18a. Bering Sea and Aleutian Islands skates

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Executive Summary

The Bering Sea and Aleutian Islands (BSAI) skate complex is managed in aggregate, with a single set of harvest specifications applied to the entire complex. Beginning with the 2008 assessment, harvest recommendations for Alaska skate (*Bathyraja parmifera*), the most abundant skate specie sin the BSAI, are made using the results of an age structured model and Tier 3. The remaining species ("other skates") are managed under Tier 5 due to a lack of data. The Tier 3 and Tier 5 recommendations are combined to generate recommendations for the complex as a whole.

Summary of Major Changes

In 2010, the North Pacific Fishery Management Council passed amendment 95 to the BSAI Fishery Management Plan, which removed skates from the Other Species complex and into the target category. Amendment 96 eliminated the Other Species complex and requires separate annual catch limits for its constituent species groups. Thus, BSAI skates will now be managed as an independent complex with its own harvest specifications.

Changes in the input data:

- Total catch (t) for the BSAI skate assemblage has been updated through October 10, 2010.
- Biomass estimates from the 2010 EBS shelf , EBS slope, and Aleutian Islands surveys were incorporated for all species.
- Fishery and survey length composition data have been updated.

Changes in assessment methodology:

- For the 2010 assessment, all size composition datasets used in the Alaska skate model are assigned an *N* of 100 (previously, a weighted # of actual hauls was used).
- A slightly different approach to estimating average biomass for Other Skates was used: for each subregion (EBS shelf, EBS slope and AI), biomass was estimated as the average of the 3 most recent surveys. This compares to the 9-year average used in previous assessments.

Summary of results

The ABC and OFL recommendations for Alaska skates and Other Skates are slightly higher in the 2010 assessment than in 2009. The model estimate of total and spawning biomass was down slightly relative to 2009, but the allowable *F*s were a bit larger, resulting in a small increase in the recommendations. For Other Skates, the average biomass estimate increased due to new survey data and the adoption of a 3-survey-average approach. The 2010 survey and 2009 fishery length compositions were very similar to those in the previous year.

Alaska skate harvest recommendations				
	Last year		**This year**	
Quantity/Status	2010	2011	**2011**	2012
M (natural mortality)	0.13	0.13	**0.13**	0.13
Specified/recommended Tier	3a	3a	**3a**	3a
Projected biomass (ages 0+)	525,887	522,177	**517,384**	502,627
Female spawning biomass (t)				
Projected	57,192	56,788	**53,188**	52,692
$B_{100\%}$	90,573	90,573	**88,637**	88,637
$B_{40\%}$	36,229	36,229	**35,455**	35,455
$B_{35\%}$	31,700	31,700	**31,023**	31,023
F_{OFL}	0.08	0.08	**0.09**	0.09
$maxF_{ABC}$ (maximum allowable = F40%)	0.069	0.069	**0.077**	0.077
Specified/recommended F_{ABC}	0.069	0.069	**0.077**	0.077
Specified/recommended OFL (t)	27,817	27,665	**28,348**	27,700
Specified/recommended ABC (t)	24,017	23,886	**24,421**	23,864
Is the stock being subjected to overfishing?	No	No	**No**	No
Is the stock currently overfished?	No	No	**No**	No
Is the stock approaching a condition of being overfished?	No	No	**No**	No

other skates harvest recommendations				
	last year		**this year**	
Quantity/Status	*2010*	*2011*	**2011**	2012
M (natural mortality)	*0.1*	*0.1*	**0.1**	0.1
Specified/recommended Tier	*5*	*5*	**5**	5
3-survey average biomass estimate	*82,207*	*82,207*	**94,690**	94,690
F_{OFL} (F=M)	*0.1*	*0.1*	**0.1**	0.1
$maxF_{ABC}$ (maximum allowable = 0.75 x F_{OFL})	*0.075*	*0.075*	**0.075**	0.075
Specified/recommended F_{ABC}	*0.075*	*0.075*	**0.075**	0.075
Specified/recommended OFL (t)	*8,221*	*8,221*	**9,469**	9,469
Specified/recommended ABC (t)	*6,166*	*6,166*	**7,102**	7,102
Is the stock being subjected to overfishing?	*no*		**no**	
(for Tier 5 stocks, data are not available to determine whether the stock is in an overfished condition)				

aggregate harvest recommendations for the BSAI skate complex				
Specified/recommended OFL (t)	*36,038*	*35,886*	**37,817**	37,169
Specified/recommended ABC (t)	*30,183*	*30,052*	**31,523**	30,966

Responses to SSC Comments

<u>SSC comments specific to the BSAI Skates assessment:</u>
The SSC provided extensive comments regarding the lack of fit to survey size-at-age data for the Alaska skate, and requested presentation of a revised model with more realistic representation of growth. Due to time constraints, this was not possible, but the authors expect to be able to provide this next year.

Response: Due to time constraints and continued problems with the SS3 growth models, the same model used in 2009 was used in 2010, with the addition of new data. The results were very similar to the 2009 assessment, and the fit to the length-at-age data continue to be problematic. We plan to address this next year.

General Introduction

<u>Description, scientific names, and general distribution</u>

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 (Fig. 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 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 (Fig. 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) (Fig. 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 at 250 to 500 m depth (Fig. 4; Stevenson et al. 2006). The EBS shelf skate complex is dominated by a single species, the Alaska skate (*Bathyraja parmifera*) (Table 2 & Fig. 3). The Alaska skate is distributed throughout the EBS shelf habitat area (Fig. 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 (Fig. 6).

While skate biomass is much higher on the EBS shelf than on the slope, skate diversity is substantially greater on the EBS slope (Fig. 3). The dominant species on the EBS slope is the Aleutian skate (*B. aleutica*) (Table 2 & Fig. 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 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 2 & Fig. 3). The whiteblotched skate is found primarily in the eastern and far western Aleutian Islands (Fig. 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 (Fig. 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 currently managed as part of the "Other species" management category within the Bering Sea Aleutian Islands (BSAI) Fishery Management Plan (FMP). 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). In October 2009 the NPFMC approved amendment 95 to the BSAI FMP, which separates skate from the BSAI Other Species complex. Beginning in 2011, skates will be managed as a single complex with skate-specific ABC and OFL. Currently 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.

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).

Life history and stock structure (Alaska-specific)

Known life history parameters of Alaskan skate species are presented in Table 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 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 needs to 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 (Fig. 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 in Bering Canyon 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 (Fig. 10; 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 (Fig. 11; 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% per year (Hoff 2007). 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 pers. comm.), 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

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 only reports species-specific catch for big (*Raja binoculata*) and longnose (*Raja rhina*) skates. All remaining skate species are reported as "other". Big and longnose skates make up only a small fraction of BSAI skate biomass, which is dominated by the Alaska skate. The fraction of Alaska skate catch in the total "other skates" is estimated by applying the average species composition encountered during trawl surveys (see Data section below). Changes to the CAS in 2009 resulted in slightly different catch estimates for 2003-2008 and the data in this assessment are updated accordingly.

Skates constitute the bulk of the Other Species FMP category catches, accounting for between 51% and 75% of the estimated totals in 1992-2009 (Table 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 catch significant amounts (Tables 4 & 5). The catch of skates in pollock fisheries has increased in recent years, possibly because the fisheries are targeting pollock closer to the bottom. In this assessment, "bycatch" is interpreted as 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 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 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 (Fig. 12). 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). Changes made to the observer manual at the author's request have resulted in a large increase in skate length measurements in 2008 and 2009.

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 (Fig. 12).

Reporting areas encompassing the EBS outer shelf and upper continental slope experienced high catch rates during 2003-2006 (Fig. 13). 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

Overview

The model presented here begins in 1992. In the 2007 assessment, we included an alternative model starting in 1958 that included historical catch data and survey biomass estimates from 1982. The alternative model was eliminated from the 2008 assessment due to uncertainty in catch and survey data prior to 1992, as well as a short history of fishery length composition data. For these reasons, the population is modeled during the "modern era" for skates in the BSAI, where the biomass has remained relatively stable and available data are substantially more complete and reliable.

This assessment model resembles teleost groundfish models in many ways, but we made some changes to incorporate life history features unique to elasmobranchs. As previously discussed, all skate species have an extended embryonic period during which they develop within protective eggcases on the seafloor. Alaska skates do not appear to form visible annual growth marks in their vertebrae during embryonic development. However, 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 approximately 3.6 years, possibly due to the cold ocean temperatures in the EBS (Hoff 2007; Fig. 10). 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 (Fig. 11; 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). Incorporating this information in the model is complicated by the possibility that embryo development times may be temperature-dependent (G. Hoff, pers. comm.).

The timing of *B. parmifera* reproduction is also uncertain. While most females appear to deposit eggcases during the summer, with emergence of young skates occurring during the winter, some level of skate reproduction seems to occur year-round. We assigned the first three age classes of Alaska skates (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 3½ years old. In addition, we adjusted parameters of the length model and age selectivity to accommodate the developmental delay and the uncertainty in its duration. This approach 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 present a base model that we determined to provide the best description of Alaska skate population dynamics given the data and the limitations of the modeling software. The alternative model presented in the 2008 assessment is not included in the 2009 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 (1999-2010) survey information on species composition was used to describe the relative proportion (0.95) of the Alaska skate to all other skate species ("Other Skates") within the EBS shelf area (Table 7 & Fig. 14). Biomass estimates from 1992 through 2010 were utilized in the Alaska skate model. 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 the 1999-2010 surveys (Table 7). The model employs the coefficient of variation (CV) as the standard deviation (*s*) associated with each estimate. For the estimates prior to 1999, a value of *s* was chosen that was intermediate to recent values and a high *s* observed in 1999 (Table 7).

Survey length composition

Total length (TL) data from the EBS shelf survey were available from 2000-2010 (Table 8). The survey takes length measurements for every skate in each haul. An N of 100 for each length composition was used in the model.

Binning: Discussions with staff from the Resource Assessment and Conservation Engineering (RACE) division at the AFSC during summer 2008 indicated that there may be a slight bias in the length measurements of skates in the EBS shelf survey towards odd-numbered sizes. This is likely due to the design of the length measuring boards, which display the odd sizes along the edge closest to the biologists, and the general difficulty of measuring a disc-shaped animal like a skate. This bias might be important when 5-cm length bins are used, as the bins contain different proportions of odd and even sizes. To ameliorate this problem, in 2008 the length composition bins were changed to a 4-cm width that includes equal numbers of odd and even sizes.

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 1992-2009 were made by the Blend system and AKRO CAS as described in the 2007 BSAI skate assessment. Catches were broken down by habitat area (EBS shelf, EBS slope, and AI) and by fishery gear type from 1992-2010 (Table 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 2003-2009 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 1999-2010 bottom trawl surveys (Fig. 14) 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 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. 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 9 and Fig. 15).

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. In 2008, the observer manual was changed to require collection of skate lengths on every haul where they were present in the target fisheries for Pacific cod and flatfishes. Fishery length composition varies by season, with larger skates caught later in the year (Figure 16). Fishery length data from 2007-2009was included for both gear types. The number of hauls sampled for the fishery length data is much higher than in the survey because observers take a small number of length measurements from a large number of hauls, and an N of 100 (identical to the survey data) was applied to each fishery length composition. Length data were aggregated into 4-cm bins as for the survey data (Table 10).

Length at age

Mean length at age data were obtained from Matta (2006) and from production ageing at the AFSC. Age was determined through examination of annual growth rings which begin to form in vertebral thin sections following hatching from the eggcase. Skate age determination is inherently difficult due to the typically faint appearance of growth zones, and CVs associated with many skate ageing studies tend to be high. However, Matta (2006) was able to corroborate ages generated from two different ageing structures in the Alaska skate, vertebrae and caudal thorns, as well as to verify the annual periodicity of vertebral growth ring formation through marginal increment analysis. Three sample sets were included in the model; one from the 2003 EBS shelf survey (n=182; Fig. 17), one from the 2005 longline fishery (n=208; Fig. 18), and one from the 2007 EBS shelf survey (n=243).

Weight at length

Parameters from the allometric length-weight relationship ($W = aTL^b$, 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; Fig. 19).

Analytic 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.

[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]

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 Fig. 20. 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 expected 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. Model estimates of recruitment deviate from the expected level according to the standard deviation of log recruitment (σ_R), which can be fixed or estimated within the model. In all cases, catch is modified by fishery age and length selectivity. 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 value of σ_R. The objective function combines these four components to calculate overall likelihood. All likelihood components were weighted equally in the model.

This assessment model 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. No informative priors were used. We also assumed that parameters did not vary with season or year and were not influenced by environmental conditions. All parameters used in the base model are listed in Table 11 and described in more detail below.

<u>Parameters estimated independently:</u>

Natural mortality (M)

In 2007, a conservative value of 0.13 was chosen from a set of *M* values estimated using different life history parameters (Matta 2006; Table 12): growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), reproductive potential (Rikhter and Efanov 1976, Roff 1986), von Bertlanffy k (Jensen 1996, Gunderson 2003), and age at maturity (Jensen 1996). Previous runs of the model have demonstrated that this value of *M* provides the best model fit, so M in the model contionues to be fixed at 0.13.

Length at maturity

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

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

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 (Table 11 & Fig. 21). 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
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; Fig. 22). To incorporate this capture probability data into the model, we assumed a catchability of 1.0 and fixed the survey length selectivity parameters according to parameters of the logistic equation given in Kotwicki and Weinberg (2005; see below). In addition, we did not adjust catchability for the segments of the Alaska skate population (AI and EBS slope) that are not observed by the EBS shelf survey. Over 96% of the Alaska skate population is on the shelf, surveys from the other areas are infrequent, and the AI survey has not been conducted since 2006. We felt it was a precautionary measure not to account for the small amount of Alaska skate biomass on the slope and in the AI.

Length selectivity
A logistic selectivity pattern was specified for the EBS shelf survey. Parameters of the logistic function given in Kotwicki and Weinberg (2005) were adapted for the form of the function used in SS2, and both parameters were fixed (Table 11). Fishery length 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. Selectivity parameters are summarized in Table 11. For each fishery, p6 was fixed so that selectivity was asymptotic and all other parameters were estimated within the model. With the exception of p1, all bounds were the default values specified in the SS2 documentation. Bounds for p1 were taken from an SS2 model for longnose skates in the Pacific Northwest (Gertseva et al. 2007).

Age selectivity
The uncertainty surrounding the embryonic development period for the Alaska skate posed some problems in this assessment, and age selectivity was used to partially offset these problems. The best estimate of embryo development times is approximately 3.6 years (Hoff 2007), and the majority of young skates appear to emerge during the winter. Therefore, surveys conducted during the following summer would be catching age-4 skates. A logistic age selectivity function was used for the survey and both fisheries. In all cases, the age at 50% selection was fixed and the width of the selectivity curve was estimated within the model. Age at 50% selectivity was set at age 3.5 for the trawl fishery and age 6 for the longline fishery (based on the lack of earlier ages in the length-at-age data available for the longline fishery). An age of 4 was specified for the trawl survey; a likelihood-profile analysis of this specification is discussed in the model evaluation section.

<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 3.5 and 20 years, respectively, because these ages were frequently observed and represented nearly the entire age range of the Alaska skate. L_1, L_2 and k were estimated within the model.

Spawner-recruit parameters
SS2 uses a Beverton-Holt function to describe the spawner-recruit relationship of the Alaska skate (Table 11). The steepness of this function was fixed at 1.0 in the Alaska skate model, so recruitment is effectively treated as a mean value from which recruitment estimates are allowed to deviate. This value was chosen because there is very little contrast in SSB for the modeling time period and the data are thus uninformative regarding steepness. The unfished level of recruitment (R_0) was freely estimated within the model. Recruitment deviations were included in the model, and the standard deviation of log recruitment (σ^R) was fixed at 0.4. A likelihood-profile analysis and discussion of this specification are discussed in the model evaluation section.

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

Results

Model Evaluation
Because the new input data (survey biomass estimate, catch, length compositions) and the model results were very similar to those used for the 2009 assessment, some of the model evaluation procedures (e.g. likelihood profiles) were not conducted in 2010.

Model evaluation criteria
Likelihood values are given in Table 13. We evaluated the model based on the following criteria:
1) Model fit to survey biomass estimates.
2) Model fit to length compositions.
3) Model fit to length-at-age data.
4) Reasonable estimates of fishery length selectivity parameters.
5) Reasonable estimates of unfished recruitment and recruitment variability.

Evaluation of the model
1) The expected survey biomass produced by the model provided a good fit to the observed biomass (Fig. 23). The expected survey biomass is within the confidence interval of all but 3 of the observed biomass estimates. The model fit is relatively flat, which is likely due in part to the lower survey biomass estimates during 2008-2010.

2) The model continues to provide good fits to the length composition data from the EBS shelf survey (Fig. 24) and both fisheries (Fig. 25). The model is unable to capture the spikes in large

skates observed in the 2003 and 2004 surveys, but it does fit the two modes observed in the survey length composition data. The fit to the fishery data is very good.

3) The model fit the observed length-at-age data from the survey (Fig. 26) and longline fishery (Fig. 27) reasonably well, except for older skates. These fits are improved relative to the 2007 assessment. Fig. 28 shows the fit of the population growth estimate (in contrast to the observed estimate) to the three length-at-age datasets.

   The model continues to underestimate length for skates older than 13 years. The lack of a better fit may be partially due to the limitations of the von Bertalanffy growth model employed in SS2. In future assessments we anticipate moving to a new version of Stock Synthesis that has more flexibility in modeling growth.

   An alternative explanation is that the length-at-age data do not accurately reflect skate growth. In the survey length compositions, a single length bin (96-99 cm) consistently has the highest proportion of skates throughout the 9-year time series (marked in red in Figs. 24 &25). The magnitude of this length bin proportion declined from 2002 onwards, presumably as members of that size class were removed by natural mortality. The observation that the length-bin position of this size class did not move suggests that for most skates, growth stops when they reach approximately 100 cm in length (approximately 13 years of age). This is approximately the age of maturation, and a cessation of growth after reaching maturity has been hypothesized for some elasmobranch species. A possible contradiction is that the mean length of older skates is higher than 100 cm. However, these may be exceptional cases. If the growth of most skates ceases, growth in the vertebrae that are used for aging likely ceases as well. Thus, there may be 23-year-old skates 100 cm in length may be misidentified as younger skates. Because the collection of skate vertebrae is length-stratified, it may be that skates with extended growth are preferentially selected. This is supported by the observation that sample size for length-at-age drops considerably after 14-15 years of age. Although the model may underestimate spawning biomass due to the lack of fit of the length-at-age data, the error is in a precautionary direction.

4) Estimates of selectivity parameters (Table 11) and selectivity at length (Fig. 29) for the longline and trawl fisheries were reasonable. Longline fisheries displayed high selectivity for larger skates, which is consistent with the length composition data. This selectivity may be due in part to the emergence of large skates from the nursery grounds during the third quarter of the year, when the longline catch of large skates is particularly high (Fig. 16). The estimate of trawl selectivity also seems reasonable, as the increased selectivity on smaller skates (relative to longline) is likely due to the concentration of trawl fisheries in areas where small skates are less abundant.

5) The base model estimate of unfished recruitment was consistent with the amount of spawning biomass and our limited knowledge of skate fecundity. Evaluating recruitment variability is difficult because little is known about recruitment of equilibrium strategists. The estimated levels of recruitment variability (Figs. 30 & 31) were higher than expected but still seem reasonable for this population.

Time series results

Results presented below are from the base model.

Definitions

Biomass is shown as total (age 0+) 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 Alaska skates at age 0. As described above, this corresponds to the number of viable embryos deposited in egg cases.

Biomass time series

Time series of total biomass and spawning biomass estimates from 1992-2010 are reported in Table 14 and in Fig. 34, respectively. These estimates suggest that while total skate biomass has been increasing slightly since 2000, spawning biomass has decreased somewhat during the same period.

Recruitment

Time series of age 0 recruitment are reported in Table 14 and Fig. 30, and the relationship between spawning biomass and recruitment is shown in Fig. 31. The model suggests that recruitment has been relatively low in recent years after being above average during the late 1990s and early 2000s.

Exploitation rate

A time series of exploitation (catch/total biomass) is given in Table 15. The exploitation rates estimated in the 2009 assessment are slightly higher than those estimated in 2008.

Projections and Harvest Alternatives

Reference points and tier assignment

This assessment using the base model 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 ABC

The 2010 estimate of female spawning biomass for BSAI Alaska skates is 53,119 t. The estimate of $B_{40\%}$ is 35,455 t, so $B/B_{40\%}$ is 1.50 and 2011-2012 Alaska skate harvest levels can be assigned according to subtier 3a. Therefore, $F_{OFL}= F_{35\%} = 0.09$ and maximum $F_{ABC}= F_{40\%} = 0.077$. The corresponding 2011 OFL is 28,348 t and maximum allowable ABC is 24,421 t. For 2012, OFL is projected to be 27,700 t and maximum allowable ABC is 23,864 t.

OTHER SKATES – Tier 5 assessment

Data

Survey biomass

The biomass of the skate assemblage as a whole has increased since the early 1980s (Table 16, Fig. 35). Because skates as a group are contiguous and found in nearly all habitats, the uncertainty (measured as the coefficient of variation, CV) in aggregate skate biomass estimates is rather low, but the uncertainty for individual species is greater (Table 2). Survey species identifications are considered reliable after 1998. 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 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 2). To generate harvest recommendations, we used the average biomass for each area during 2000-2008. This approach allowed the use of four surveys in the AI, nine surveys from the EBS shelf, and two surveys from the EBS slope. The 2002 biomass estimate from the slope was excluded because it is much higher than the estimate from the other two years and was affected by extremely high catch of skates in a single tow.

Analytic Approach

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 life history studies (McFarlane and King 2006, Gburski et al. 2007). These 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), 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.

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 exist, 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. We recommend using an average of the last 3 surveys in each BSAI subregion so that we may include multiple estimates from each of the trawl surveys, while capturing recent biomass levels.

