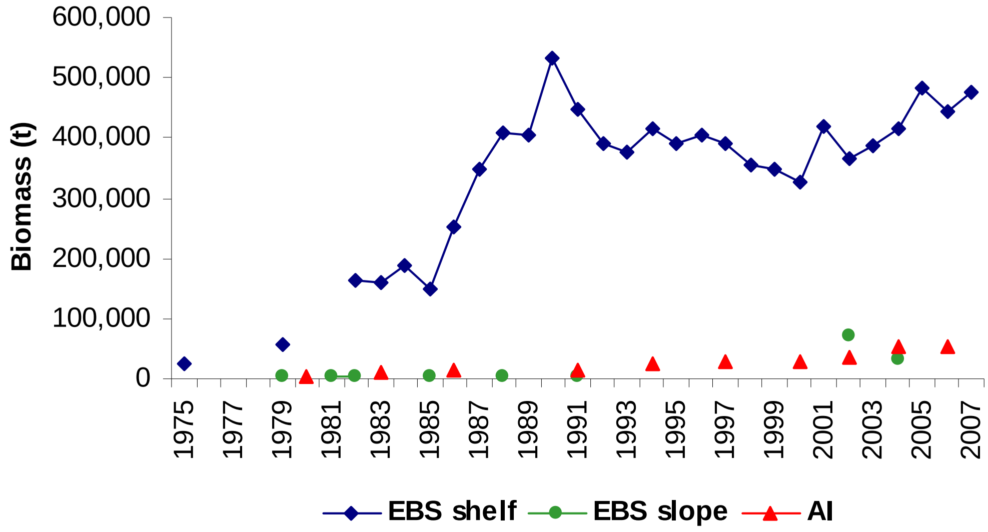


Figure 17-39. Aggregated skate biomass (metric tons) estimated from RACE scientific bottom trawl surveys in each of the three major habitat areas (1975 – 2007).