Results

Tier 5 other skates ABC and OFL

Applying the *M* estimate of 0.10 to the 3-survey average of survey biomass estimates, we calculate an ABC of 0.75 * 0.10 * (total BSAI biomass of 94,690 t) = 0.075 * 94,690 t = 7**,102 t**. Applying the *M* estimate of 0.10 to the 3-survey average of survey biomass estimates, we calculate an OFL of 0.10 * (total BSAI biomass of 94,690 t) = 0.1 * 94,690 t = **9,469 t**.

other skates harvest recommendations				
		EBS shelf	AI	EBS slope
	2004	14,205	40,344	28,908
	2005	20,127		
	2006	18,045	40,726	
	2007	17,083		
	2008	19,617		33,033
	2009	20,162		
	2010	18902	48,342	33,956
average biomass		19,560	43,137	31,992
total BSAI other skates average biomass				94,690
2010-2011 ABC				**7,102**
2010-2011 OFL				**9,469**

Assemblage analysis and recommendations

Beginning in the 2011 fishing season, skates will be managed as a single complex with skate-specific ABC and OFL. We welcome this advance in skate management.

Given this change, we recommend that Alaska skates and “other skates” be managed under separate OFLs, ABC, and TACs (as is done for big and longnose skates in the GOA. 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. Because the incidental skate catch in the BSAI is already high relative to ABC, we also recommend that no directed fishing be allowed for skates in the BSAI.

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 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 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 36; 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. 2007).

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 (Fig. 37 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 (Fig. 37 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 Fig. 37 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 (Fig. 38, 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 (Fig. 38, 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 (Fig. 39, 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 (Fig. 39, 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 (Fig. 40, 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 (Fig. 40, 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 (Fig. 40, 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 (Fig. 40, 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; Fig. 41 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; Fig. 41 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 (Fig. 41 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 (Fig. 41 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 (Fig. 42), 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).

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

In the following tables, 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	Currently declining from high biomass levels	Probably still adequate forage available for piscivorous skates	Probably 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	Has varied from 12,226 t to 22,982 t from 1992-2007	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 is 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

Data gaps and research priorities

Aggregate skate and Alaska skate catches have been estimated using several different methods each 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 prior to 1999, and 2) we assume that survey species composition is representative of the catch species composition. Also, 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. In 2008, approximately 1,200 skates were tagged and released during the shelf and slope surveys. The vast majority of these releases occurred during the shelf survey, and releases were distributed over the entire shelf survey area. As of October 2008, two of these tags had already been recovered through the commercial longline fishery. We expect to deploy additional tags during future trawl surveys and other 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 be 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 that 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.

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Literature Cited

Agnew, D.J., C.P. Nolan, J.R. Beddington, and R. Baranowski. 2000. Approaches to the assessment and management of multispecies skate and ray fisheries using the Falkland Islands fishery as an example. Can. J. Fish. Aquat. Sci. 57: 429-440.

Allen, M.J., and G.B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. NOAA Technical Report NMFS 66, 151 pp.

Alverson, D.L., and W.T. Pereyra. 1969. Demersal fish explorations in the northeastern Pacific Ocean: An evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Bd. Canada 26: 1985-2001.

Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36:133-143.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. NOAA Tech Memo. NMFS-AFSC-178

Brander, K. 1981. Disappearance of common skate *Raja batis* from Irish Sea. Nature 290: 48-49.

Casey, J.M. and R.A. Myers. 1998. Near extinction of a large, widely distributed fish. Science 281(5377):690-692.

Charnov, E.L. 1993. Life history invariants some explorations of symmetry in evolutionary ecology. Oxford University Press Inc., New York. 167p.

Davis, C.D. 2006. Age, growth, and reproduction of the roughtail skate, *Bathyraja trachura* (Gilbert, 1892). M.S. thesis, Moss Landing Marine Laboratories, CSU Monterey Bay.

Dulvy, N.K., J.D. Metcalfe, J. Glanville, M.G. Pawson, and J.D. Reynolds. 2000. Fishery stability, local extinctions, and shifts in community structure in skates. Conservation Biology 14(1): 283-293.

Ebert, D.A. 2003. Sharks, rays, and chimeras of California. University of California Press, Berkeley, CA, 285 pp.

Ebert, D.A. 2005. Reproductive biology of skates, *Bathyraja* (Ishiyama), along the eastern Bering Sea continental slope. J. Fish. Biol. 66: 618-649.

Ebert, D.A., Smith, W.D., Haas, D.L., 1, Ainsley, S.M., Cailliet, G.M. 2007. Life history and population dynamics of Alaskan skates: providing essential biological information for effective management of bycatch and target species. Final Report to the North Pacific Research Board, Project 510.

Eschmeyer, W.N., E.S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston: 336 pp.

Frisk, M.G., T. J. Miller, and M. J. Fogarty. 2001. Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. Can. J. Fish. Aquat. Sci. 58: 969-981.

Frisk, M. G. , T. J. Miller, and M. J. Fogarty. 2002. The population dynamics of little skate *Leucoraja erinacea*, winter skate *Leucoraja ocellata*, and barndoor skate *Dipturus leavis*: predicting exploitation limits using matrix analysis. ICES J. Mar. Sci. 59: 576-586.

Fritz, L. W. 1996. Squid and other species. Chapter 13 In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Fritz, L. W. 1997. Squid and other species. Pp. 463-484 In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Fritz LW, Greig A, Reuter RF. 1998. Catch-per-unit-effort, length, and depth distributions of major groundfish and bycatch species in the Bering Sea, Aleutian Islands, and Gulf of Alaska regions based on groundfish fishery observer data, 179 p. NTIS No. PB98-139298

Gaichas, S., J. Ianelli, and L. Fritz. 1999. Other species considerations for the Gulf of Alaska.

Gaichas, S., M. Ruccio, D. Stevenson, and R. Swanson. 2003. Stock assessment and fishery evaluation for skate species (Rajidae) in the Gulf of Alaska.

Gburski, C.M., S.K. Gaichas, and D.K. Kimura. 2007. Age and growth of big skate (*Raja binoculata*) and longnose skate (*R. rhina*) and implications to the skate fisheries in the Gulf of Alaska. Env. Bio. Fishes 80: 337-349.

Gunderson, D.R. 1997. Trade-off between reproductive effort and adult survival in oviparous and viviparous fishes. Can. J. Fish. Aquat. Sci. 54: 990-998.

Gunderson, D.R., Zimmerman, M., Nichol, D.G., and Pearson, K. 2003. Indirect estimates of natural mortality rate for arrowtooth flounder (*Atheresthes stomias*) and darkblotched rockfish (*Sebastes crameri*). Fishery Bulletin 101: 175 – 182.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82(1): 898-902.

Hoff, G.R. 2006. Investigations of a skate nursery area in the eastern Bering Sea. Progress report to the NPRB. March 7, 2006.

Hoff, G.R. 2007. Reproduction of the Alaska skate (*Bathyraja parmifera*) with regard to nursery sites, embryo development and predation. PhD dissertation, University of Washington, Seattle.

Ishihara, H. and R. Ishiyama. 1985. Two new North Pacific skates (Rajidae) and a revised key to *Bathyraja* in the area. Jpn. J. Ichthyol. 32(2): 143-179.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Aquat. Fish. Sci. 53: 820-822.

King, J.R., and G.A. McFarlane. 2003. Marine fish life history strategies: applications to fishery management. Fish. Man. and Ecology, 10: 249-264.

Kotwicki, S., and Weinberg, K.L. 2005. Estimating capture probability of a survey bottom trawl for Bering Sea skates (*Bathyraja spp.*) and other fish. Alaska Fishery Research Bulletin 11(2): 135-145.

Martin, L. and G.D. Zorzi. 1993. Status and review of the California skate fishery. In Conservation biology of elasmobranchs (S. Branstetter, ed.), p. 39-52. NOAA Technical Report NMFS 115.

Matta, M.E. 2006. Aspects of the life history of the Alaska skate, *Bathyraja parmifera*, in the eastern Bering Sea. M.S. thesis, University of Washington, Seattle.

McEachran, J.D., and K.A. Dunn. 1998. Phylogenetic analysis of skates, a morphologically conservative clade of elasmobranchs (Chondrichthyes: Rajidae). Copeia, 1998(2), 271-290.

McEachran, J.D. and T. Miyake. 1990a. Phylogenetic relationships of skates: a working hypothesis (Chondrichthyes, Rajoidei). In Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt, Jr., S.R. Gruber, and T. Taniuchi, eds.), p. 285-304. NOAA Technical Report NMFS 90.

McFarlane, G.A. and J.R. King. 2006. Age and growth of big skate (*Raja binoculata*) and longnose skate (*Raja rhina*) in British Columbia waters. Fish Res. 78: 169-178.

Mecklenberg, C.W., T.A. Mecklenberg, and L.K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, 1037 pp.

Methot RD. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. International North Pacific Fisheries Commission Bulletin 50:259-277

Methot RD. 2005. Technical description of the Stock Synthesis II assessment program. NOAA Fisheries, Seattle, WA.

Methot, R. 2007. User manual for the integrated analysis program Stock Synthesis 2 (SS2). Model version 2.00b. Northwest Fisheries Service, NOAA Fisheries, Seattle, WA.

Moyle, P.B., and J.J. Cech, Jr. 1996. Fishes, an introduction to ichthyology (Third edition). Prentice Hall: New Jersey, 590 pp.

Murray, J.D. 1989. Mathematical Biology. Springer-Verlag: New York. 767 pp.

Musick, J.A., S.A. Berkeley, G.M. Cailliet, M. Camhi, G. Huntsman, M. Nammack, and M.L. Warren, Jr. 2000. Protection of marine fish stocks at risk of extinction. Fisheries 25(3):6-8.

Myers RA, Bowen KG, Barrowman NJ. 1999. Maximum reproductive rate of fish at low population sizes. Canadian Journal of Fisheries and Aquatic Sciences 56:2404-2419

New England Fishery Management Council (NEFMC). Skate Fishery Management Plan. http://www.nefmc.org/skates/index.html

Nelson, J. S. 1994. Fishes of the world, Third edition. John Wiley and Sons, Inc., New York: 600 pp.

NMFS 2000. Skate complex. In Draft 30th Northeast Regional Stock Assessment Workshop (30th SAW), Stock assessment review committee (SARC) consensus summary of assessments, p. 7-173.

NMFS PSEIS 2001. Draft Programmatic Environmental Impact Statement.

Northeast Fisheries Science Center (NEFSC). 2007. 44th Northeast Regional Stock Assessment Workshop (44th SAW). Section B. Skate Complex: Assessment Summary for 2006. *In:* 44th SAW assessment summary report. US Dep Commer, Northeast Fish Sci Cent Ref Doc. 07-03; 58 p.

Orlov, A.M. 1998. The diets and feeding habits of some deep-water benthic skates (Rajidae) in the Pacific waters off the northern Kuril Islands and southeastern Kamchatka. Alaska Fishery Research Bulletin 5(1): 1-17.

Orlov, A.M. 1999. Trophic relationships of commercial fishes in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands. p. 231-263 in Ecosystem Approaches for Fishery Management, AK Sea Grant College Program AK-SG-99-01, U. of AK Fairbanks, 756 pp.

Ormseth, O.A. and B. Matta. 2007. Gulf of Alaska skates. In: Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska Region. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

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

Rikhter, V.A., and V.N. Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc. 76/VI/8. Serial N. 3777. 13p.

Robinson, H.J. 2006. Dietary analysis of the longnose skate, *Raja rhina* (Jordan and Gilbert, 1880), in California waters. M.S. thesis, Moss Landing Marine Laboratories, CSU Monterey Bay.

Roff, D.A. 1986. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Sosebee, K. 1998. Skates. In Status of Fishery Resources off the Northeastern United States for 1998 (Stephen H. Clark, ed.), p. 114-115. NOAA Technical Memorandum NMFS-NE-115.

Stevenson, D. 2004. Identification of skates, sculpins, and smelts by observers in north Pacific groundfish fisheries (2002-2003), U.S. Department of Commerce Technical Memorandum NMFS-AFSC-142. 67 p.

Stevenson, D.E. and J.W. Orr. 2005. New records of two deepwater skate species from the eastern Bering Sea. Northwestern Naturalist 86: 71-81.

Stevenson, D.E., J.W. Orr, G.R. Hoff, and J.D. McEachran. 2004. *Bathyraja mariposa*: a new species of skate (Rajidae: Arhynchobatinae) from the Aleutian Islands. Copeia 2004(2):305-314.

Stevenson, D.E., J.W. Orr, G.R. Hoff, and J.D. McEachran. 2006. The skates of Alaska: distribution, abundance, and taxonomic progress. Marine Science in Alaska 2006 Symposium, Anchorage, AK, Jan 2006, poster.

Stevenson, D. E., Orr, J. W., Hoff, G. R., and McEachran, J. D. 2007. Field guide to sharks, skates, and ratfish of Alaska. Alaska Sea Grant.

Thompson, G.G. 1993. A proposal for a threshold stock size and maximum fishing mortality rate. Pages 303-320 in Risk evaluation and biological reference points for fisheries management (S.J. Smith, J.J. Hunt, and D. Rivard, eds.). Can. Spec. Publ. Fish. Aquat. Sci. 120, 440 pp.

Wakefield, W.W. 1984. Feeding relationships within assemblages of nearshore and mid-continental shelf benthic fishes off Oregon. M.S. Thesis, OSU.

Walker, P.A., and R. G. Hislop. 1998. Sensitive skates or resilient rays? Spatial and temporal shifts in ray species composition in the central and north-western North Sea between 1930 and the present day. ICES J. Mar Sci., 55: 392-402.

Winemiller, K.O., and K.A. Rose. 1992. Patterns of life history diversification in North American fishes: implications for population regulation. Can. J. Fish. Aquat. Sci. 49: 2196-2218.

Yang, M-S. 2007. Food habits and diet overlap of seven skate species in the Aleutian Islands. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-177, 46 p.

Zeiner, S.J. and P. Wolf. 1993. Growth characteristics and estimates of age at maturity of two species of skates (*Raja binoculata* and *Raja rhina*) from Monterey Bay, California. In Conservation biology of elasmobranchs (S. Branstetter, ed.), p. 39-52. NOAA Technical Report NMFS 115.

Tables

Table 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 2. Species composition of the EBS and AI skate complexes from the 2008 shelf and slope survey and 2006 AI survey.

Skate species	Common name	2008 EBS shelf bio (t)	cv	2008 EBS slope bio (t)	cv	2006 Aleutians bio (t)	cv
Bathyraja abyssicola	deepsea			165	0.62	0	
Bathyraja aleutica	Aleutian	6,278	0.57	17,160	0.15	6,684	0.23
Bathyraja interrupta	Bering	9,943	0.16	2,520	0.16	186	0.55
Bathyraja lindbergi	Commander			3,437	0.15	0	
Bathyraja maculata	whiteblotched	238	1.00	4,574	0.17	29,712	0.19
Bathyraja minispinosa	whitebrow			1,934	0.17	0	
Bathyraja parmifera	Alaska	362,127	0.06	4,516	0.32	13,484	0.19
Bathyraja taranetzi	mud	125	1.00	1,018	0.22	2,970	0.28
Bathyraja trachura	roughtail			2,213	0.14	0	
Bathyraja violacea	Okhotsk			0		0	
Raja binoculata	big	2,870	0.63	0		568	0.72
Raja rhina	longnose	162	1.00	12	1.00	0	
Rajidae unid	Unidentified skate species					605	0.41
Total skate complex		**381,744**		**37,548**		**54,210**	

Table 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	25,728	19,156	74%
2004	46,810	27,205	81,150	29,478	22,300	76%
2005	53,860	29,000	87,920	29,575	23,084	78%
2006	58,882	29,000	89,404	27,107	20,249	75%
2007	68,800	37,355	91,700	26,648	18,615	70%
2008	78,100	50,000	104,000	29,630	21,614	73%
2009	63,700	50,000	80,800	27,992	20,598	74%
2010*	61,100	50,000	88,200	19,402	14,445	74%

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: 2003-2010 Other Species and BSAI skate catch from AKRO CAS. *2010 data incomplete; retrieved on October 10, 2010.

Table 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 5a. Estimated catch (t) of all skate species combined by target fishery, 2003-2010. Source: AKRO CAS. *2010 data incomplete; retrieved on October 10,2010.

target fishery	2003	2004	2005	2006	2007	2008	2009	2010*
Alaska plaice	0	0	0	1	0	1	1	0
arrowtooth flounder	103	64	127	281	81	297	193	169
Atka mackerel	91	143	140	141	153	179	185	208
flathead sole	627	1,184	844	851	769	664	362	261
Greenland turbot	221	136	168	121	174	58	209	330
IFQ halibut	265	282	130	84	18	1,336	25	33
other flatfish	26	78	43	7	64	2	14	2
other target	228	95	28	115	70	63	33	0
Pacific cod	14,950	18,336	19,450	15,109	13,459	14,291	12,701	7,514
rock sole	530	509	423	931	1,000	559	944	35
rockfish	73	23	30	37	72	64	96	34
sablefish	57	13	26	123	61	40	99	62
yellowfin sole	1,513	596	942	1,133	1,405	1,301	1,802	1,481
pollock	471	841	732	1,308	1,287	2,758	3,856	1,865
EBS total	**19,155**	**22,300**	**23,084**	**20,242**	**18,613**	**21,614**	**20,520**	**11,992**

Table 5b. Estimated catch (t) of all skate species combined by reporting area, 2003-2010. Source: AKRO CAS. *2010 data incomplete; retrieved on October 10, 2010.

region	rep. area	2003	2004	2005	2006	2007	2008	2009	2010*
EBS	508	0	0	0	0	0	0	0	0
	509	1,968	2,160	3,267	3,537	3,577	4,037	5,006	2,105
	512	25	205	15	0	0	29	16	13
	513	2,757	2,821	4,010	2,667	2,360	2,061	2,541	1,472
	514	279	67	196	221	445	86	134	79
	516	132	408	239	253	398	488	573	607
	517	2,863	2,946	3,669	2,399	2,139	2,441	3,168	1,864
	518	25	6	16	11	5	480	56	28
	519	184	139	104	69	109	185	55	72
	521	8,946	10,313	8,478	8,351	7,105	7,605	6,180	5,811
	523	306	325	243	283	334	242	263	335
	524	1,016	2,025	2,151	1,493	1,137	2,566	1,399	999
	530	0	0	0	0	0	0	1	0
	EBS total	**18,501**	**21,415**	**22,388**	**19,283**	**17,608**	**20,220**	**19,392**	**13,385**
AI	541	302	466	487	563	337	486	452	372
	542	234	278	126	336	394	565	334	400
	543	118	141	83	67	276	343	420	288
	AI total	**655**	**885**	**696**	**966**	**1,007**	**1,394**	**1,206**	**1,060**

Table 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 7. EBS shelf bottom trawl survey estimates of Alaska skate (*Bathyraja parmifera*) biomass (metric tons). Line indicates the start year of the model. Estimates and CVs in bold (1999-2010) were obtained directly from trawl survey data when species identification was reliable. Estimates and CVs prior to 1999 were partitioned using species composition data from 1999-2010.

year	biomass	CV
1982	167,826	0.10
1983	163,970	0.10
1984	190,037	0.10
1985	158,860	0.10
1986	255,409	0.10
1987	334,132	0.10
1988	392,645	0.10
1989	395,370	0.10
1990	513,751	0.10
1991	433,529	0.10
1992	379,682	0.10
1993	370,356	0.10
1994	412,663	0.10
1995	385,126	0.10
1996	426,649	0.10
1997	402,720	0.10
1998	352,101	0.10
1999	**353,197**	**0.16**
2000	**314,565**	**0.06**
2001	**415,549**	**0.06**
2002	**411,156**	**0.06**
2003	**373,520**	**0.05**
2004	**435,061**	**0.05**
2005	**548,010**	**0.05**
2006	**438,307**	**0.05**
2007	**479,633**	**0.07**
2008	**362,127**	**0.06**
2009	**350,907**	**0.06**
2010	**366,832**	**0.06**

Table 8. Alaska skate EBS shelf survey length compositions, 2000-2010. Bin number is the lower limit of each 4 cm length bin; data are proportions of each bin. N = sample size.

	year										
bin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
20	0.007	0.010	0.010	0.006	0.006	0.004	0.003	0.007	0.004	0.008	0.003
24	0.037	0.039	0.023	0.033	0.016	0.019	0.024	0.017	0.017	0.019	0.015
28	0.047	0.056	0.031	0.031	0.030	0.025	0.026	0.019	0.020	0.019	0.018
32	0.047	0.058	0.037	0.047	0.032	0.033	0.031	0.028	0.027	0.030	0.017
36	0.052	0.048	0.044	0.053	0.032	0.041	0.036	0.042	0.038	0.043	0.028
40	0.051	0.048	0.042	0.048	0.049	0.047	0.045	0.051	0.052	0.051	0.040
44	0.046	0.051	0.044	0.052	0.051	0.061	0.052	0.052	0.061	0.054	0.048
48	0.052	0.044	0.041	0.053	0.058	0.057	0.057	0.062	0.061	0.053	0.042
52	0.056	0.049	0.045	0.041	0.062	0.054	0.051	0.052	0.065	0.060	0.050
56	0.052	0.043	0.037	0.036	0.051	0.057	0.057	0.055	0.062	0.063	0.053
60	0.055	0.051	0.035	0.041	0.047	0.064	0.055	0.050	0.059	0.064	0.051
64	0.045	0.043	0.033	0.039	0.042	0.053	0.053	0.060	0.060	0.059	0.059
68	0.035	0.047	0.041	0.043	0.049	0.046	0.048	0.055	0.046	0.052	0.061
72	0.038	0.046	0.035	0.041	0.043	0.048	0.049	0.053	0.051	0.054	0.057
76	0.030	0.035	0.041	0.042	0.047	0.040	0.048	0.046	0.049	0.049	0.054
80	0.040	0.030	0.035	0.047	0.038	0.040	0.037	0.041	0.043	0.050	0.056
84	0.030	0.026	0.046	0.037	0.043	0.039	0.044	0.040	0.040	0.045	0.058
88	0.034	0.033	0.069	0.044	0.044	0.052	0.038	0.045	0.043	0.049	0.063
92	0.051	0.060	0.092	0.056	0.062	0.048	0.062	0.058	0.055	0.049	0.076
96	0.070	0.071	0.094	0.088	0.081	0.062	0.068	0.063	0.057	0.056	0.069
100	0.066	0.069	0.076	0.065	0.072	0.059	0.064	0.060	0.055	0.045	0.047
104	0.043	0.031	0.037	0.043	0.034	0.035	0.038	0.028	0.026	0.020	0.025
108	0.014	0.011	0.010	0.013	0.010	0.011	0.012	0.011	0.009	0.006	0.008
112	0.002	0.002	0.003	0.002	0.003	0.002	0.002	0.003	0.001	0.000	0.001
116	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
132	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	316	354	333	332	380	370	352	362	346	363	361

Table 9. Partitioned Alaska skate catch estimates (metric tons) based on observed catch data and survey species composition. Total BSAI catch estimates for each fishery (right-most column) were used in the SS2 base model. Because 2010 catch data are incomplete, 2009catch was used for 2010. The 2009 and 2010 values are slightly different due to the incorporation of 2010 survey biomass estimates in the catch estimation.

Year	EBS shelf Longline	EBS shelf Trawl	EBS slope Longline	EBS slope Trawl	AI Longline	AI Trawl	BSAI Longline	BSAI Trawl
1992	12,205	2,690	23	8	169	94	12,397	2,792
1993	8,797	1,939	16	6	122	68	8,935	2,013
1994	10,234	2,256	19	7	142	79	10,395	2,341
1995	10,715	2,362	20	7	148	83	10,884	2,452
1996	9,097	2,005	17	6	126	70	9,240	2,081
1997	12,885	2,840	24	8	150	84	13,059	2,932
1998	13,876	3,059	26	9	198	110	14,100	3,178
1999	9,703	2,139	19	7	141	78	9,862	2,224
2000	12,744	2,809	24	9	388	216	13,157	3,034
2001	13,973	3,080	26	9	440	245	14,438	3,334
2002	15,776	3,477	119	42	138	77	16,033	3,596
2003	13,529	3,173	30	7	102	77	13,660	3,258
2004	16,455	3,860	26	22	151	62	16,632	3,944
2005	17,738	3,379	40	4	118	72	17,896	3,455
2006	14,767	3,255	27	10	154	86	14,949	3,351
2007	13,700	3,020	25	9	177	98	13,901	3,127
2008	15,481	3,412	29	10	244	136	15,754	3,558
2009	14,800	3,262	28	10	211	118	15,039	3,390
2010	14,793	3,261	28	10	0	0	14,821	3,271

Table 10. Alaska skate length compositions from the EBS longline and trawl fisheries, 2007-2009. Bin number is the lower limit of each 4 cm length interval.

	2007		2008		2009	
bin	**longline**	**trawl**	**longline**	**trawl**	**longline**	**trawl**
4	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.001	0.000	0.000	0.000	0.001
20	0.000	0.008	0.000	0.004	0.000	0.003
24	0.000	0.017	0.000	0.022	0.000	0.011
28	0.000	0.013	0.000	0.035	0.000	0.024
32	0.000	0.023	0.000	0.043	0.001	0.035
36	0.000	0.030	0.001	0.062	0.001	0.053
40	0.002	0.040	0.002	0.056	0.002	0.065
44	0.005	0.054	0.004	0.047	0.005	0.066
48	0.006	0.061	0.014	0.049	0.009	0.056
52	0.016	0.053	0.020	0.046	0.017	0.051
56	0.027	0.046	0.027	0.037	0.023	0.044
60	0.046	0.061	0.030	0.039	0.032	0.041
64	0.062	0.067	0.053	0.037	0.043	0.048
68	0.054	0.049	0.074	0.038	0.058	0.048
72	0.072	0.053	0.062	0.039	0.063	0.048
76	0.055	0.059	0.072	0.037	0.069	0.040
80	0.059	0.045	0.072	0.041	0.069	0.054
84	0.060	0.048	0.073	0.044	0.069	0.045
88	0.065	0.059	0.078	0.052	0.083	0.061
92	0.089	0.052	0.082	0.056	0.098	0.061
96	0.117	0.060	0.110	0.075	0.129	0.058
100	0.137	0.051	0.132	0.075	0.124	0.050
104	0.080	0.025	0.063	0.040	0.068	0.027
108	0.031	0.013	0.029	0.014	0.028	0.007
112	0.010	0.008	0.001	0.006	0.006	0.002
116	0.006	0.004	0.001	0.002	0.002	0.000
120	0.002	0.001	0.000	0.001	0.001	0.000
124	0.001	0.000	0.000	0.001	0.000	0.000
128	0.000	0.000	0.000	0.001	0.000	0.000
132	0.000	0.000	0.000	0.000	0.000	0.000
N	2,911	858	1,369	2,930	18,081	8,174

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

parameter		value	min	max	fix?
growth and natural mortality	natural mortality (M)	0.13			X
	length at A1 (L1)	16.2	10	30	
	length at A2 (L2)	101.3	70	120	
	von Bertalanffy coefficient (k)	0.157	0.05	0.2	
	CV of L1	0.336	0	0.5	
	ln CV of L2	-1.77	-3	1	
length-weight relationship	coefficient (a)	4.0×10^{6}			X
	exponent (b)	3.149			X
length at maturity	length at 50% maturity (a)	93.28			X
	slope (b)	-0.548			X
weight-fecundity relationship	coefficient (a)	0.5			X
	exponent (b)	0			X
stock-recruit relationship	ln virgin recruitment level (R0)	10.62	5	15	
	steepness (h)	1			X
	SD of R0 (σR)	0.4			X
EBS shelf survey catchability	ln catchability (Q)	0			X
longline length selectivity	peak (p1)	102.2	7.6	126	
	top (p2)	1.09	-6	4	
	ascending width (p3)	3.96	-1	9	
	descending width (p4)	4.98	-1	9	
	selectivity at first size bin (p5)	-0.59.	-5	9	
	selectivity at last size bin (p6)	9.0			X
trawl length selectivity	peak (p1)	41.7	7.6	126.2	
	top (p2)	-2.14	-6	4	
	ascending width (p3)	5.52	-1	9	
	descending width (p4)	-0.09	-1	9	
	selectivity at first size bin (p5)	-5	-5	9	
	selectivity at last size bin (p6)	9	-5	9	X
survey length selectivity (logistic)	(p1)	-32.99			X
	(p2)	285.9			X
longline age selectivity (logistic)	(p1)	6.5			X
	(p2)	0.45	0	30	
trawl age selectivity (logistic)	(p1)	3.5			X
	(p2)	0.019	0	30	
survey age selectivity (logistic)	(p1)	4			X
	(p2)	0.186	0	30	
initial fishing mortality	longline fishery F	0.042	0.001	1	
	trawl fishery F	0.005	0.0004	1	

Table 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 13. Overall and component likelihoods.

overall likelihood	**207.432**
survey	-15.267
length compositions	104.004
length at age	164.216
equilibrium catch	0.0004
recruitment	-34.5255
forecast recruitment	-11.0

Table 14. Time series of total (age 0+) biomass (metric tons), spawning biomass (metric tons) and the number of age 0 recruits (thousands of fish) predicted by the base model.

	total biomass (t)	female spawning biomass (t)	recruits (1000s)
1992	489,836	56,422	28,902
1993	493,827	55,650	33,029
1994	502,196	55,642	43,140
1995	508,024	55,583	46,060
1996	511,517	55,878	46,539
1997	514,712	56,667	49,337
1998	511,935	57,054	48,965
1999	508,003	57,479	52,370
2000	510,192	58,996	38,739
2001	510,330	59,409	40,785
2002	511,228	59,332	37,479
2003	512,673	58,551	41,746
2004	518,476	57,730	50,846
2005	521,105	56,383	29,657
2006	522,526	55,438	27,639
2007	525,722	55,298	37,206
2008	529,324	55,623	37,206
2009	530,224	56,065	37,206
2010	530,092	56,867	37,206

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

year	longline	trawl	total
1992	0.042	0.006	0.047
1993	0.030	0.004	0.034
1994	0.034	0.005	0.039
1995	0.036	0.005	0.040
1996	0.030	0.004	0.034
1997	0.042	0.006	0.047
1998	0.045	0.006	0.051
1999	0.032	0.004	0.036
2000	0.042	0.006	0.048
2001	0.047	0.006	0.053
2002	0.052	0.007	0.059
2003	0.044	0.006	0.050
2004	0.053	0.007	0.061
2005	0.058	0.007	0.064
2006	0.048	0.006	0.054
2007	0.045	0.006	0.050
2008	0.050	0.007	0.057
2009	0.048	0.006	0.054
2010	0.047	0.006	0.053

Table 16. 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), 1975-2010.

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				
2008	381,744	0.05	37,548	0.08		
2009	371,069	0.06				
2010	385,734	0.06	35,251	0.08	52,005	0.13

Table 17. 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 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.

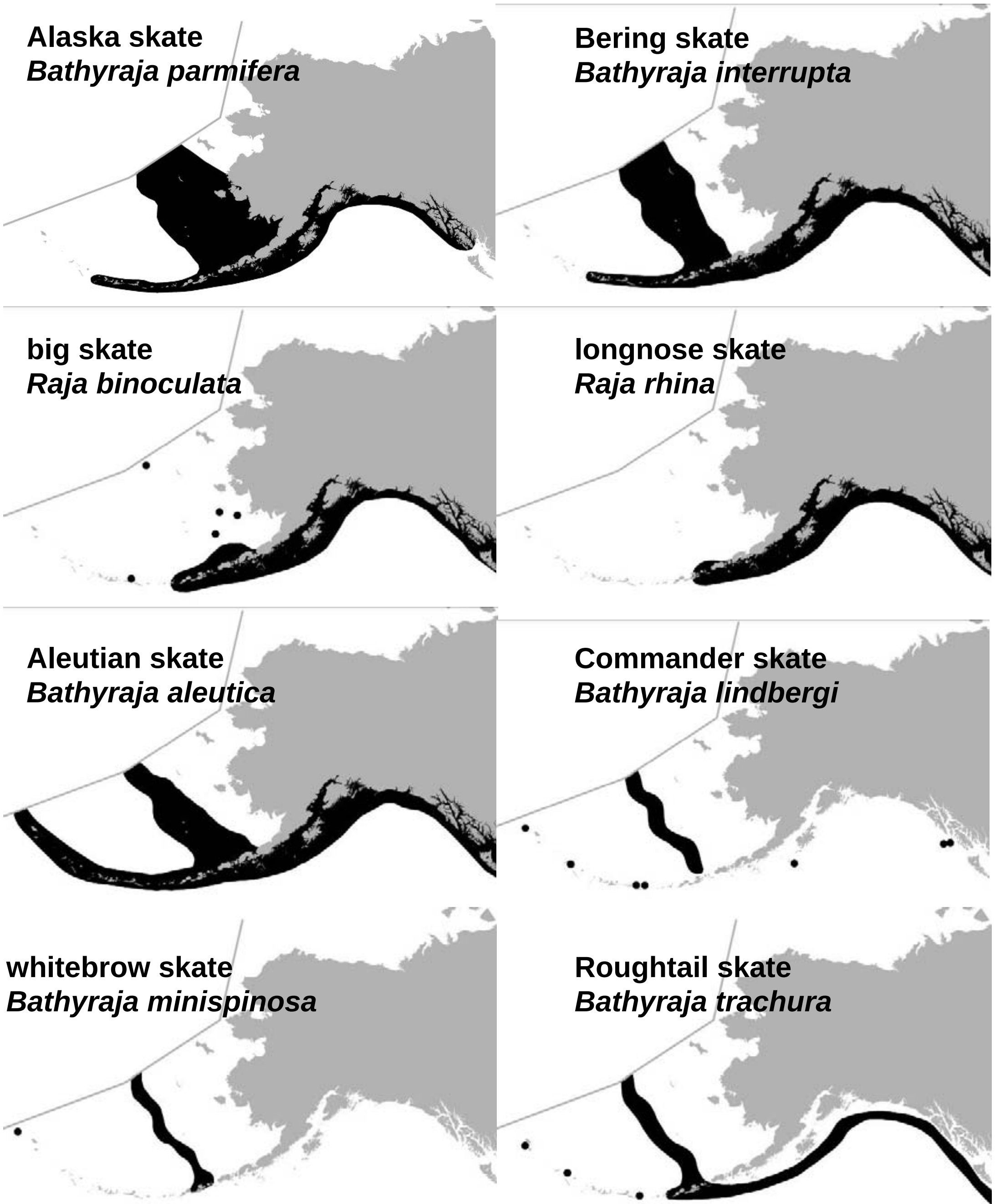


Figure 2. Distribution of skate species in Alaskan waters. These maps were created primarily using survey data, although observer records were included whenever positive species identification was possible (through voucher specimens or photographs). ***(Source: Stevenson et al. 2007)***

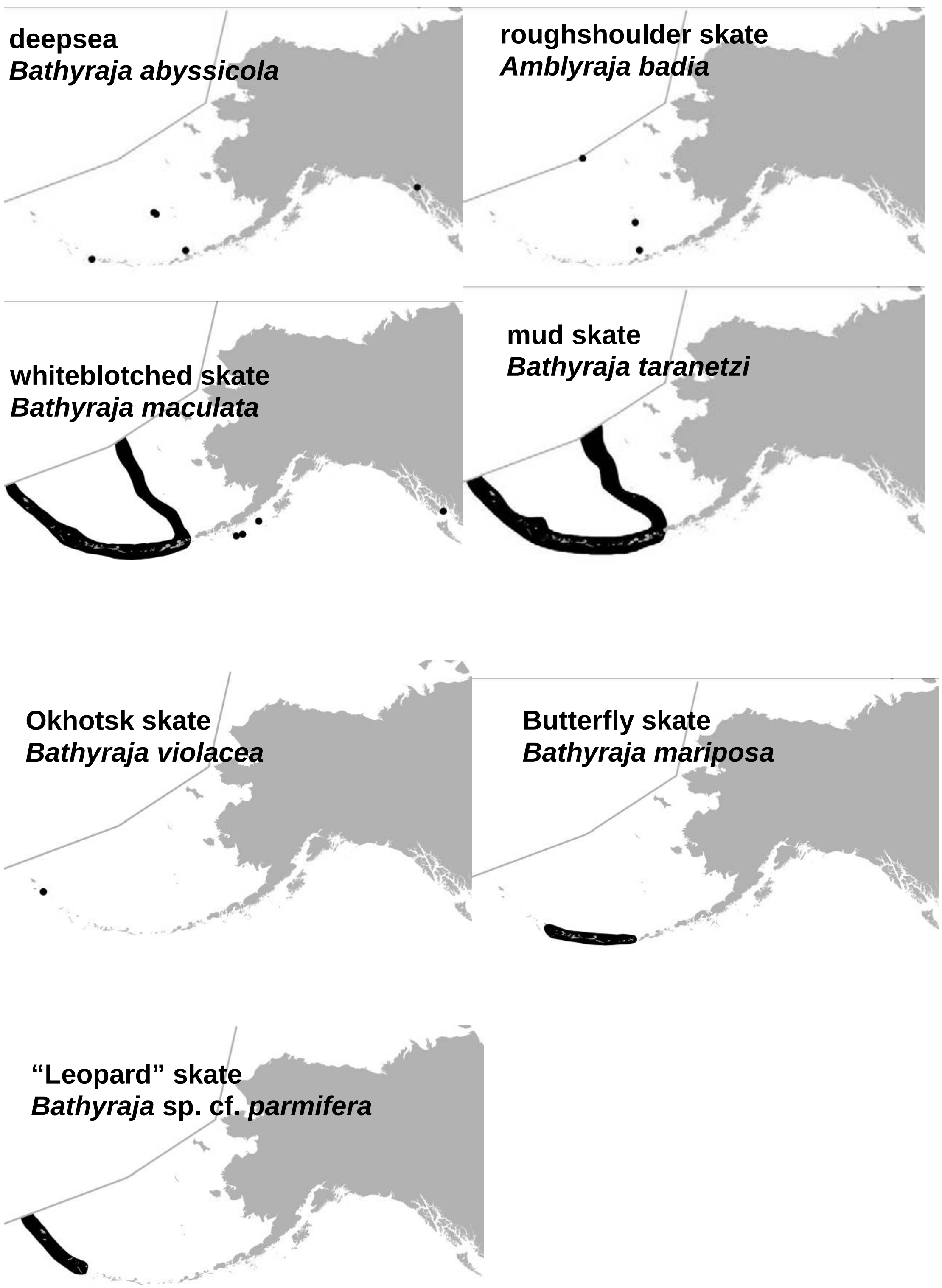


Figure 2 continued. Distribution of skate species in Alaskan waters. (Source: Stevenson et al. 2007)

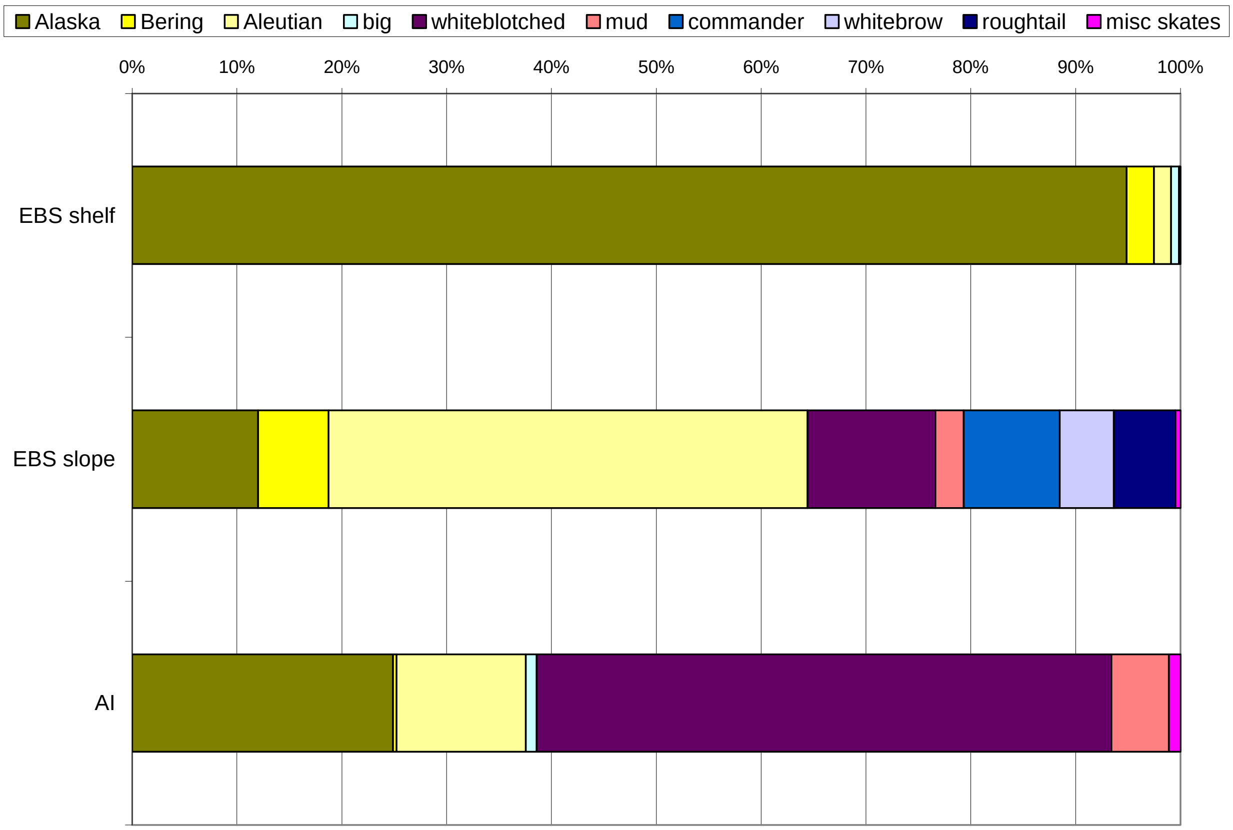


Figure 3. Skate species composition (by weight) by BSAI subregion, from surveys conducted in each region in 2010. "Misc skates" contains longnose, deepsea, and unidentified skates.

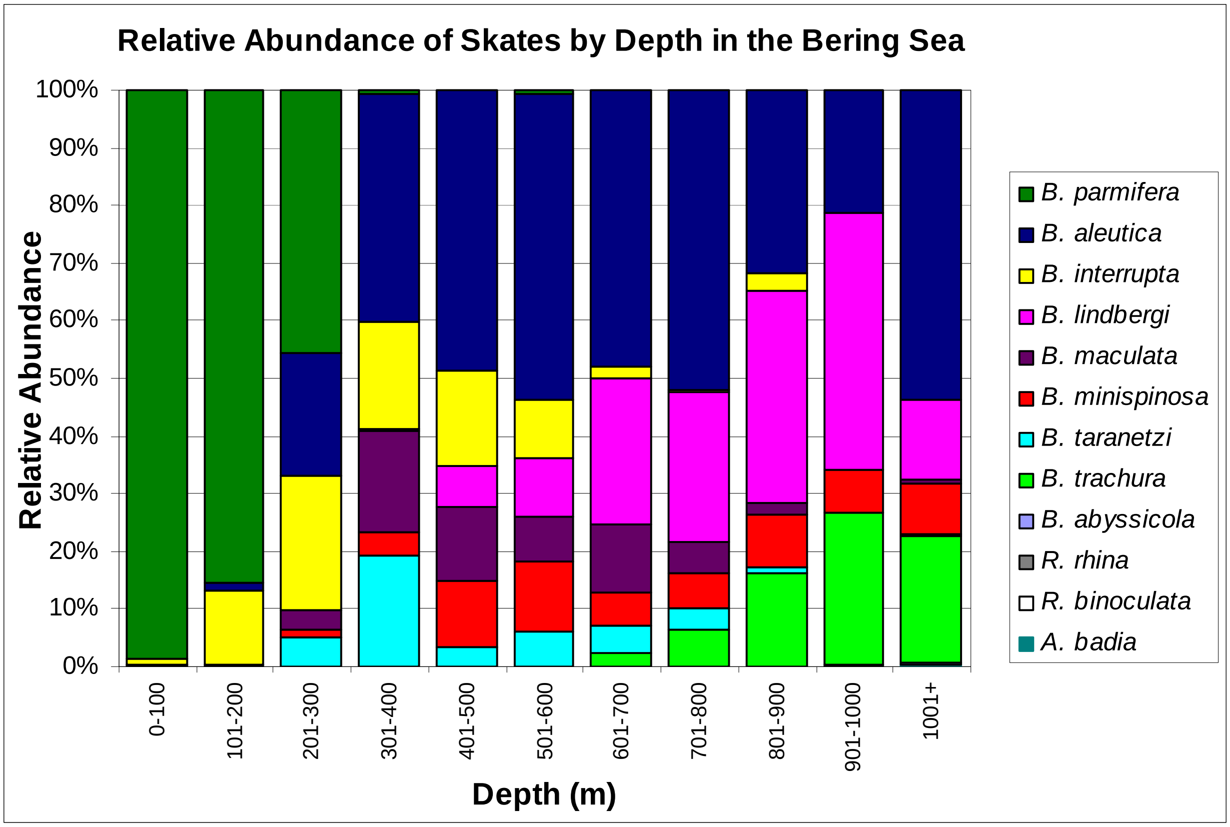


Figure 4. Relative abundance of skate species in the EBS by depth. (Source: Stevenson et al. 2006.)