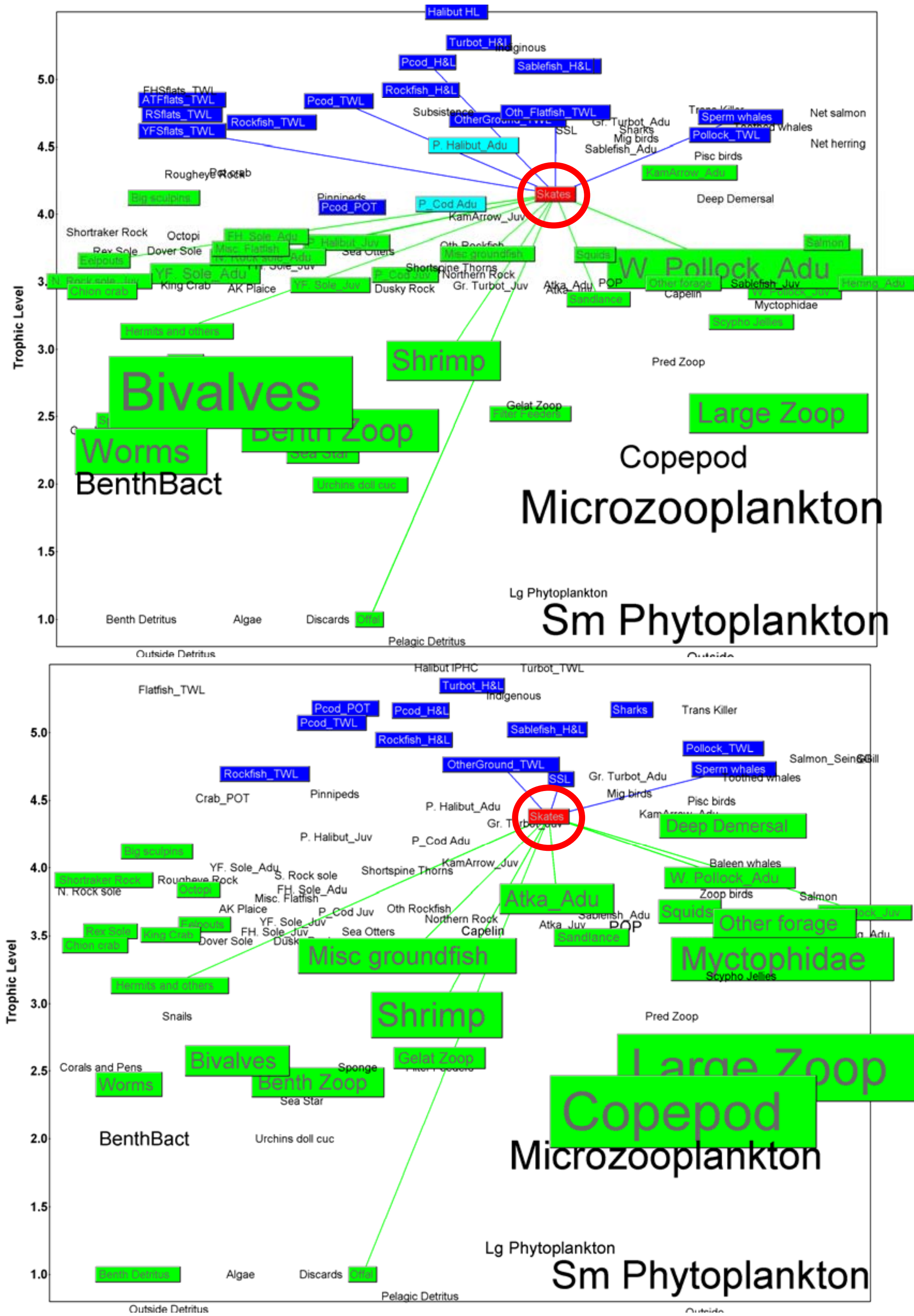


Figure 17-40. EBS (upper panel) and AI (lower panel) skate food webs derived from mass balance ecosystem models, with skate species aggregated in each area. (Source: K. Aydin, AFSC, code available upon request.)