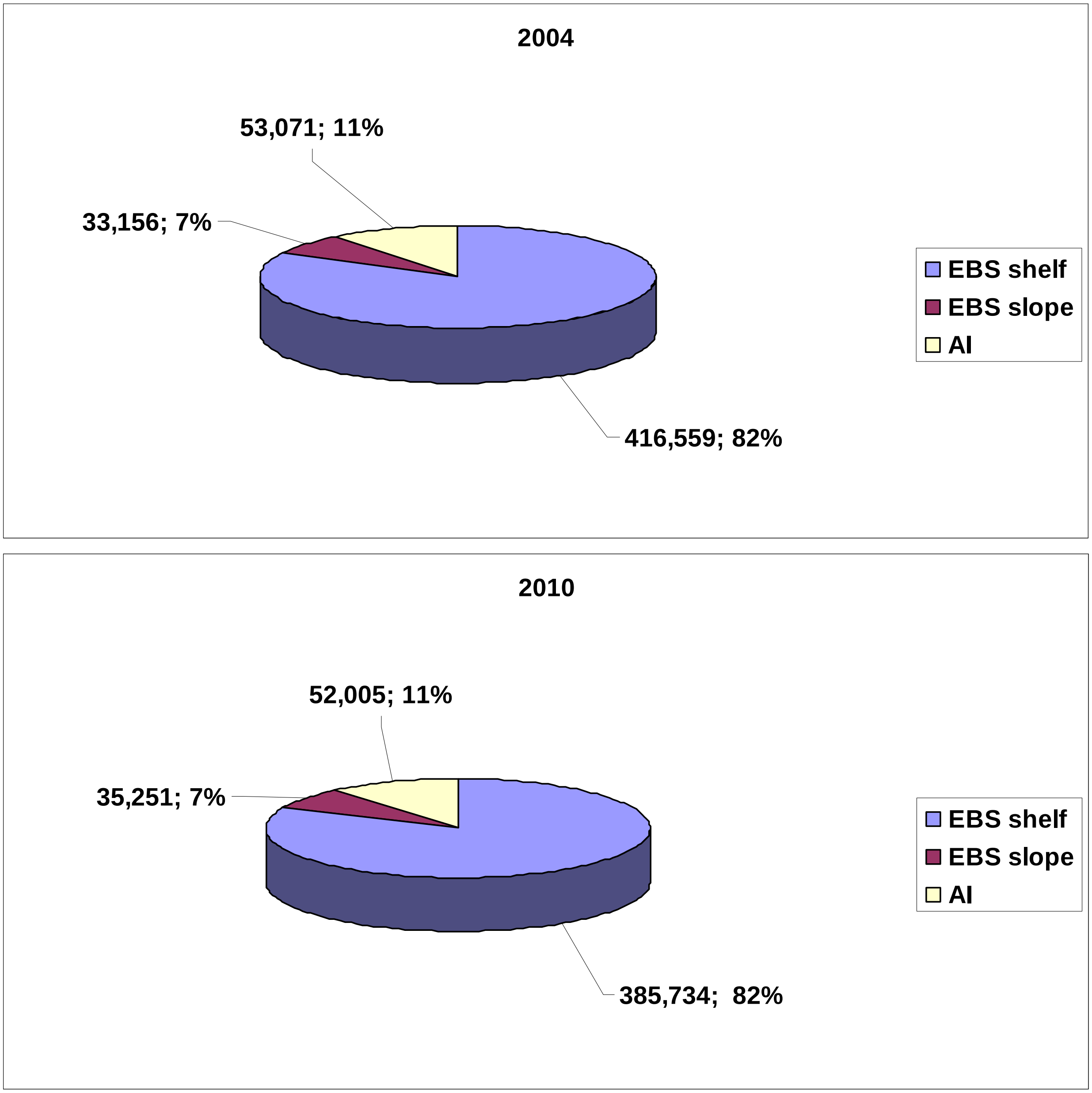
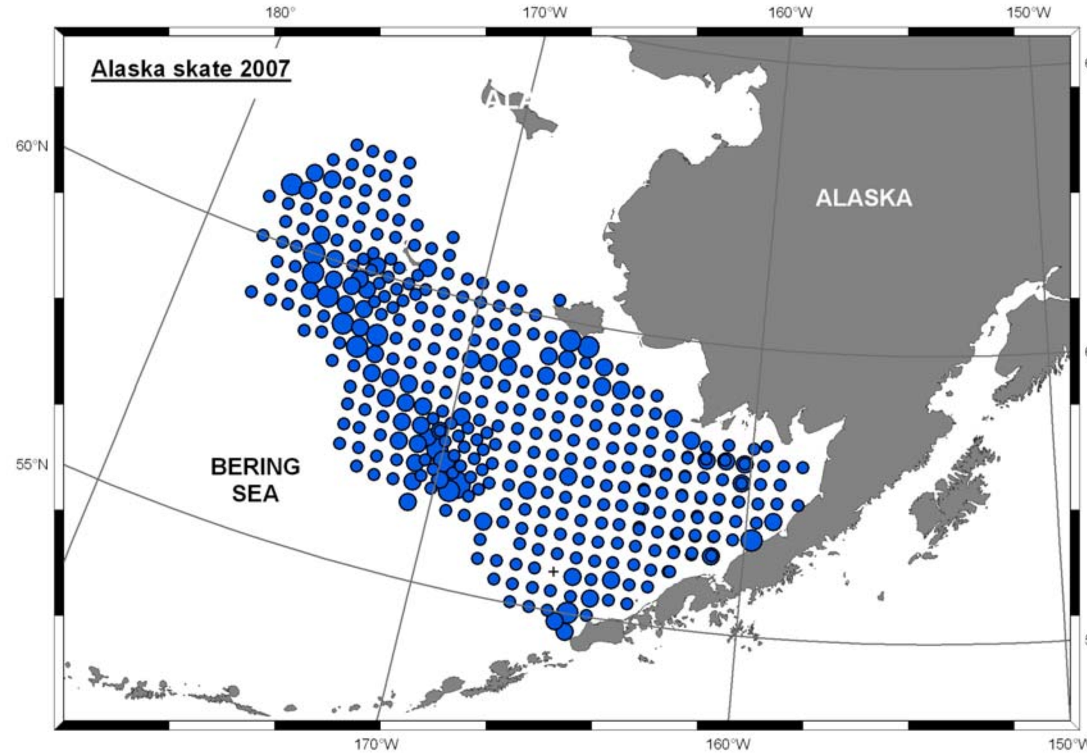


Figure 5. Distribution of skate biomass in the 3 subregions of the BSAI, 2004 and 2010. Data are biomass estimates from AFSC groundfish surveys.



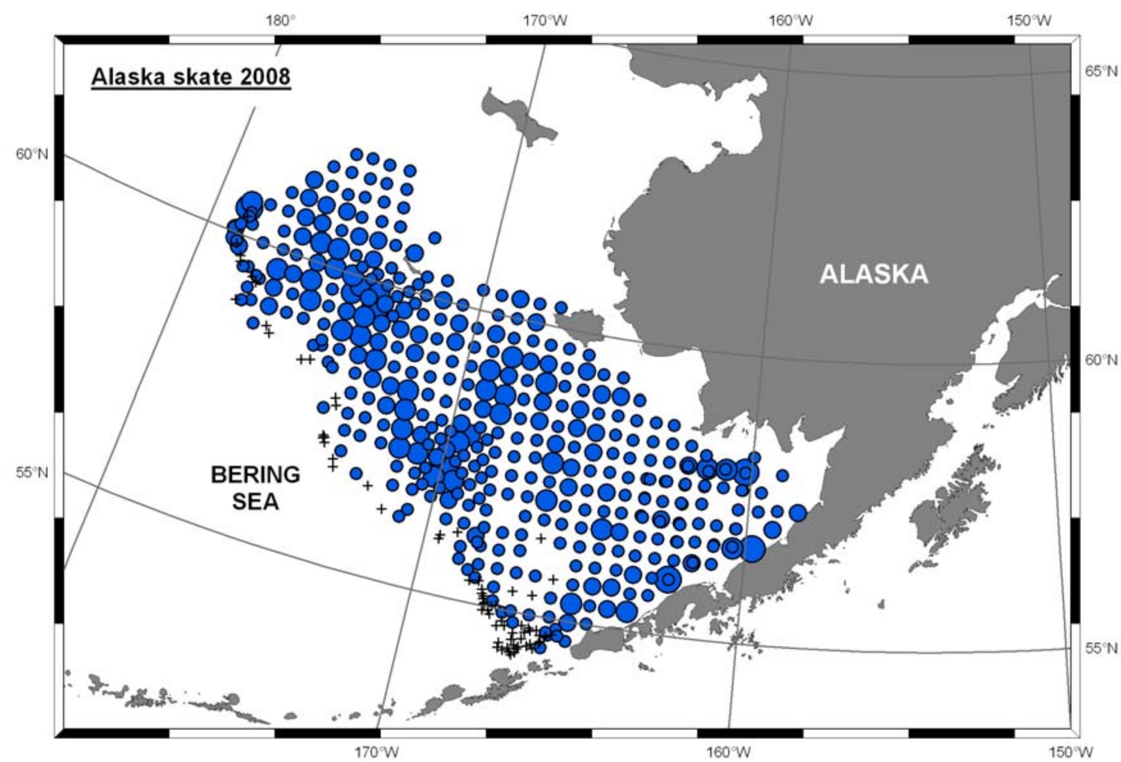


Figure 6. AFSC bottom trawl survey catches of Alaska skate in 2007 & 2008. Symbol size is proportional to total catch at each survey station. Data from 2008 include the 2008 slope survey. Crosses indicate no catch of Alaska skate at that station.

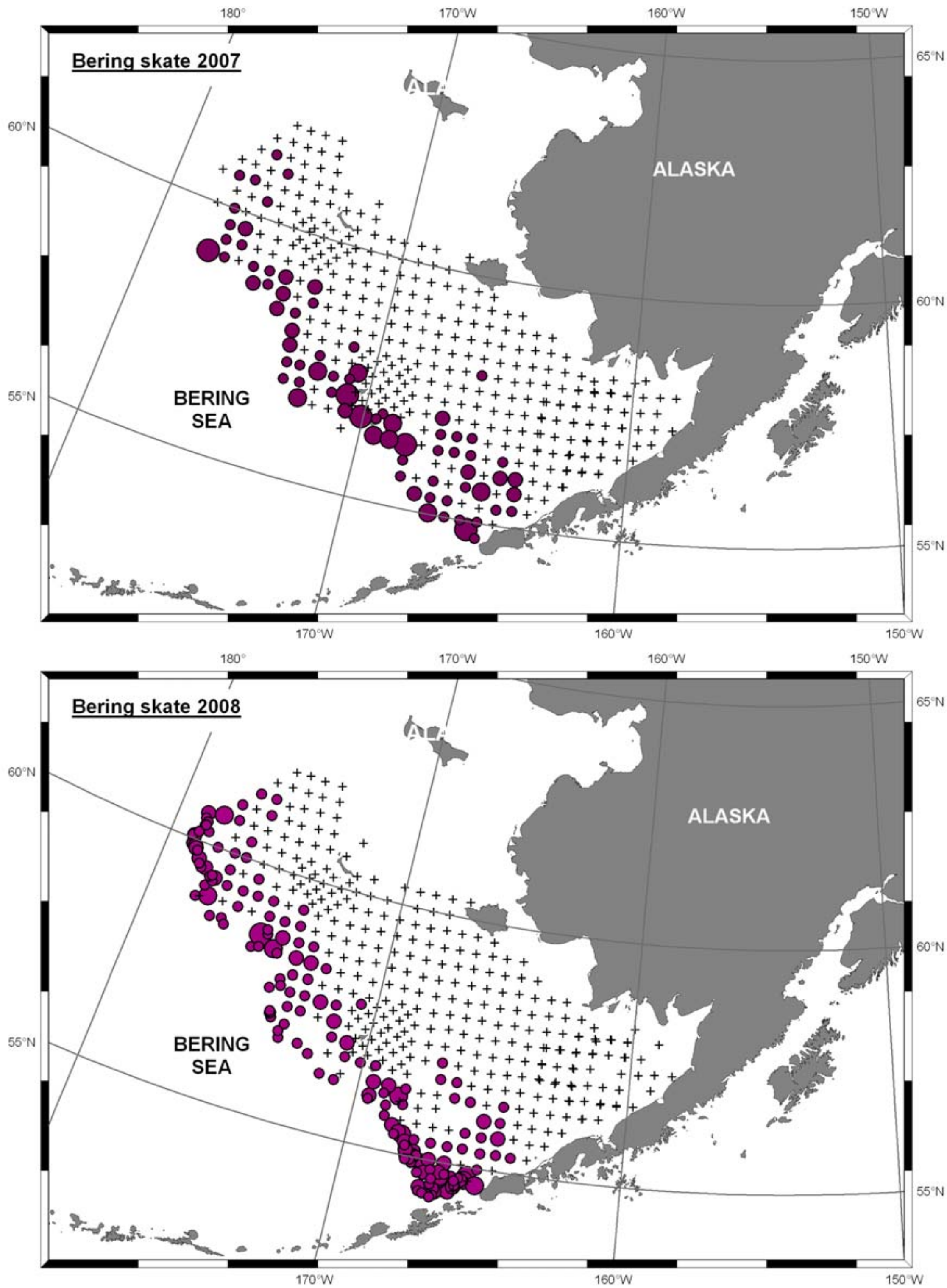


Figure 7. AFSC bottom trawl survey catches of Bering skate in 2007 & 2008. Symbol size is proportional to total catch at each survey station. Data from 2008 include the 2008 slope survey. Crosses indicate no catch of Bering skate at that station.

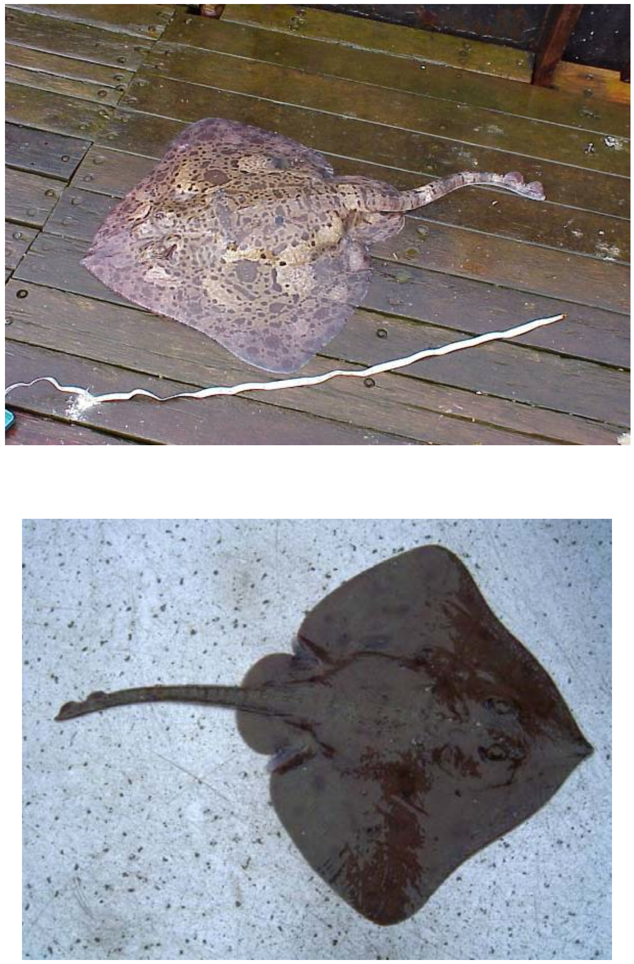


Figure 8. Skate diversity in the Aleutians: a new species, the leopard skate, from the Aleutian Islands (top) formerly thought to be the same species as the extremely common Alaska skate, *B. parmifera* (from the EBS, bottom). Photo credits: leopard skate, Richard MacIntosh; Alaska skate, Beth Matta.

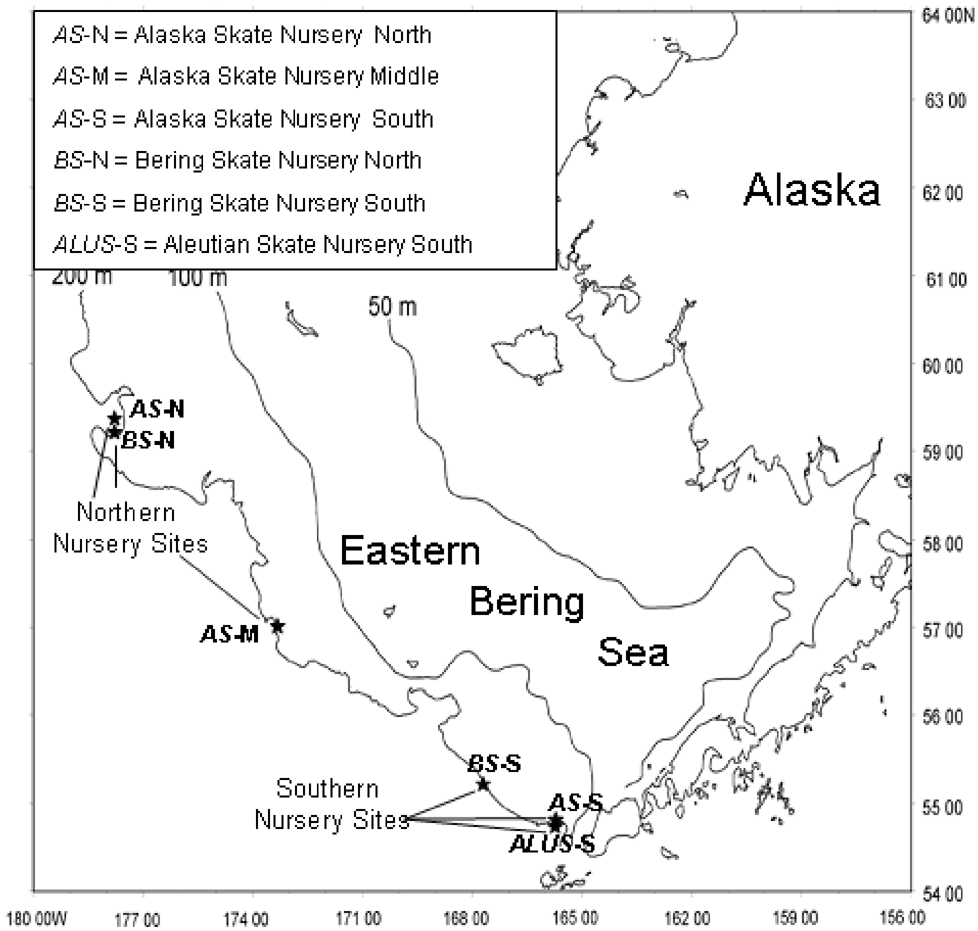


Figure 9. Map of the eastern Bering Sea with the six known skate nursery site locations and designations as a northern or southern nursery site. (See the legend for nursery site designation.) Source: Gerald Hoff, AFSC, unpublished data.

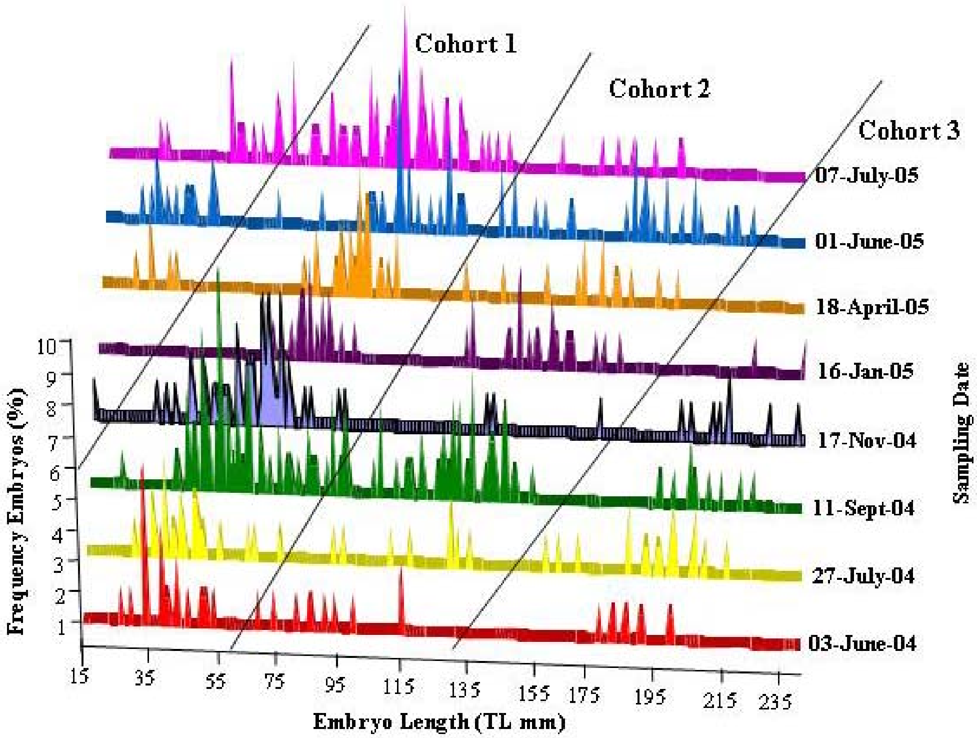


Figure 10. Embryo length composition data used in a cohort analysis of embryo development time. Figure is from G. Hoff (pers. comm.).