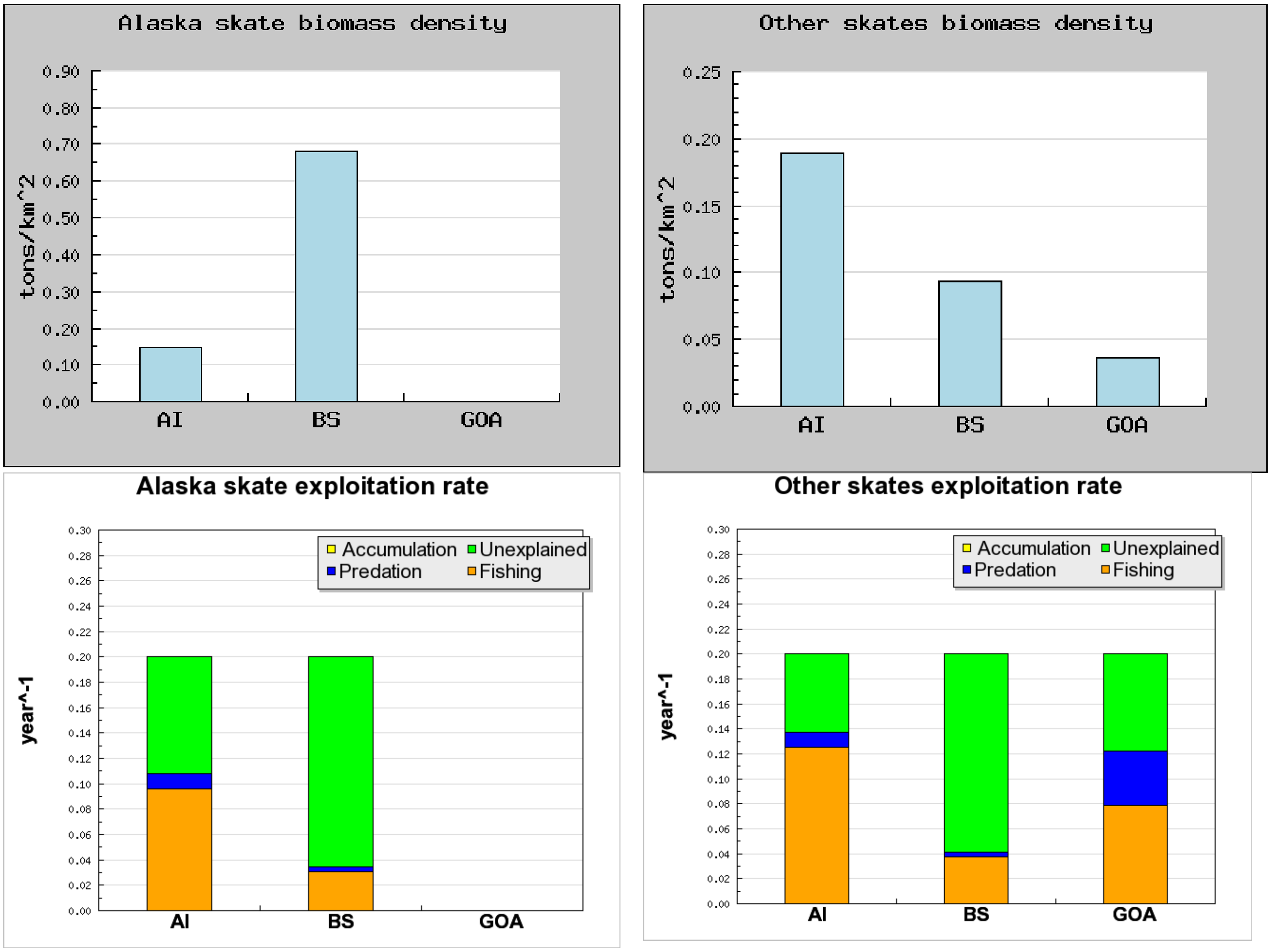


Figure 17-41. Comparative density (upper panels) and exploitation rate (lower panels) of Alaska (left panels) and all other *Bathyraja* (right panels) skates in the AI, EBS, and GOA (early 1990s, before fishery in GOA). (Alaska skates are a very small component of skate biomass in the GOA, and are therefore not modeled separately.) Note that the Other skates plot does not include the most common species in that region, the big skate and longnose skate—see the GOA skate SAFE for information on those skates. Biomass density plots are from trawl survey data; exploitation rate plots are derived from catch and biomass estimates and from assumed estimates of skate productivity (approximated from Frisk et al. 2001).