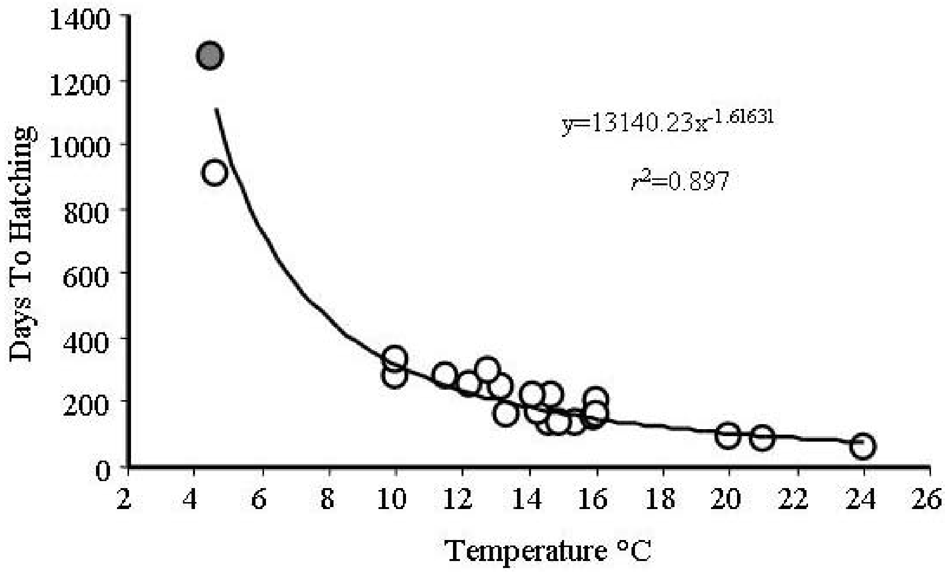


Figure 11. Ocean temperature versus embryo development time for 21 skate species. Dark grey circle is the Alaska skate. Equation and R^2 are the values of the fitted relationship. Figure is from G. Hoff, AFSC, pers. comm.

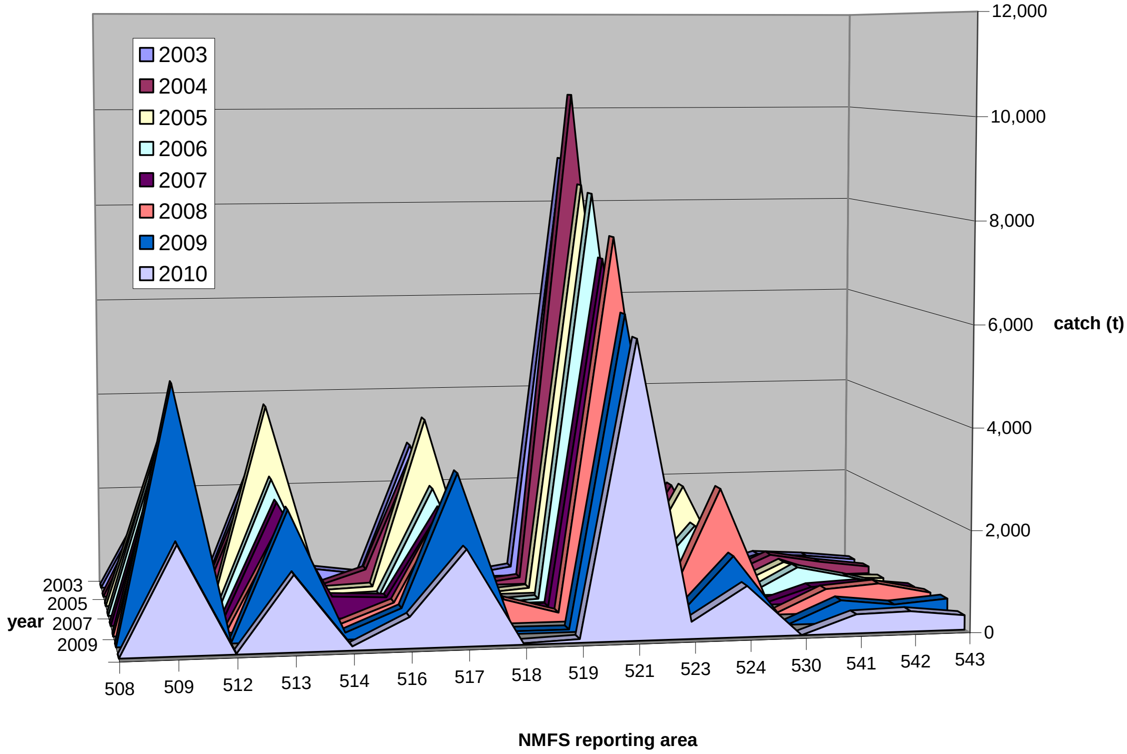


Figure 12. Total skate catch (all species combined) by FMP reporting area for both the EBS and the AI, 2003-2010. Source: AKRO CAS.

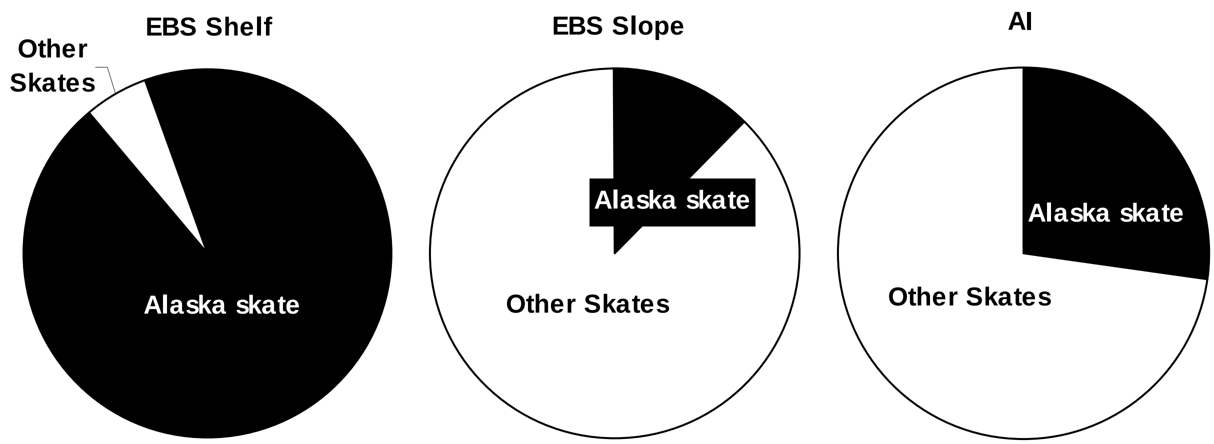


Figure 13. Relative proportion of Alaska skates and Other Skates in each habitat area. Graphs represent weighted averages from 1999-2010 trawl survey biomass estimates. These data were used to reconstruct catch data for the Alaska skate.

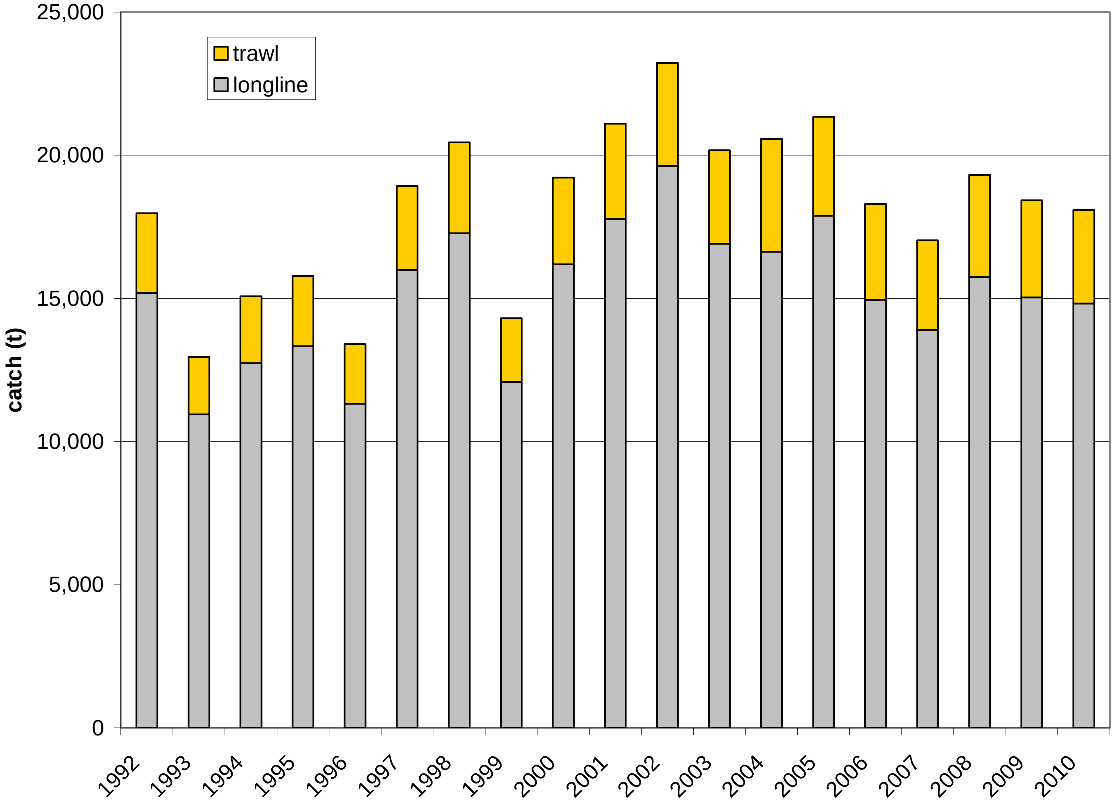


Figure 14. Estimated catch of Alaska skates (t) in the BSAI used in the model, 1992 to 2010. Data were obtained from the Blend system and AKRO CAS. Data or 2010 are incomplete and based on 2009 data.

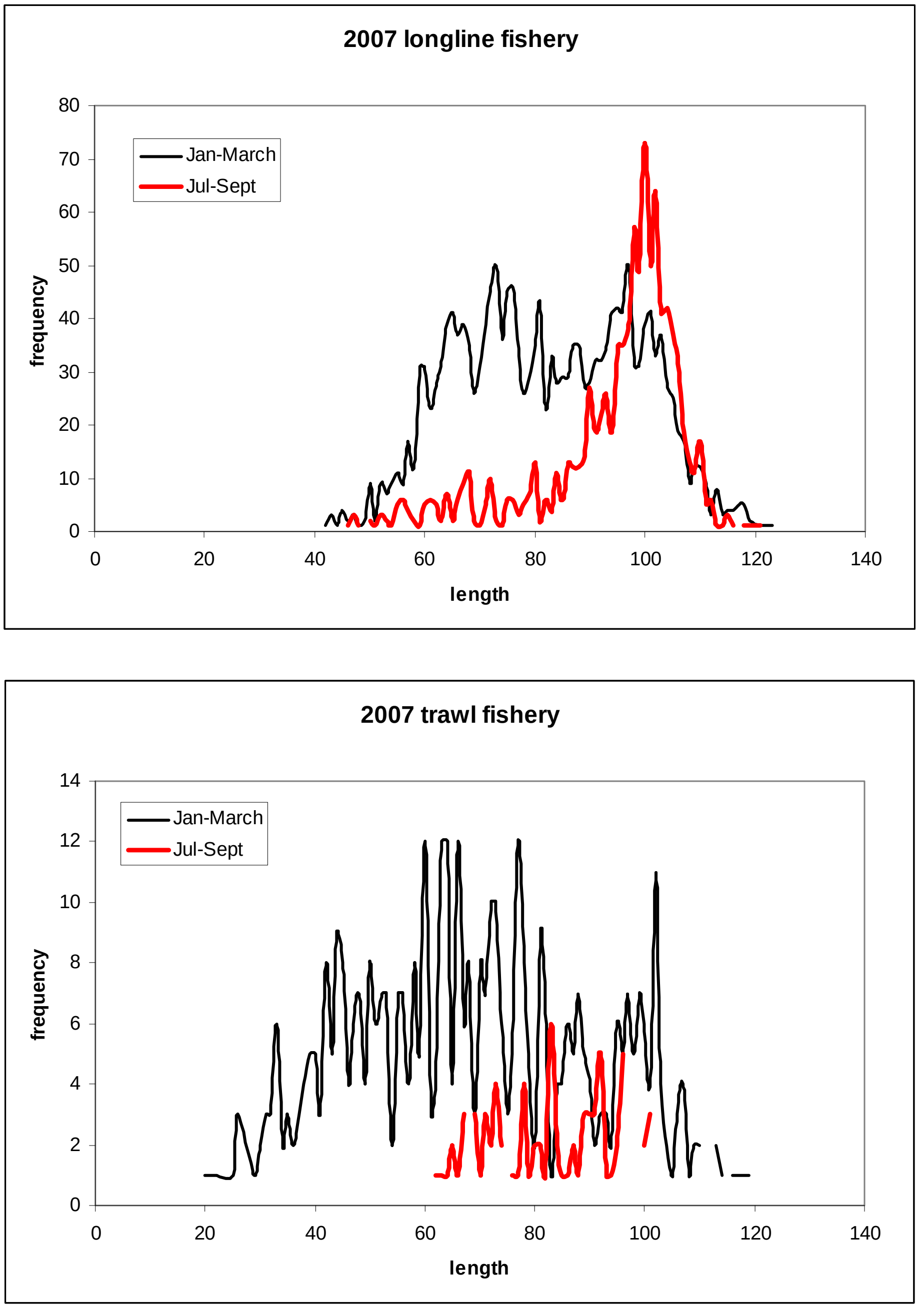


Fig. 15. Fishery length compositions by quarter (unbinned data) for Alaska skates during 2007.

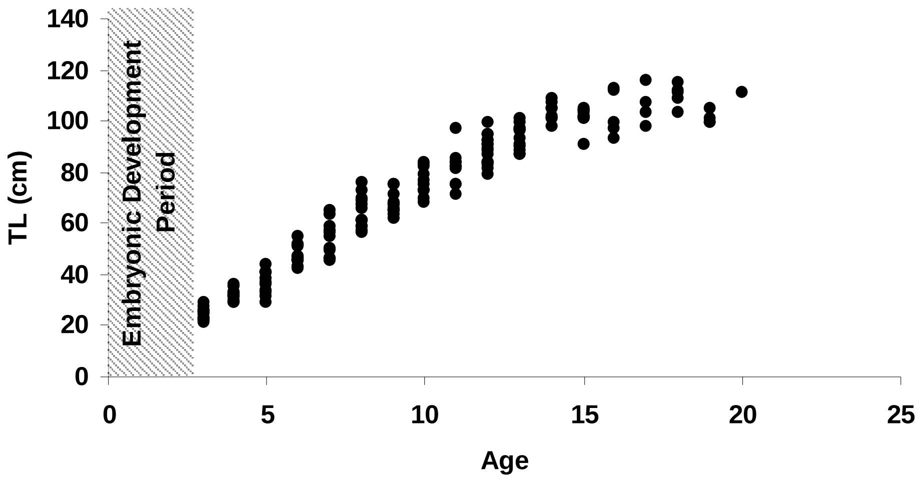


Figure 16. Observed size at age data from Alaska skates collected in the 2003 EBS shelf trawl survey, sexes combined (n=182). The three year embryonic development period included in the base model is represented by the shaded area.

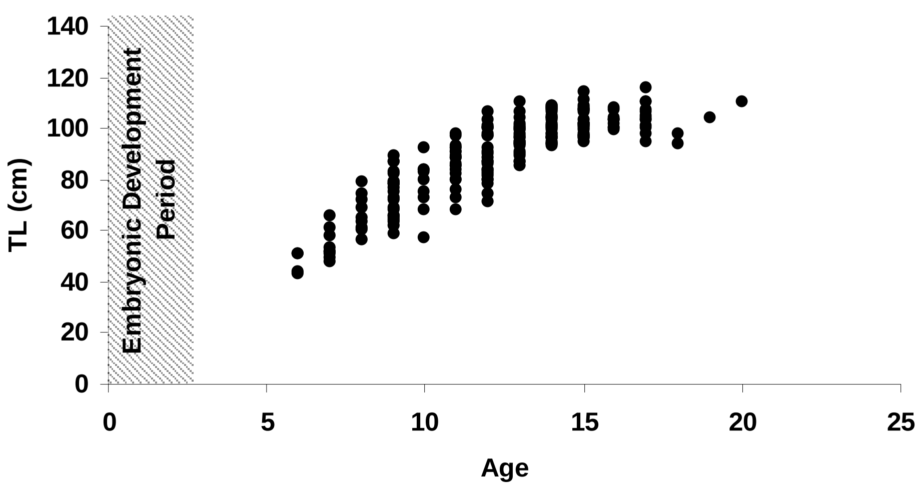


Figure 17. Observed size at age data from Alaska skates collected in the 2005 longline fishery, sexes combined (n=208). The three year embryonic development period included in the base model is represented by the shaded area.

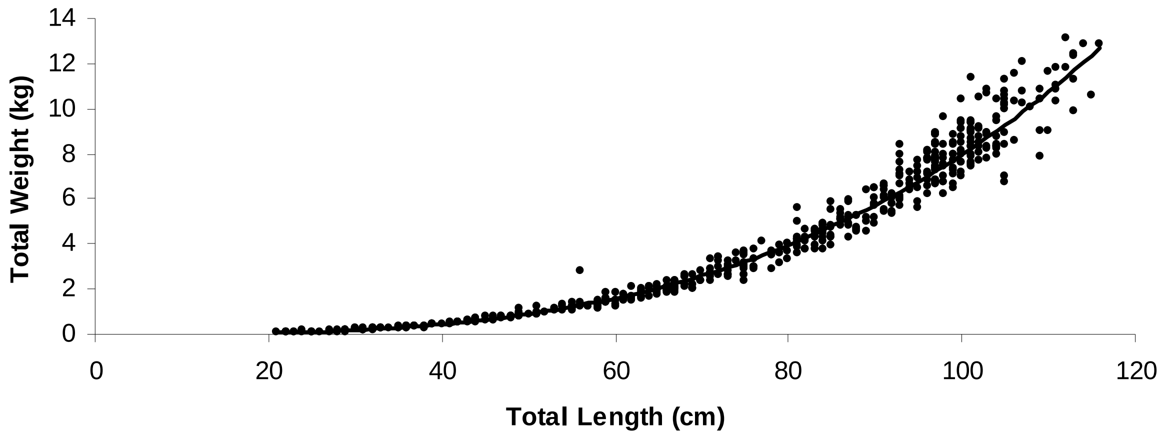


Figure 18. The relationship between total length (TL) and total body weight (W) for the Alaska skate, both sexes combined (n=526).

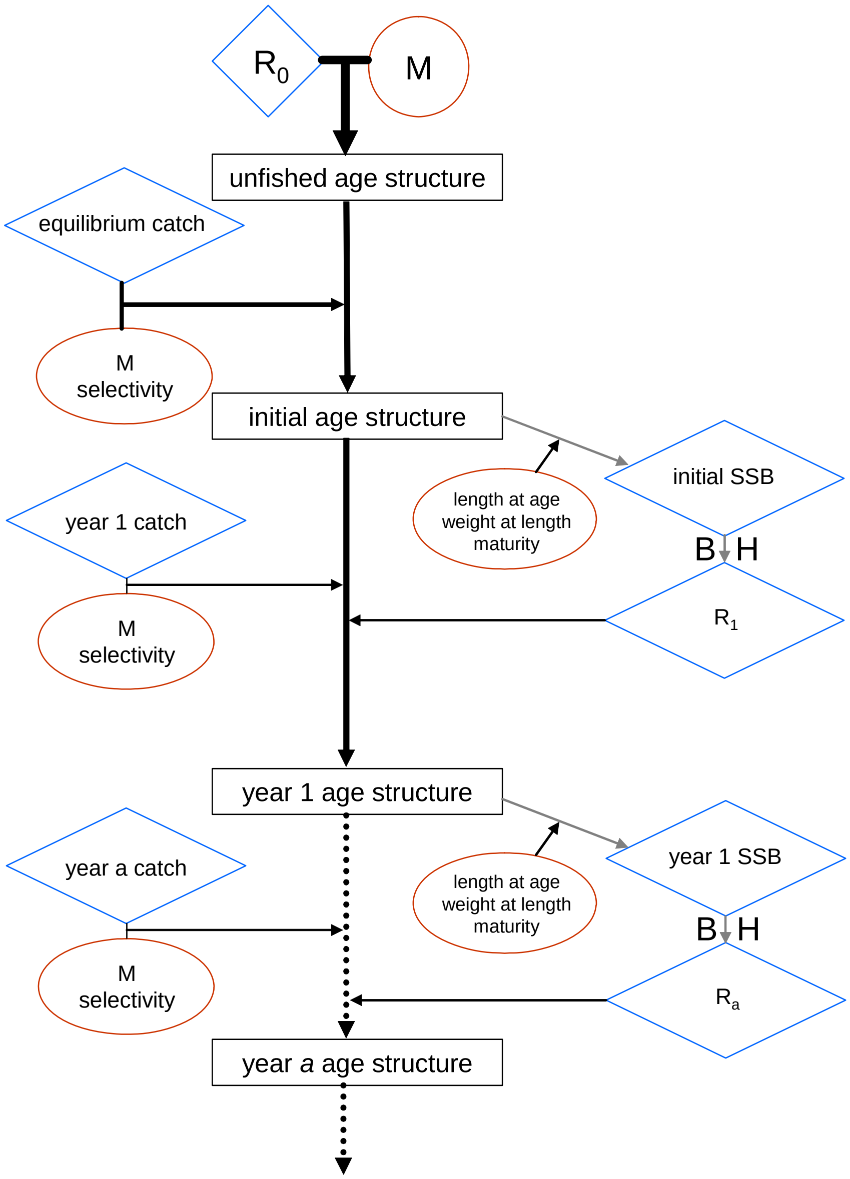


Figure 19. Simplified schematic depiction of population dynamics model used in the Alaska skate assessment. Blue diamonds indicate physical quantities, red circles indicate rates. R_a = recruitment in year a, M = natural mortality, SSB = spawning biomass, BH indicates that a Beverton-Holt stock-recruit relationship is applied to SSB to estimate recruitment.

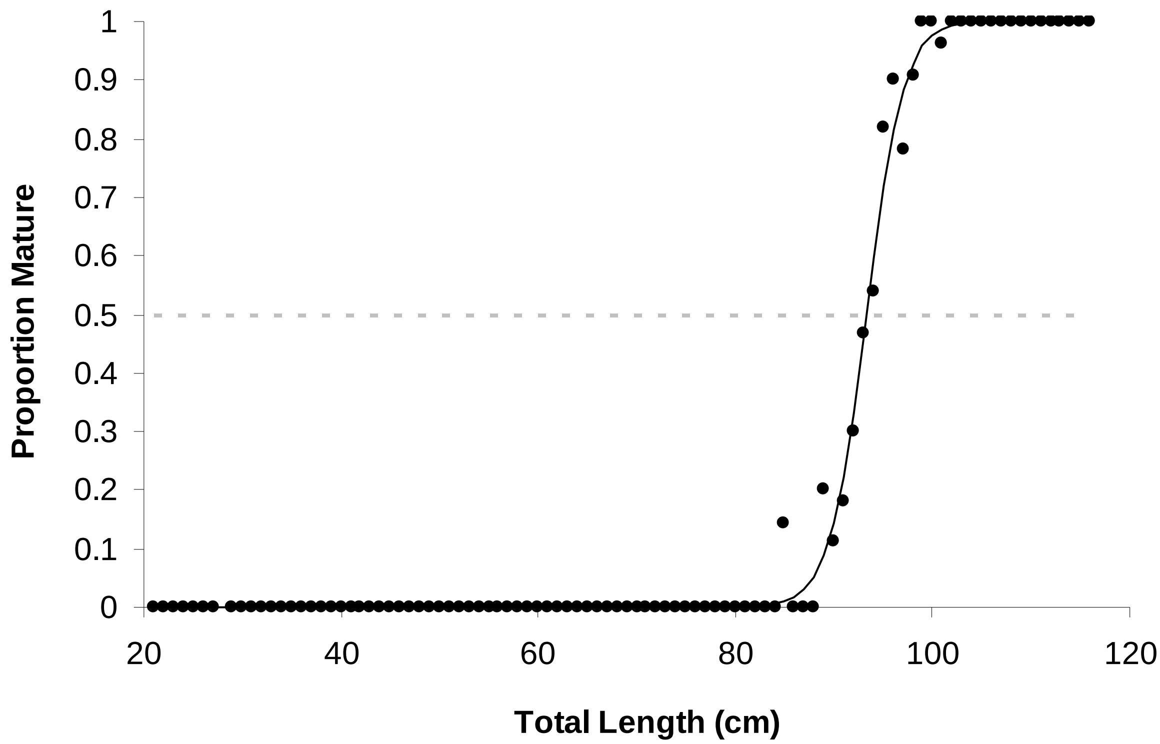


Figure 20. Female Alaska skate maturity-at-length data shown with fitted logistic curve from Matta (2006) (n=642).

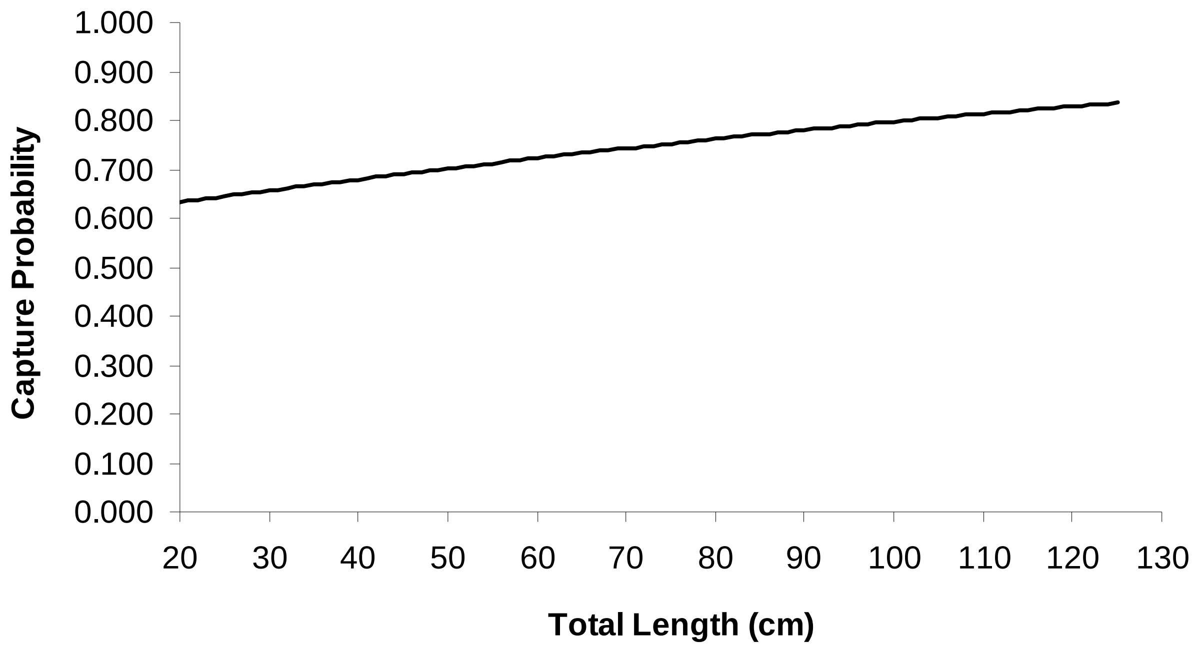


Figure 21. Length-based capture probability for skates (*Bathyraja* spp.) in the EBS shelf bottom trawl survey, based on data from Kotwicki and Weinberg (2005).

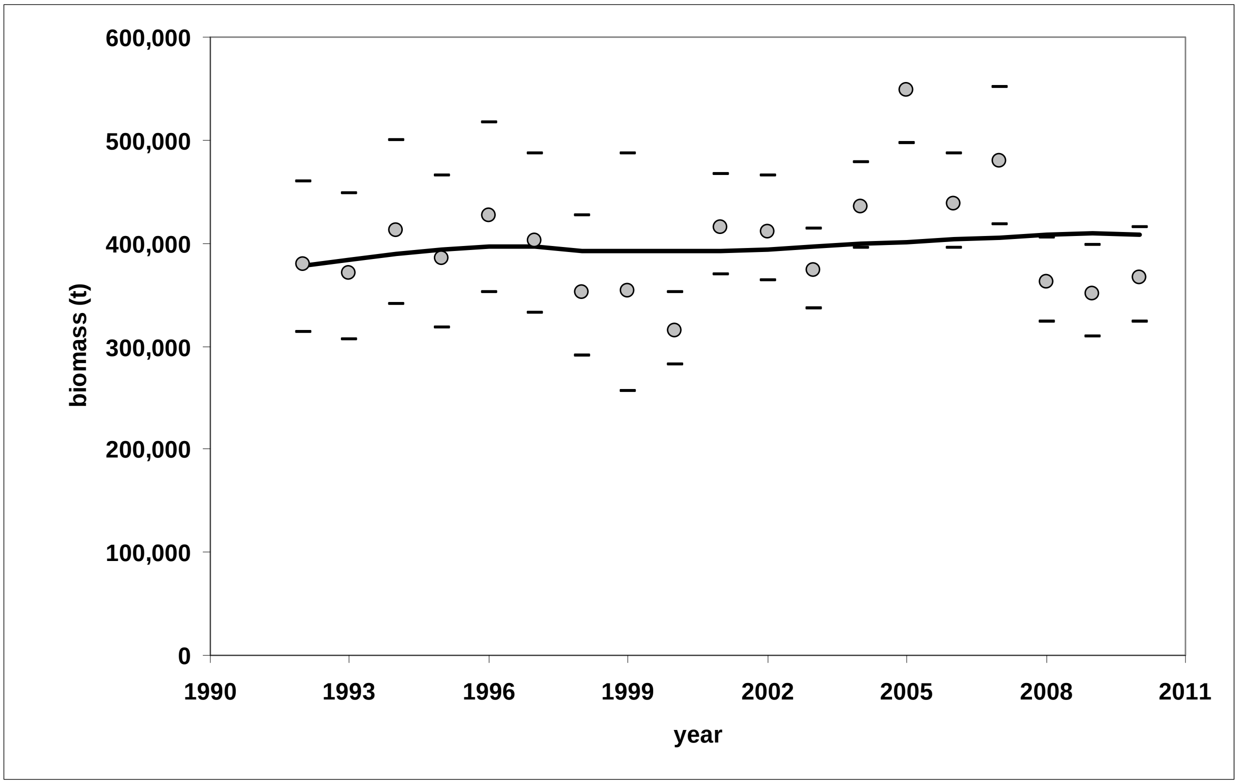


Figure 22. Observed biomass (circles) from EBS shelf surveys 1992-2009, with approximate confidence intervals (± 2 SE), and predicted survey biomass from the model (black line).

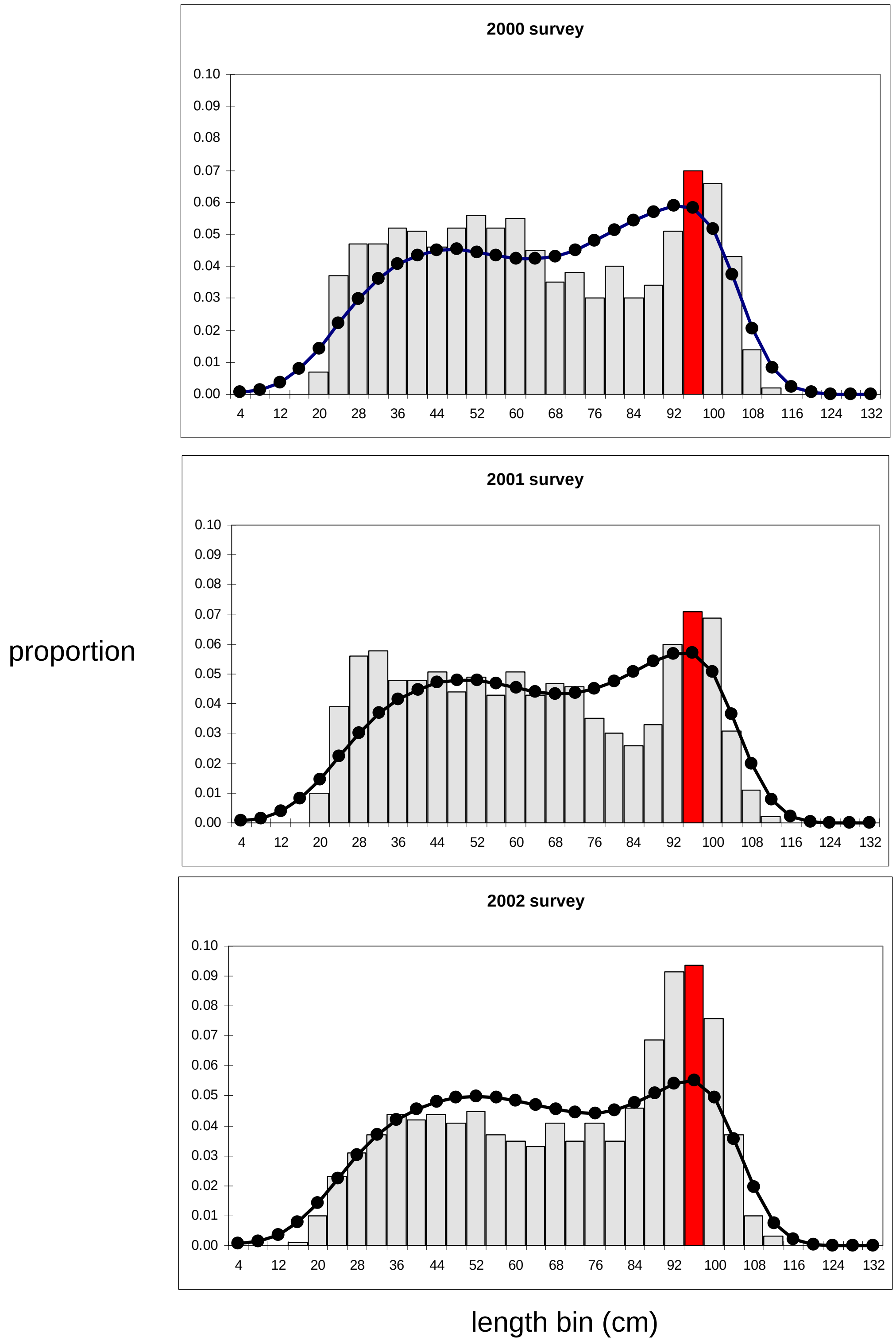


Figure 23. EBS shelf survey length compositions from 2000-2010. Grey bars = observed proportions; black line with circles = model predictions. Red column indicates 96-99 cm length bin.

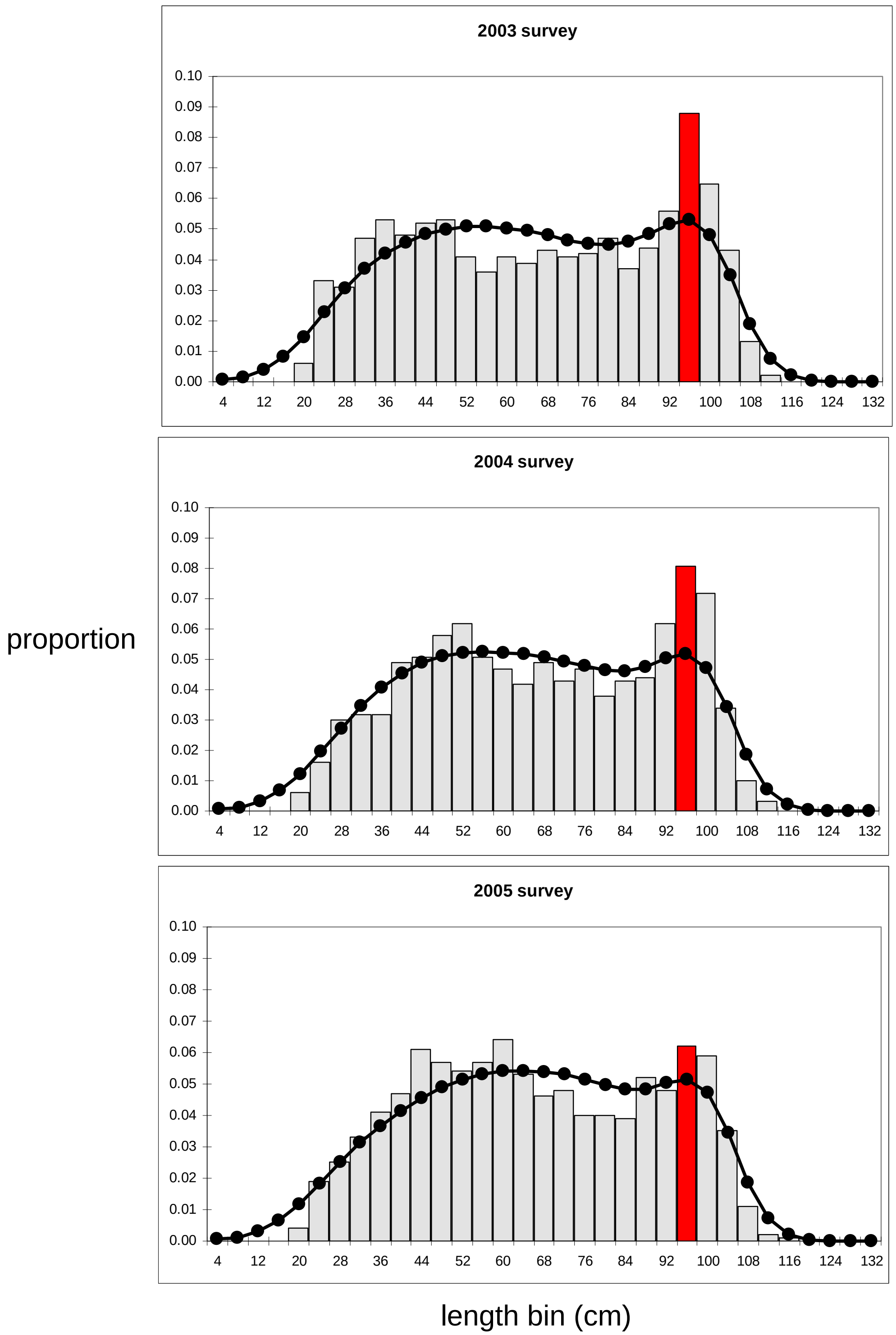


Figure 23 continued. EBS shelf survey length compositions from 2000-2010. Grey bars = observed proportions; black line with circles = model predictions. Red column indicates 96-99 cm length bin.

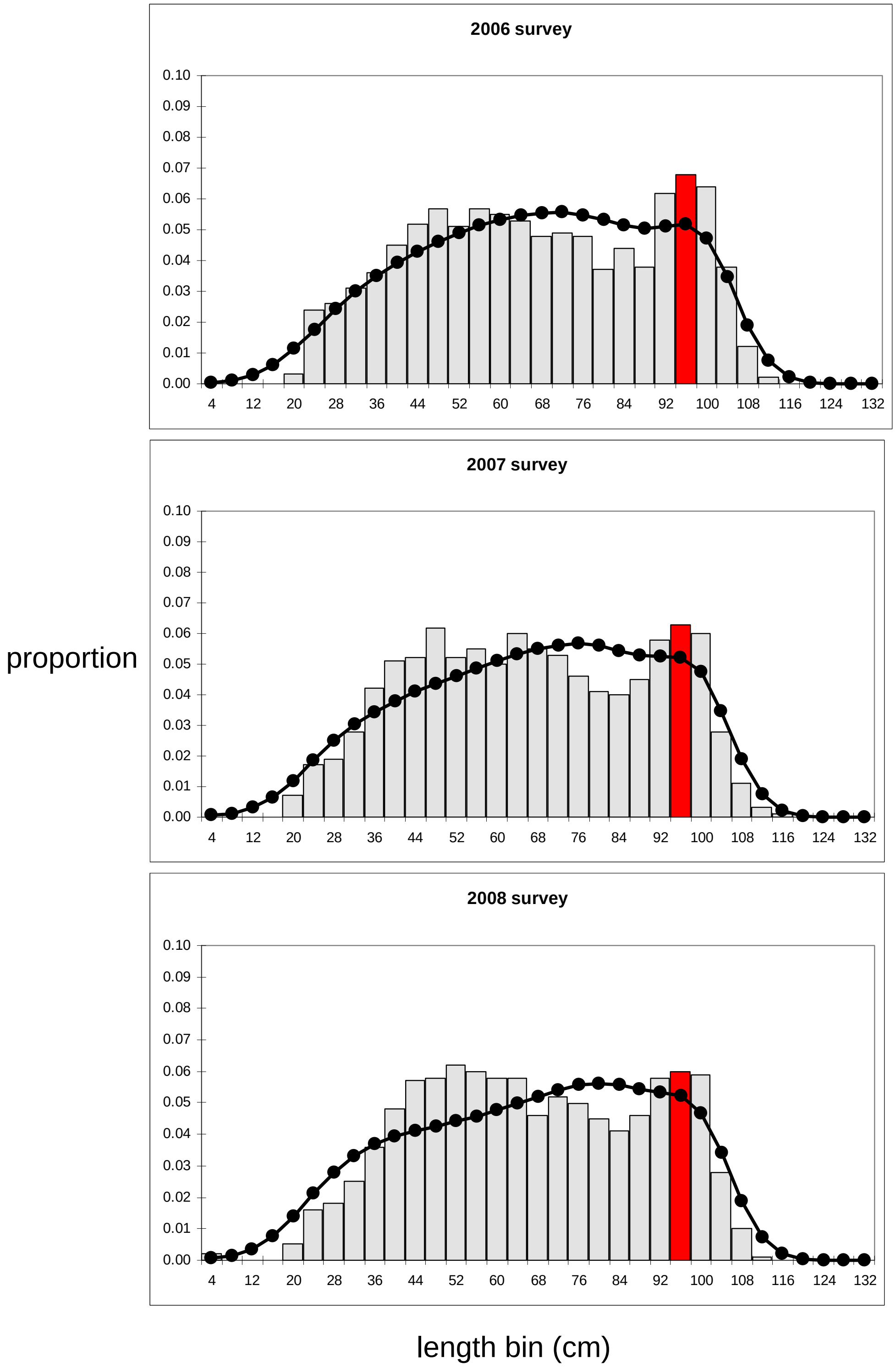


Figure 23 continued. EBS shelf survey length compositions from 2000-2010. Grey bars = observed proportions; black line with circles = model predictions. Red column indicates 96-99 cm length bin.

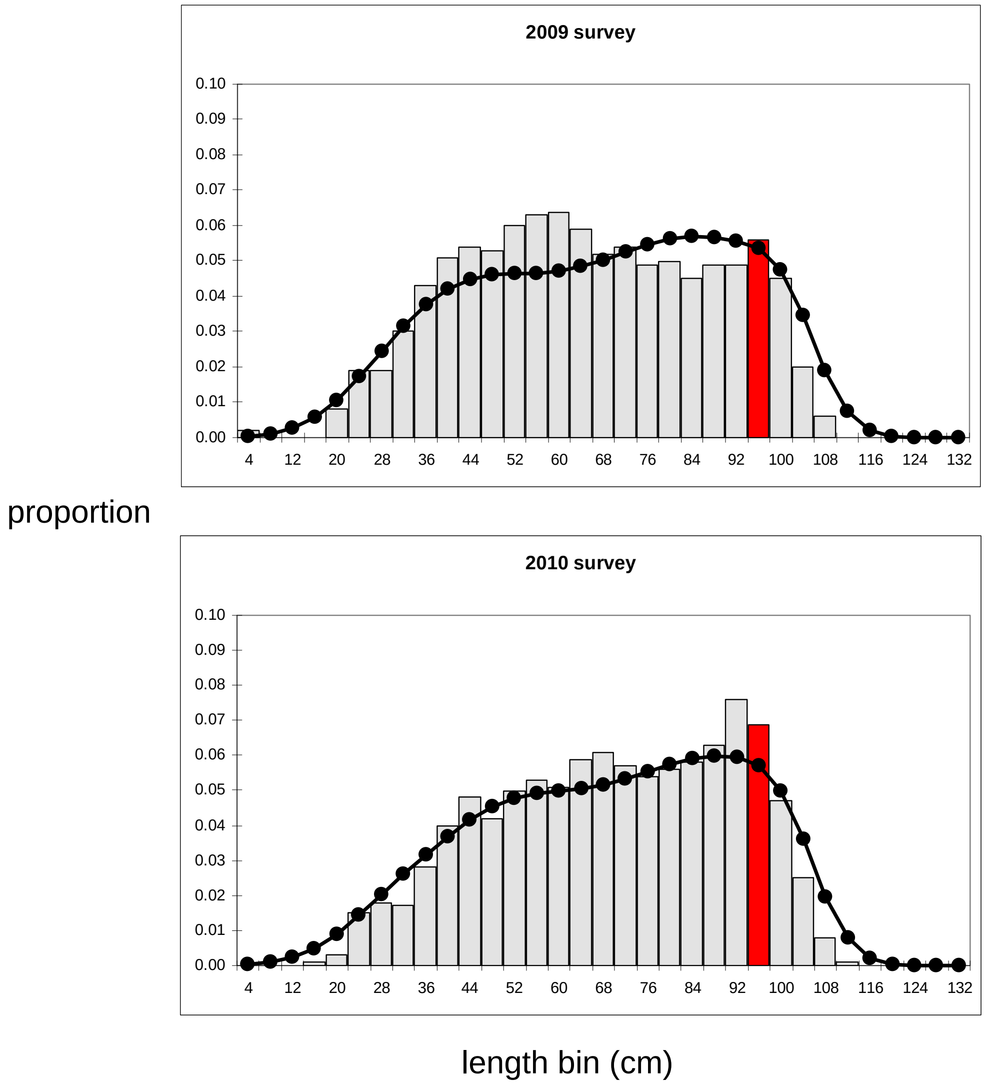


Figure 23 continued. EBS shelf survey length compositions from 2000-2010. Grey bars = observed proportions; black line with circles = model predictions. Red column indicates 96-99 cm length bin.