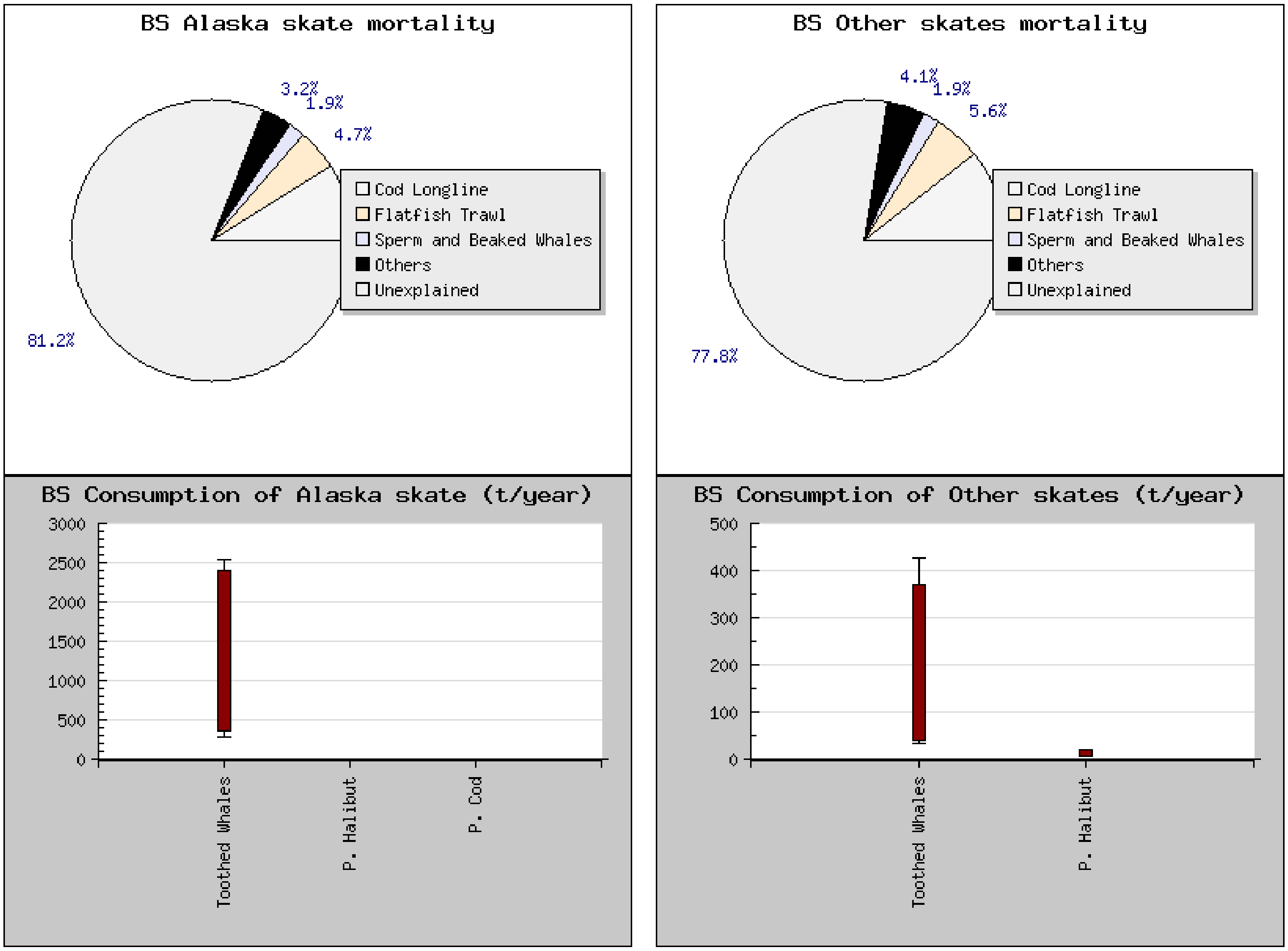


Figure 17-42. Mortality sources and consumption of skates in the EBS—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for EBS Alaska skates (left panels) and all other EBS skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

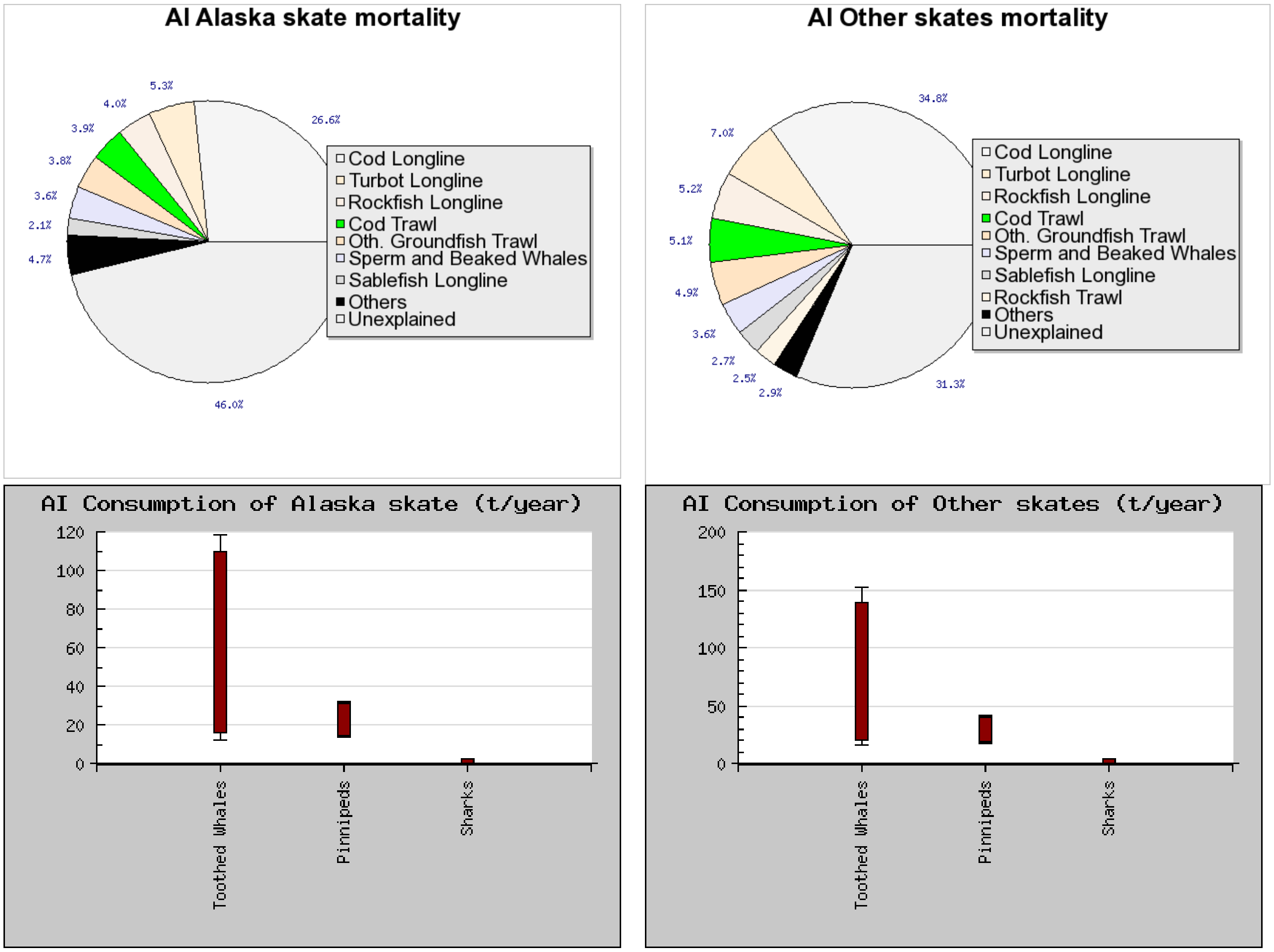


Figure 17-43. Mortality sources and consumption of skates in the AI—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for AI (former) Alaska skate (left panels) and AI Other Skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