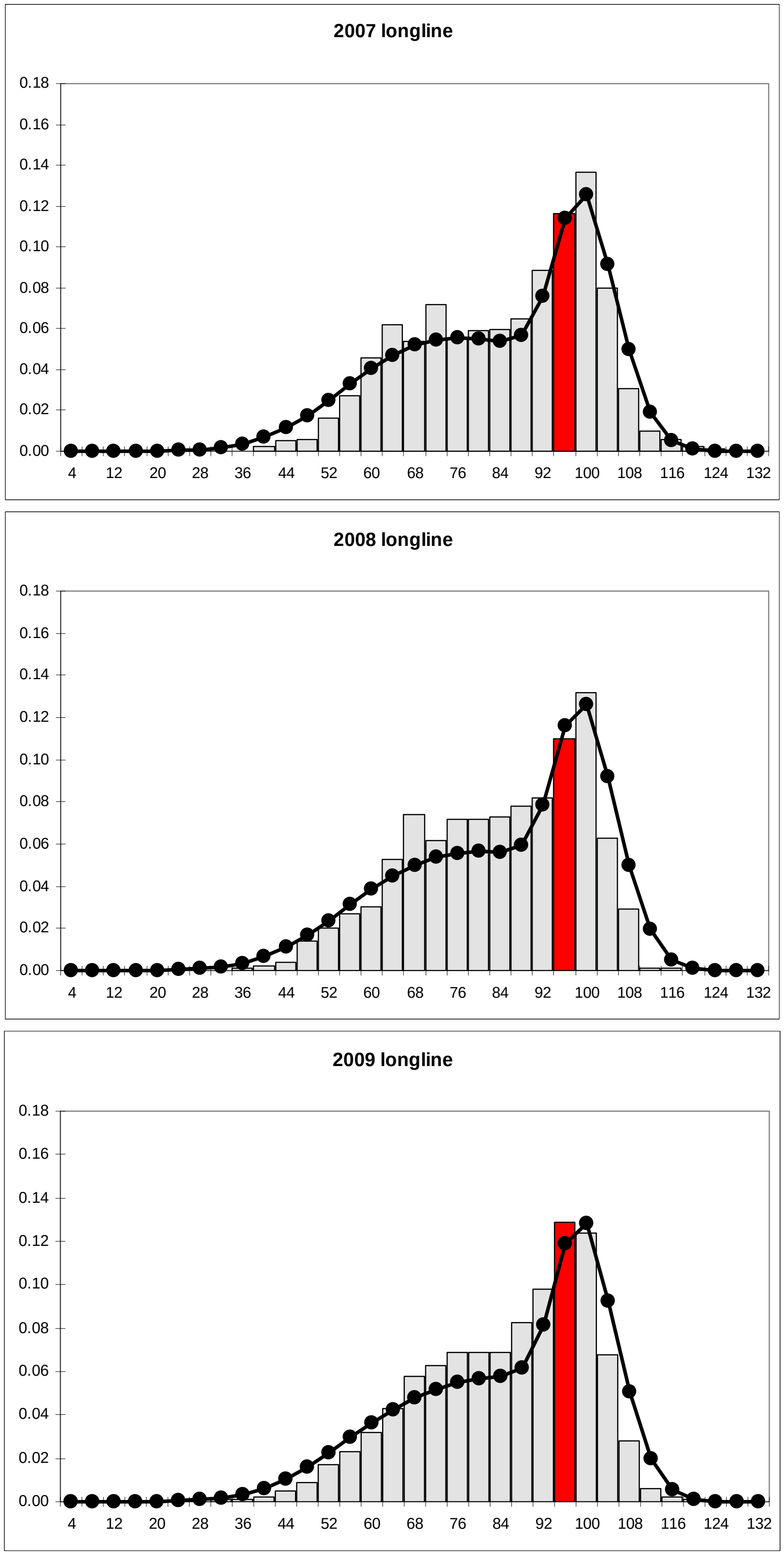


Figure 24a. Observed and model-predicted length compositions from the 2007-2009longline fisheries, with model predictions. Grey bars = observed values, black line with circles = predicted values. Red column indicates the 96-99 cm length bin.

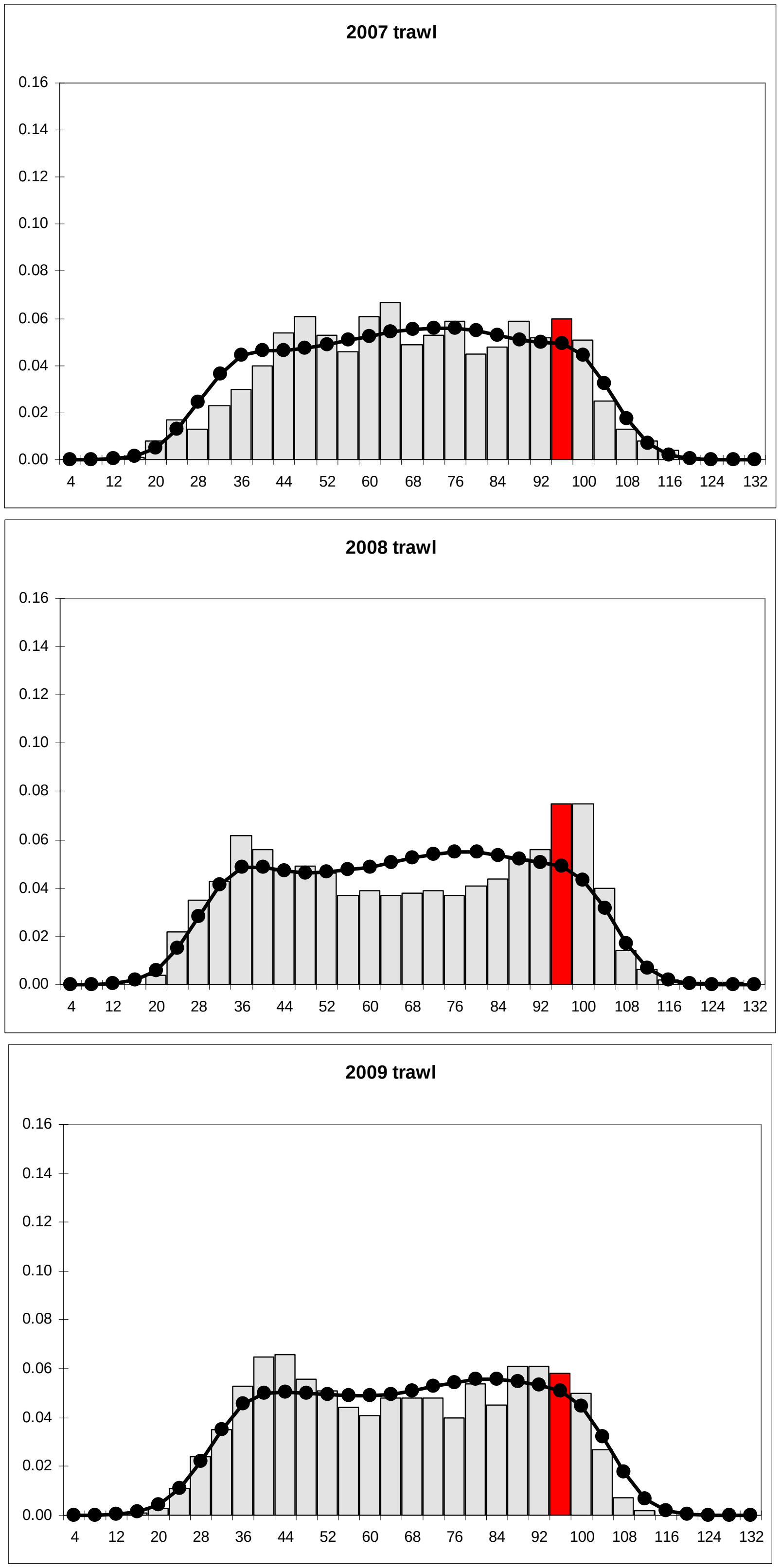
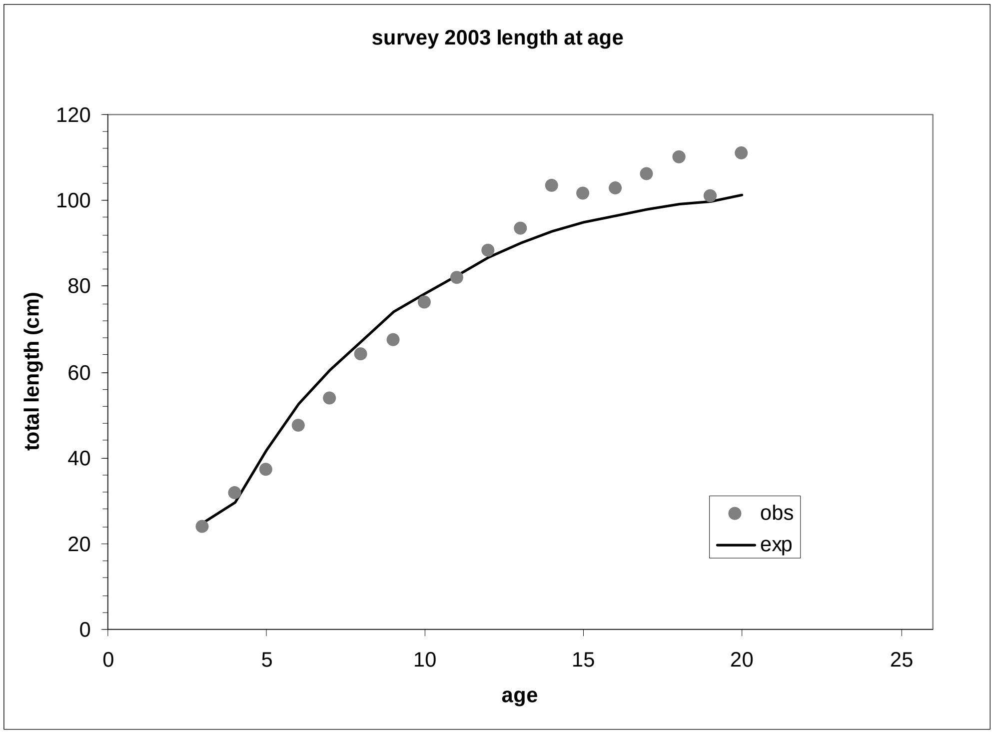


Figure 24b. Observed and model-predicted length compositions from the 2007-2009 trawl fisheries, with model predictions. Grey bars = observed values, black line with circles = predicted values. Red column indicates the 96-99 cm length bin.



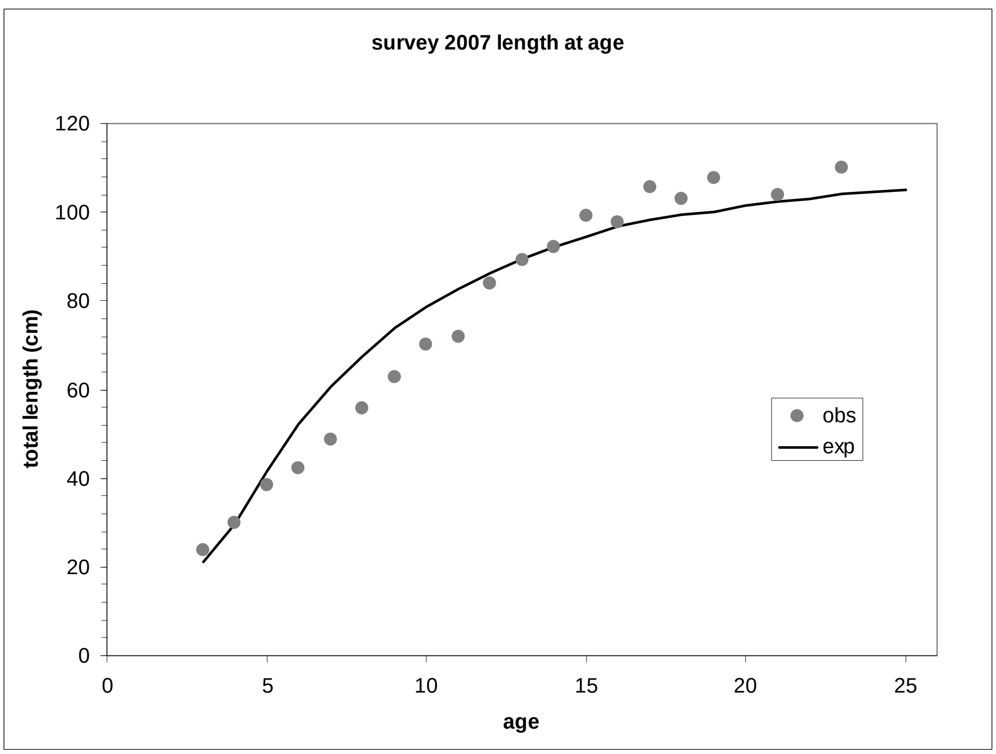


Figure 25. Observed and model-predicted length-at-age from the 2003 (upper panel) and 2007 (lower panel EBS shelf survey.

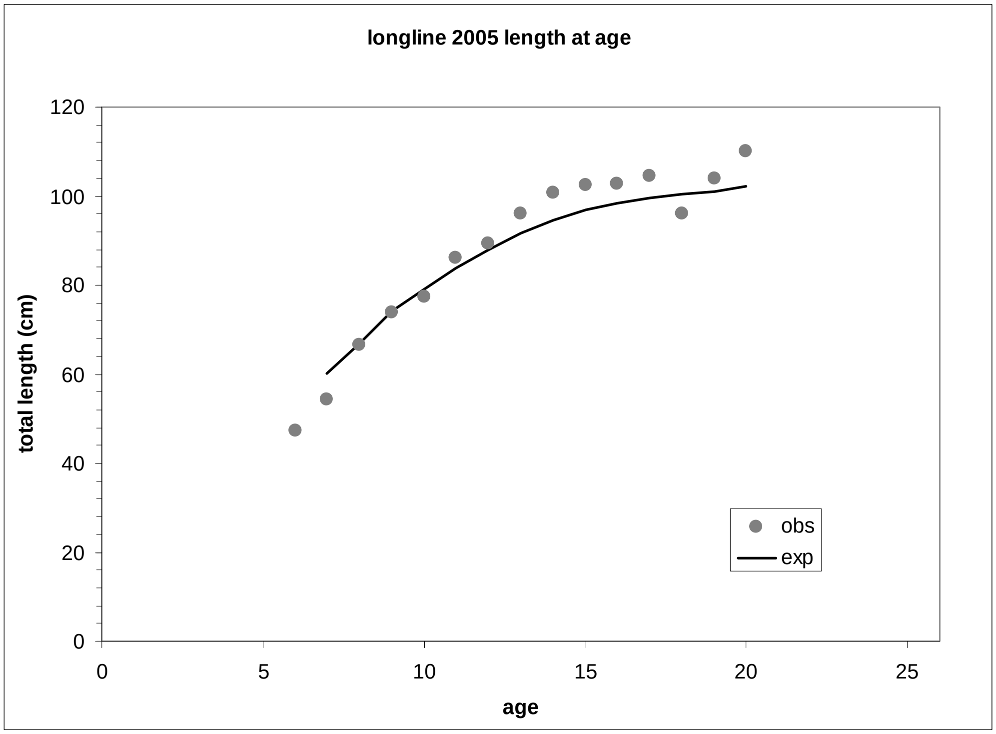


Figure 26. Observed and model-predicted length-at-age from the 2005 longline fishery.

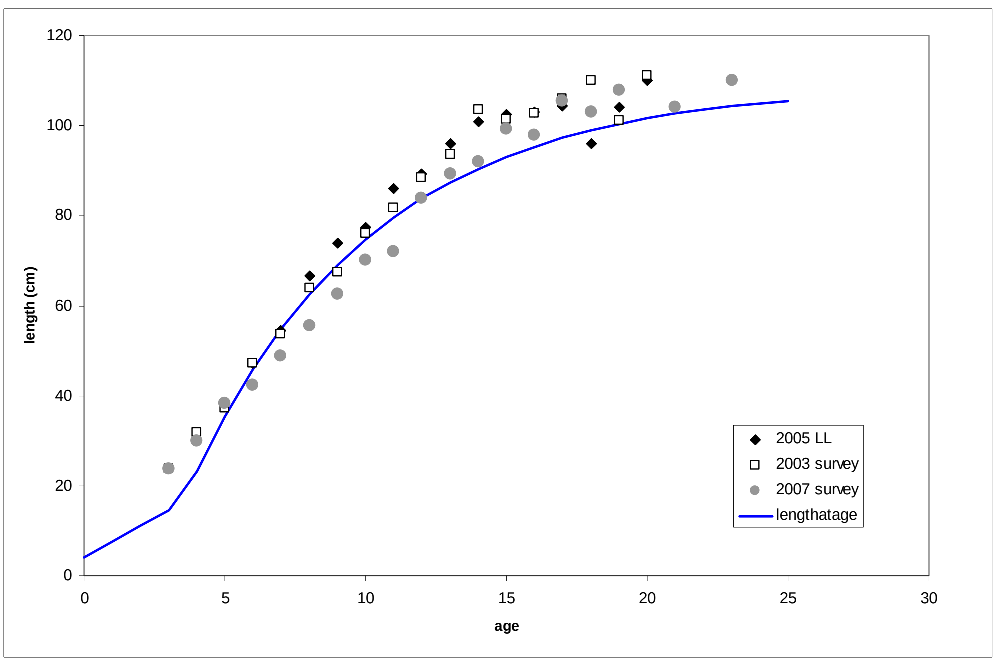


Figure 27. Observed length-at-age from the three datasets used in the model, with the population estimate of length-at-age (blue line) superimposed.

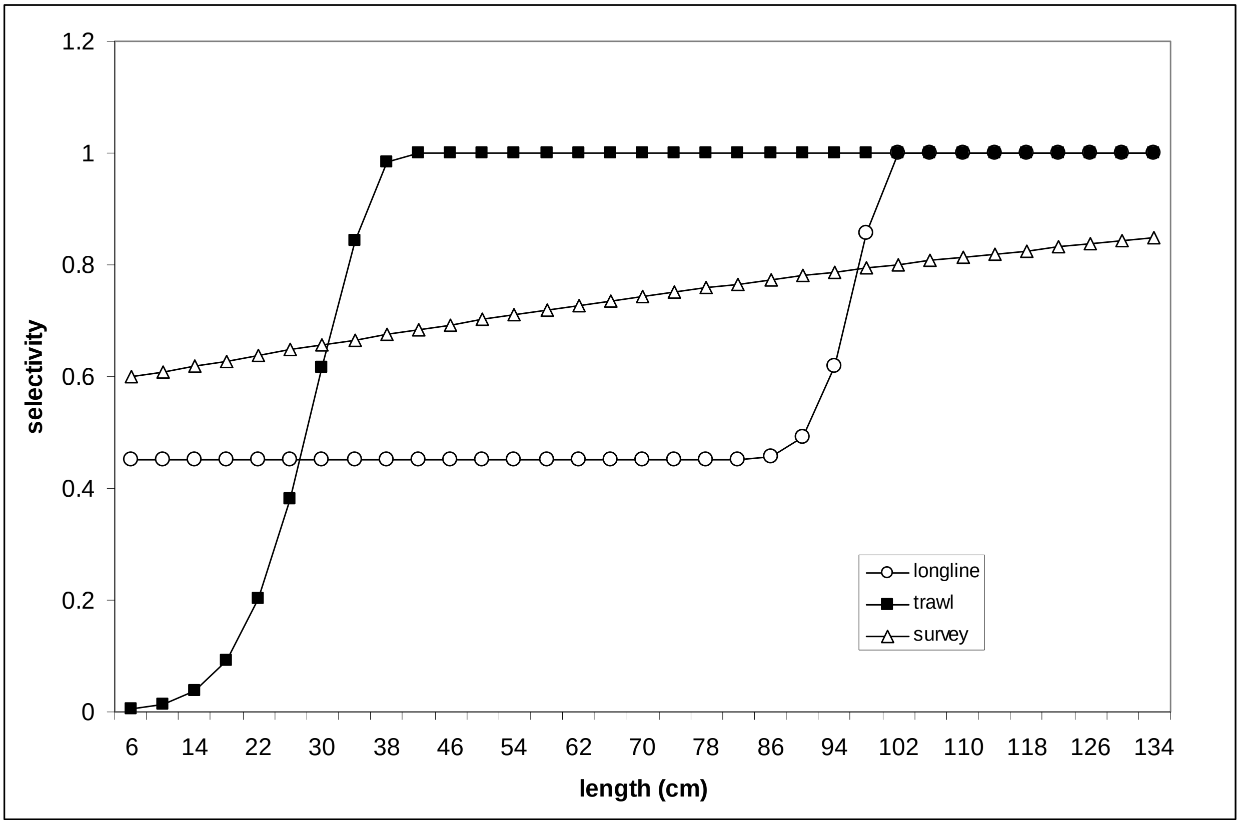


Figure 28. Length selectivities of the longline fishery, trawl fishery, and EBS shelf trawl survey.