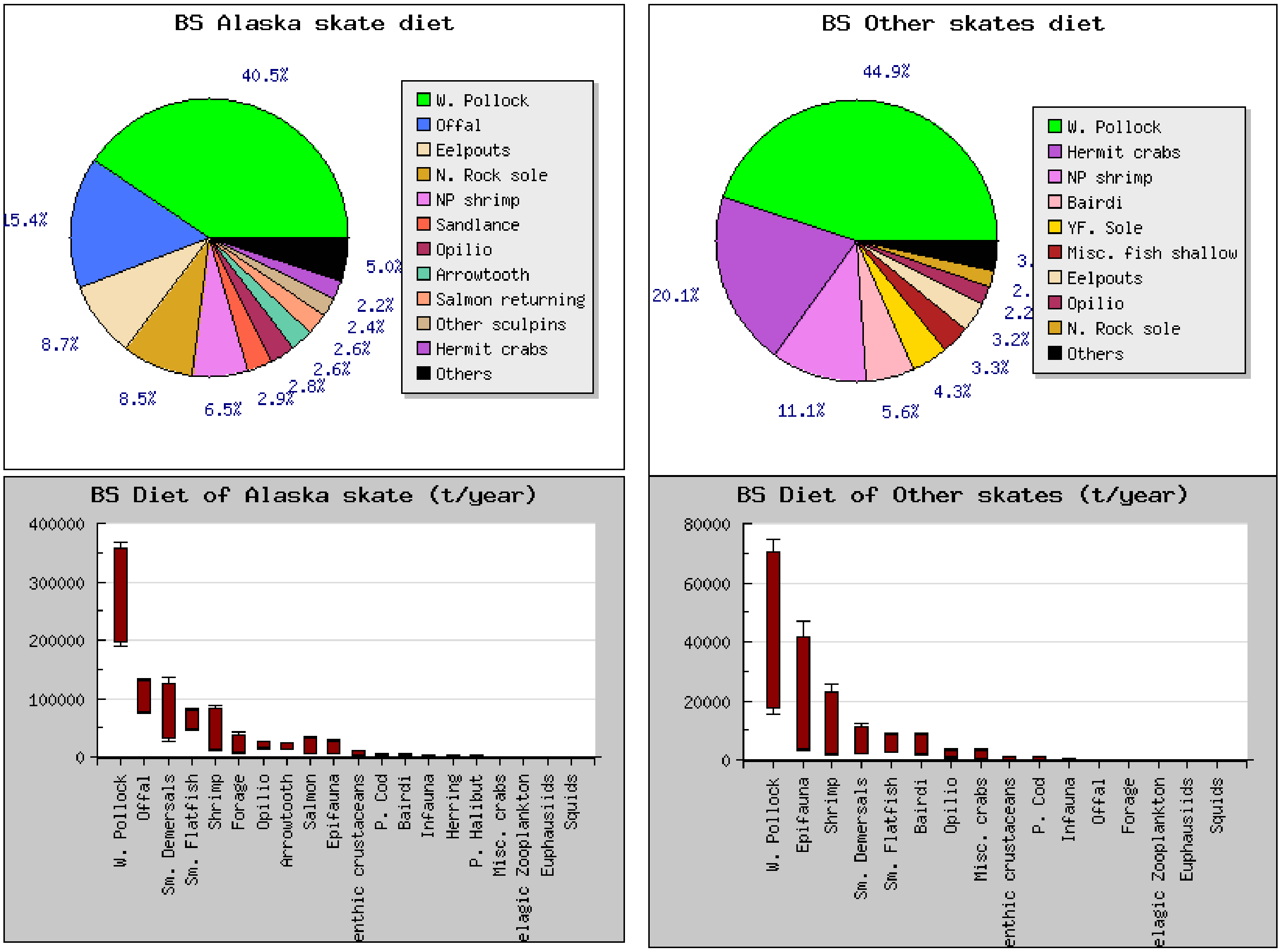


Figure 17-44. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for EBS Alaska skates (left panels) and Other Skates (right panels). Results were generated from stomach content collections occurring during RACE trawl surveys.

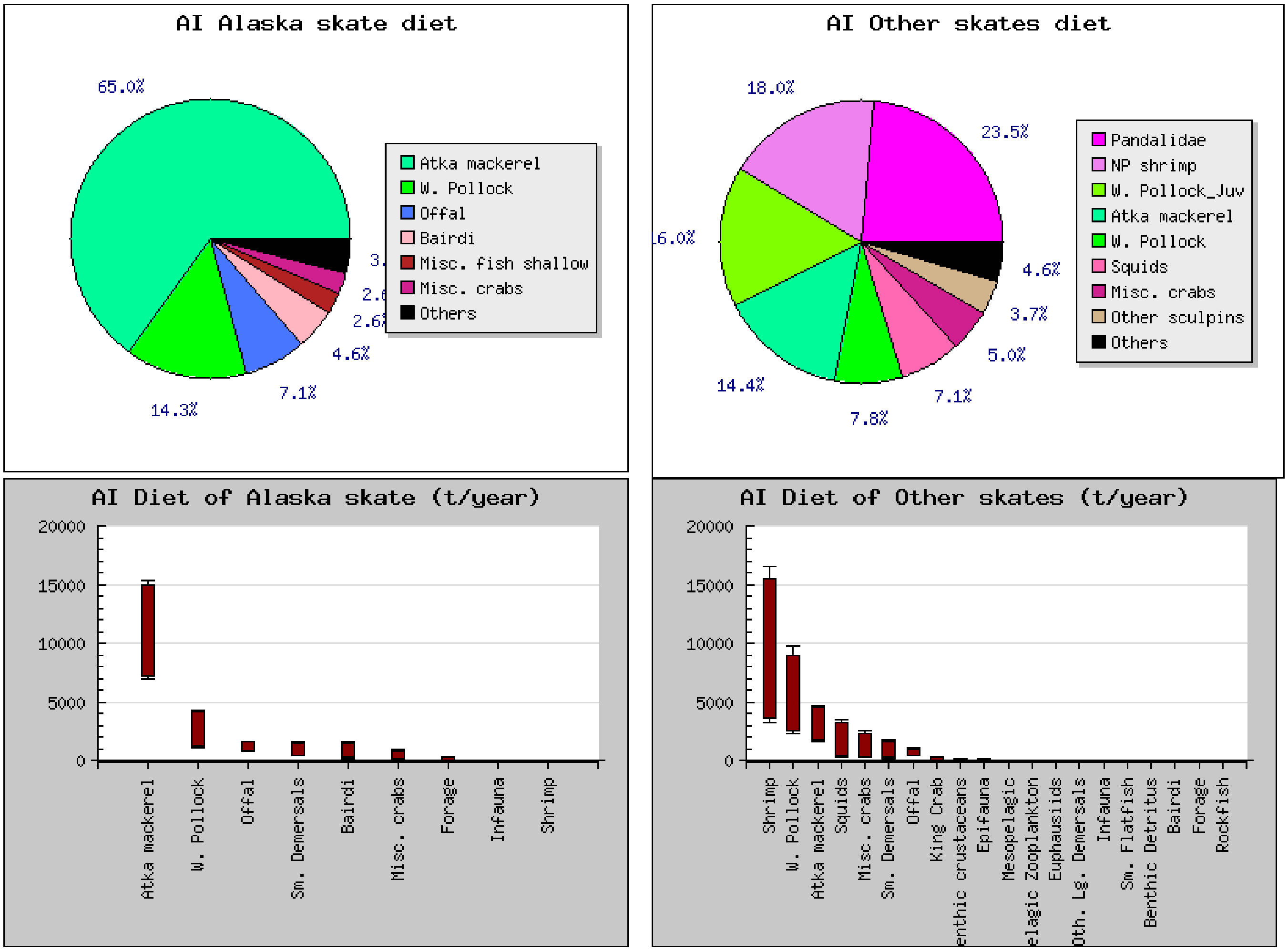
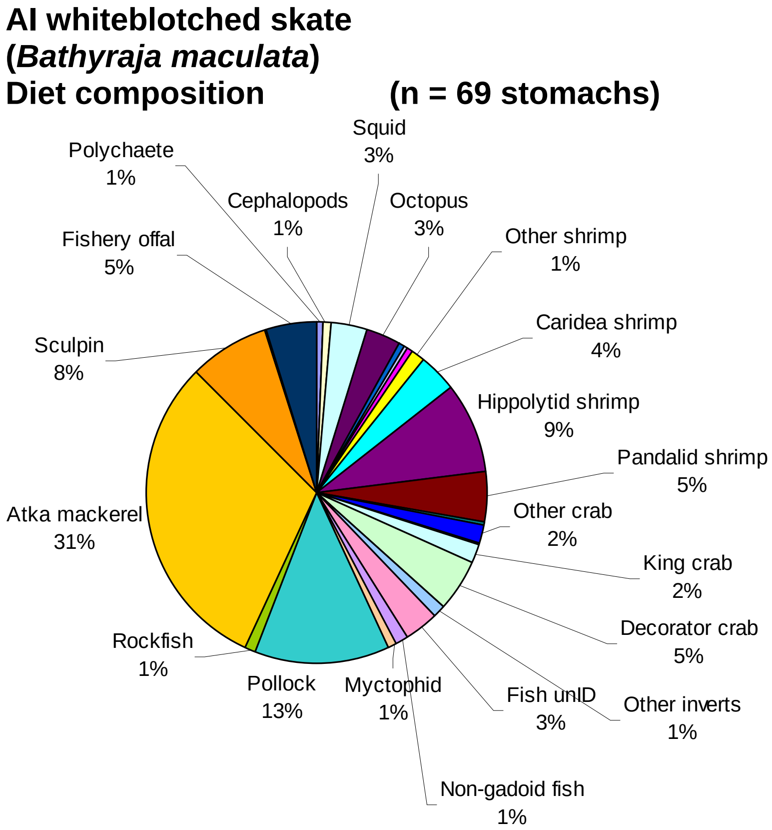


Figure 17-45. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for AI Alaska skates (left panels) and Other Skates (right panels). Consumption rates were estimated using published diet data from the Kuril Islands (Orlov 1998, 1999) and estimated prey densities.



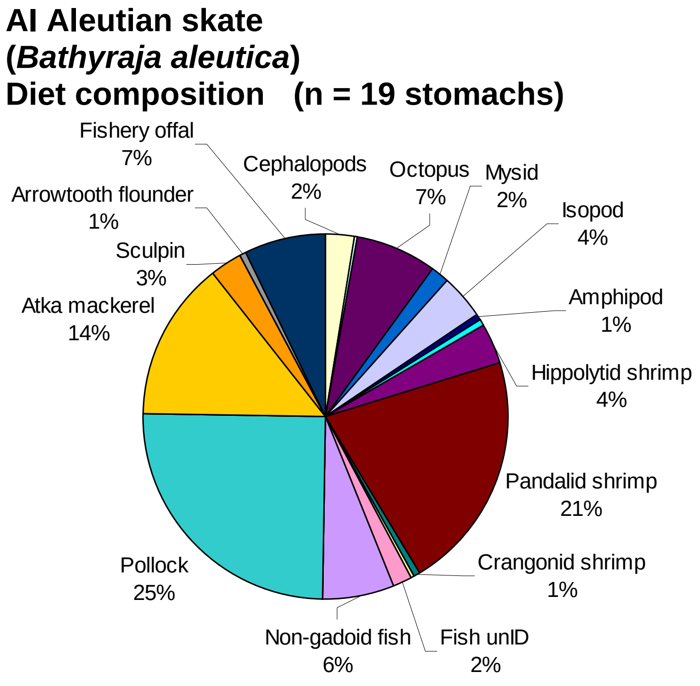


Figure 17-46. Diet composition (by weight) for the other two biomass-dominant skate species in the Aleutian Islands (which are included in the "Other Skates" group in the previous figure): whiteblotched skate (top) and Aleutian skate (bottom). Results were generated from stomach content collections occurring during trawl surveys, and are described in more detail in Yang (2007).