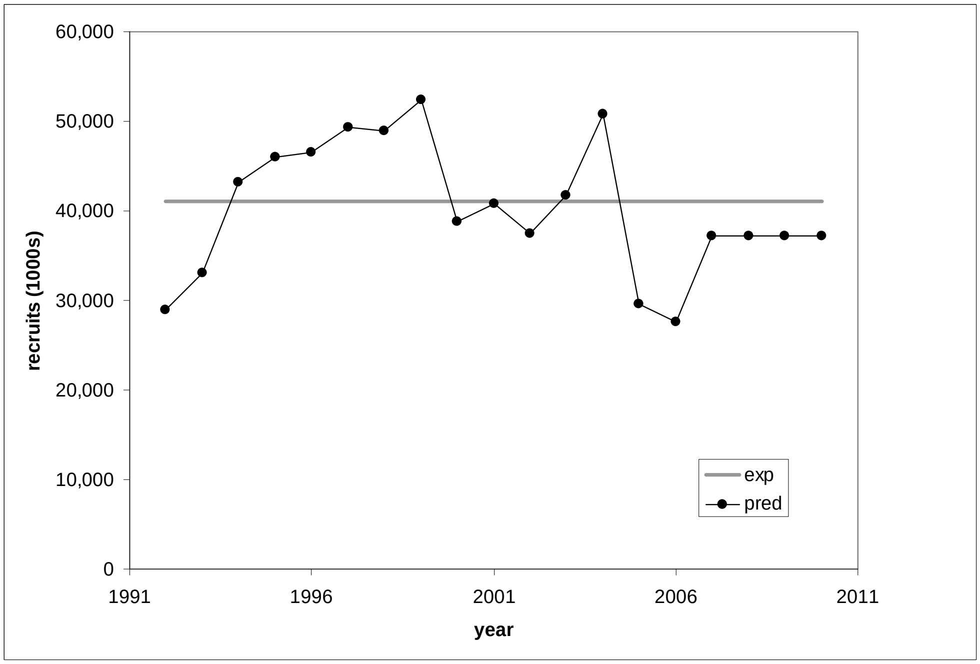


Figure 29. Time series of expected recruitment (in thousands of age 0 fish), with the time series of individual year class estimates predicted by the model and the expected Beverton-Holt stock-recruit relationship with a steepness of 1.0.

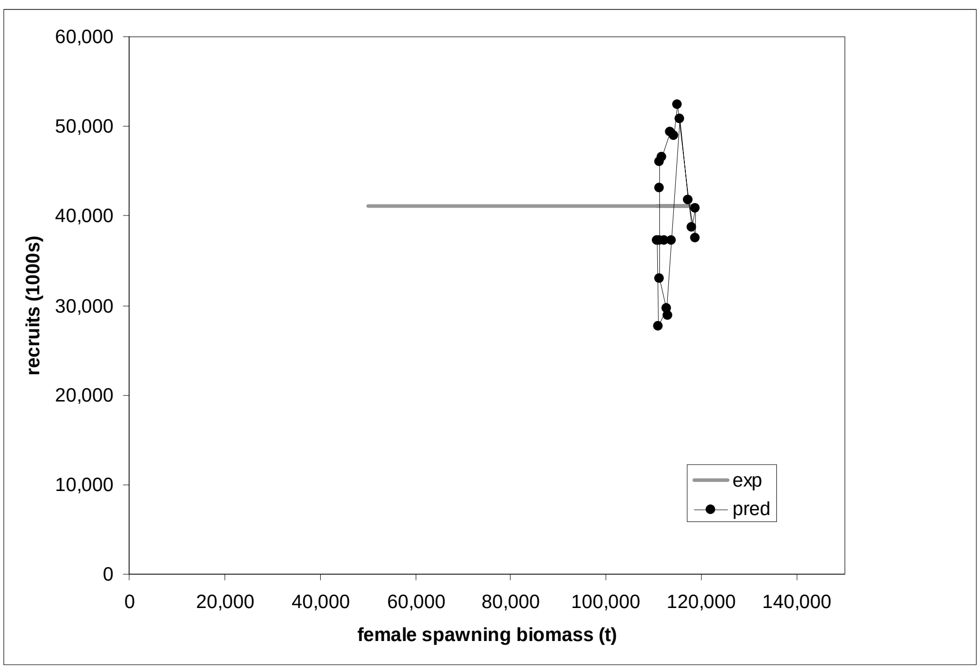


Figure 30. Relationship between the number of age 0 recruits (in thousands of fish) and female spawning biomass (t). Time series of individual year class estimates from SS2 is shown with a Beverton-Holt stock-recruit relationship with a steepness of 1.0.

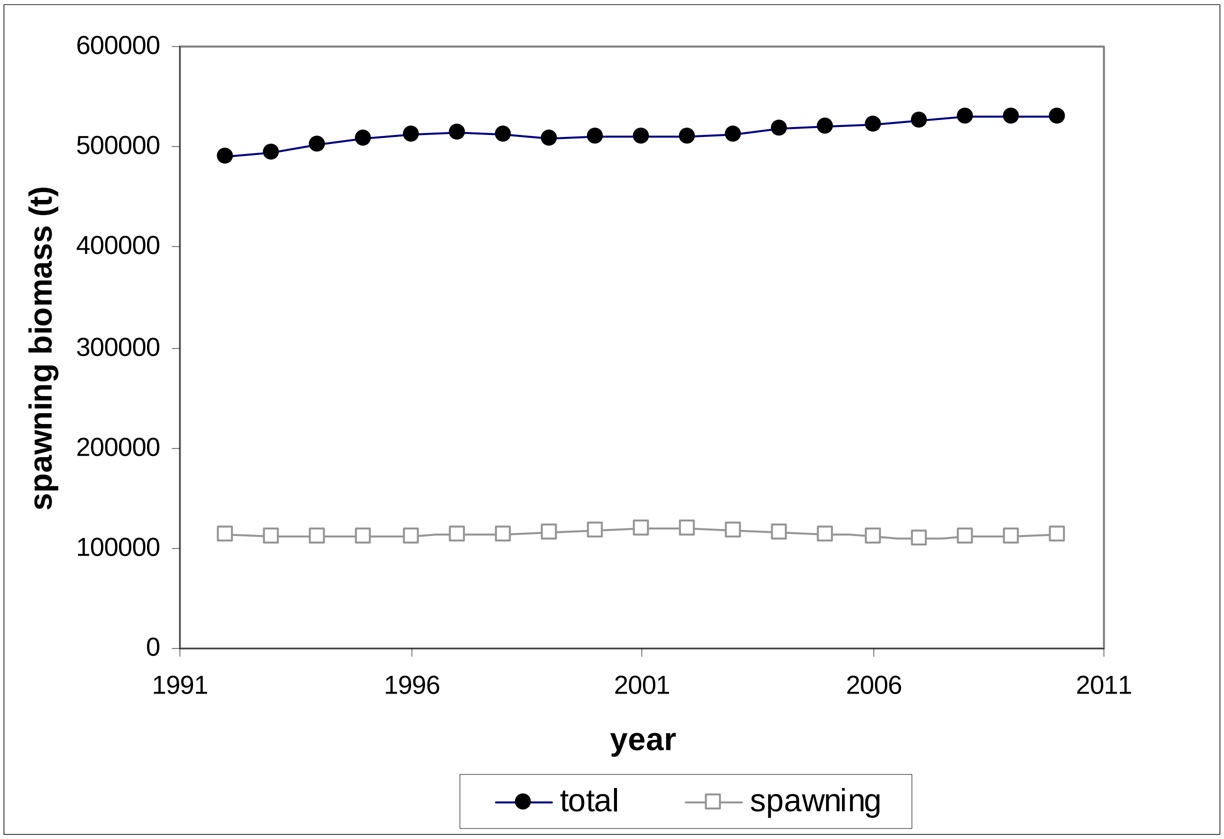


Figure 31. Time series of model estimates for total (age 0+) biomass (t) and female spawning biomass (t).

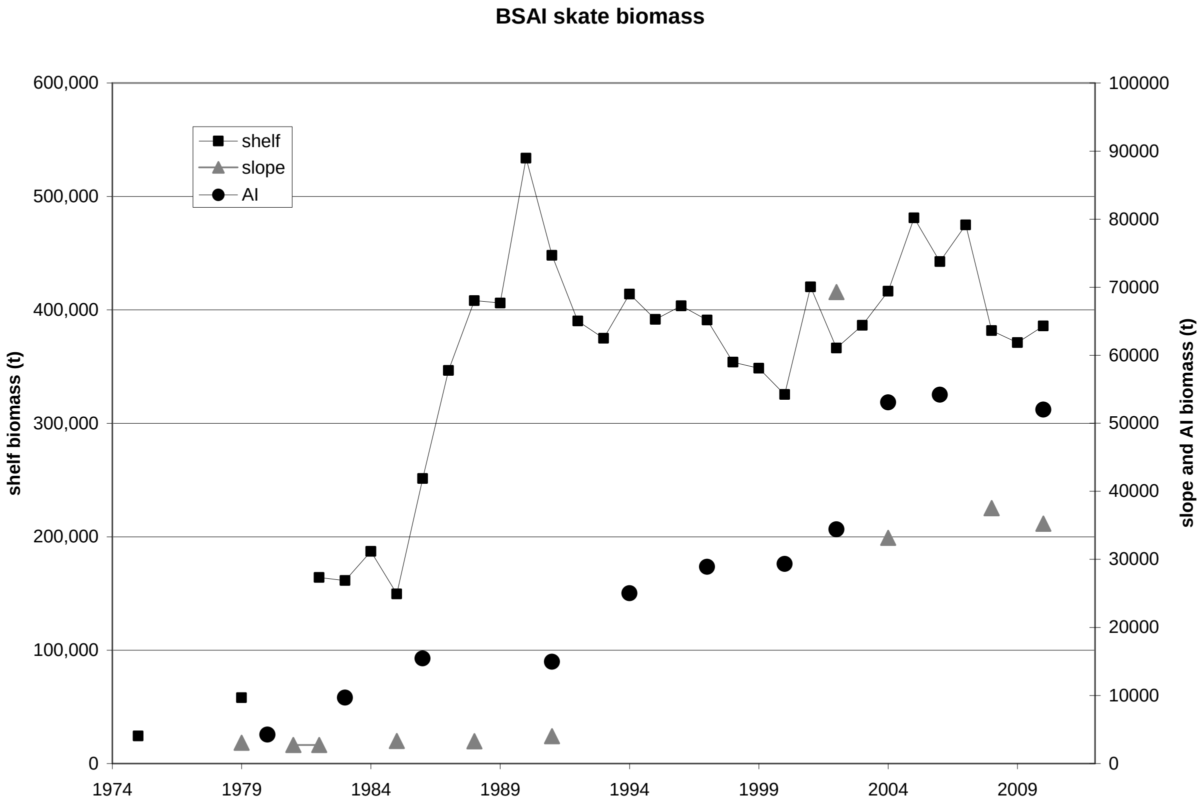


Figure 32. Aggregated skate biomass (metric tons) estimated from RACE bottom trawl surveys in each of the three major habitat areas (1975 – 2010). Note that slope and AI estimates are much smaller and pertain to the secondary y-axis.

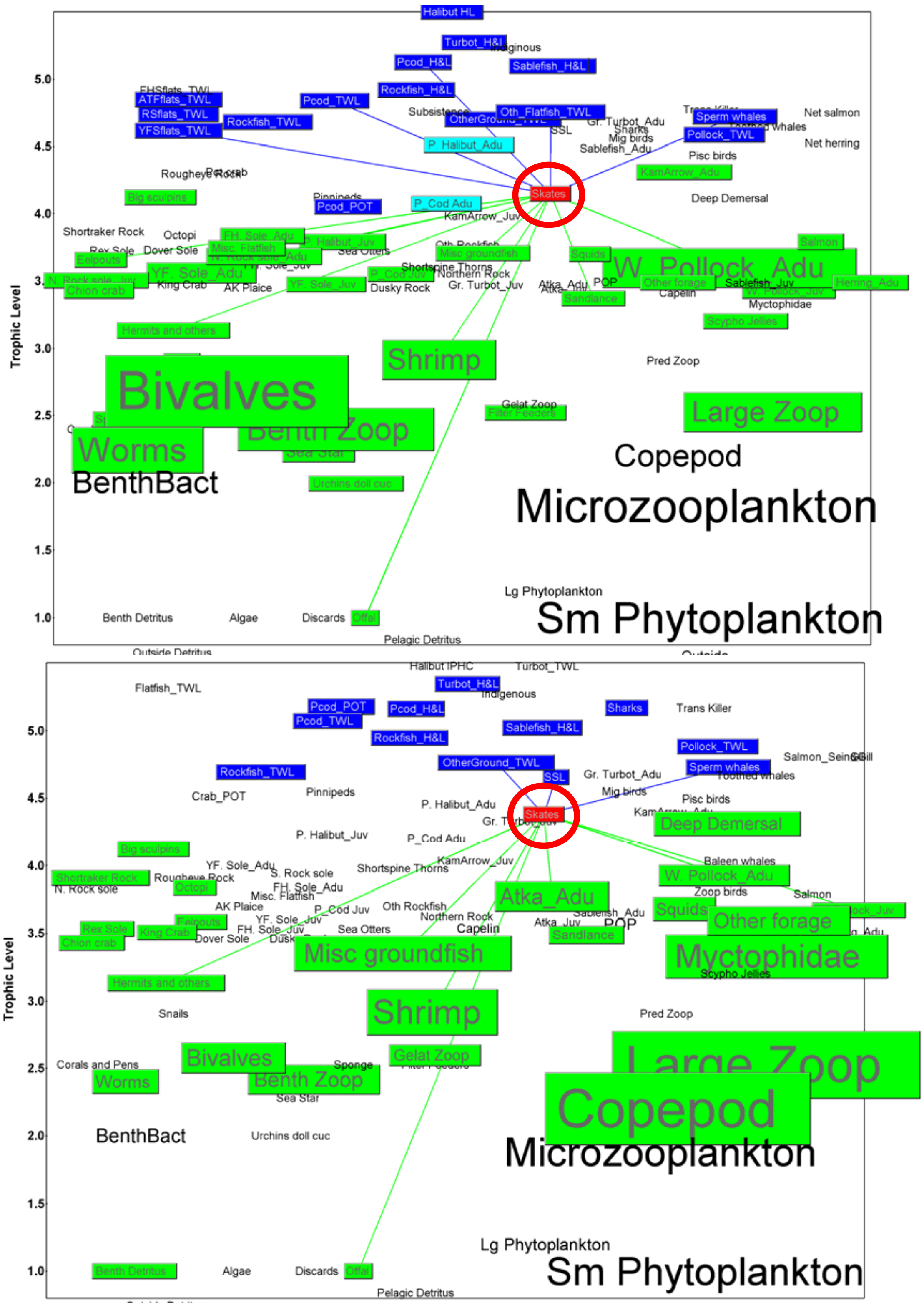


Figure 33. EBS (upper panel) and AI (lower panel) skate food webs derived from mass balance ecosystem models, with skate species aggregated in each area. (Source: K. Aydin, AFSC, code available upon request.)

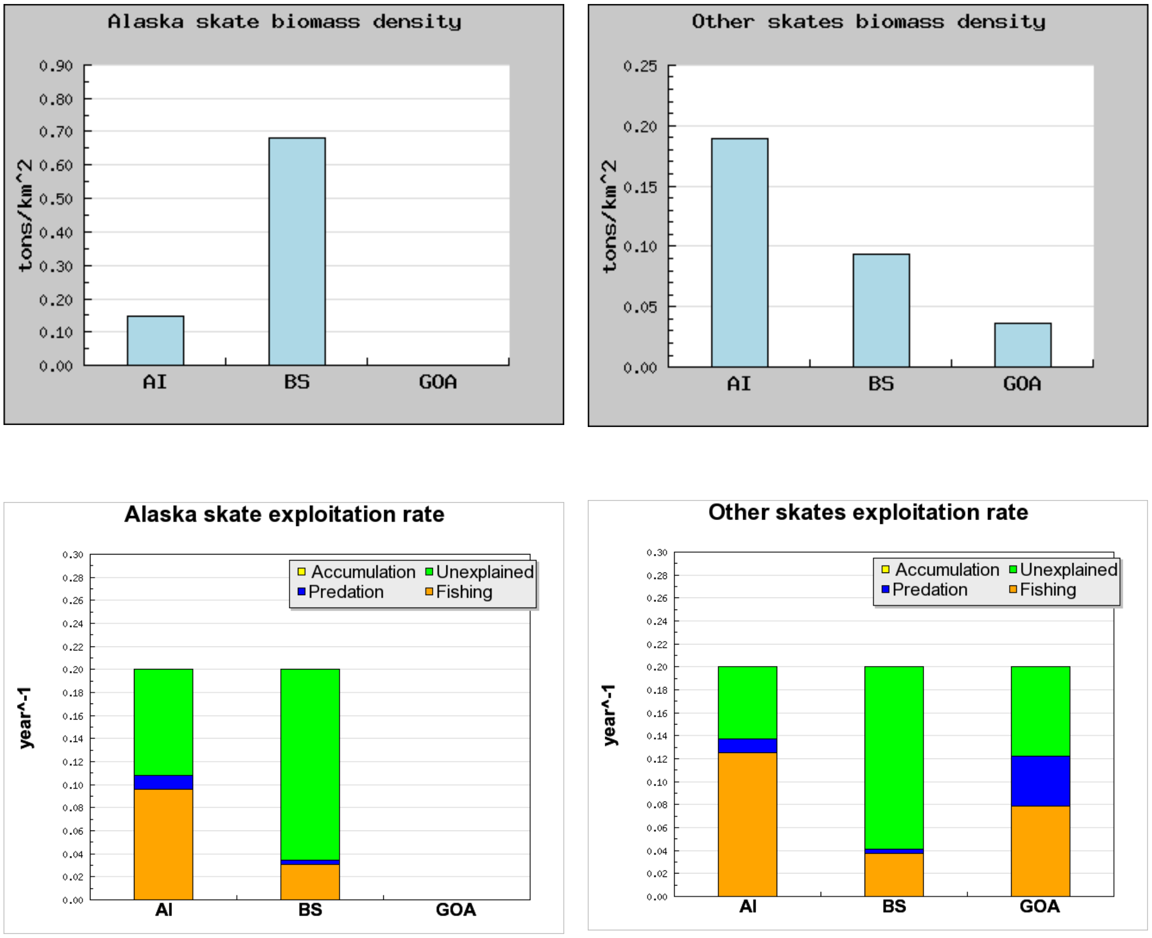


Figure 34. Comparative density (upper panels) and exploitation rate (lower panels) of Alaska (left panels) and all other *Bathyraja* (right panels) skates in the AI, EBS, and GOA (early 1990s, before fishery in GOA). (Alaska skates are a very small component of skate biomass in the GOA, and are therefore 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).

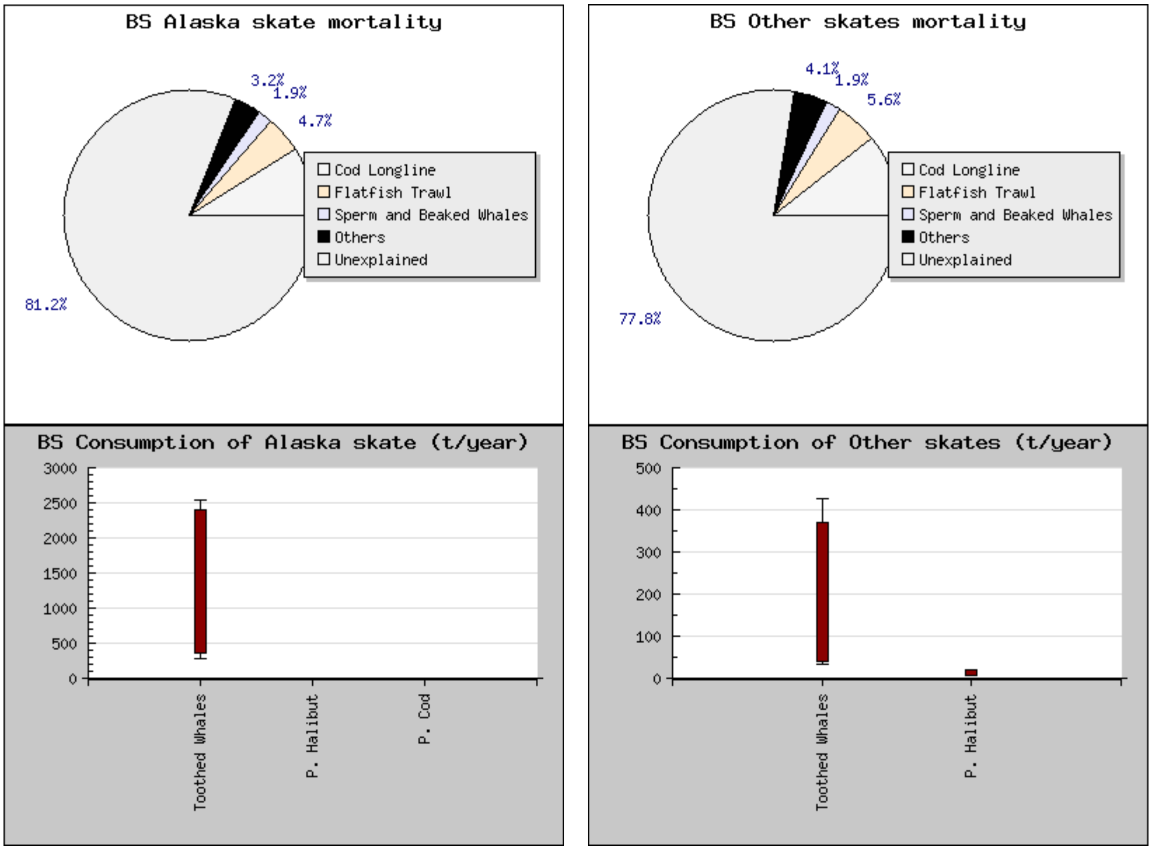


Figure 35. Mortality sources and consumption of skates in the EBS—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for EBS Alaska skates (left panels) and all other EBS skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

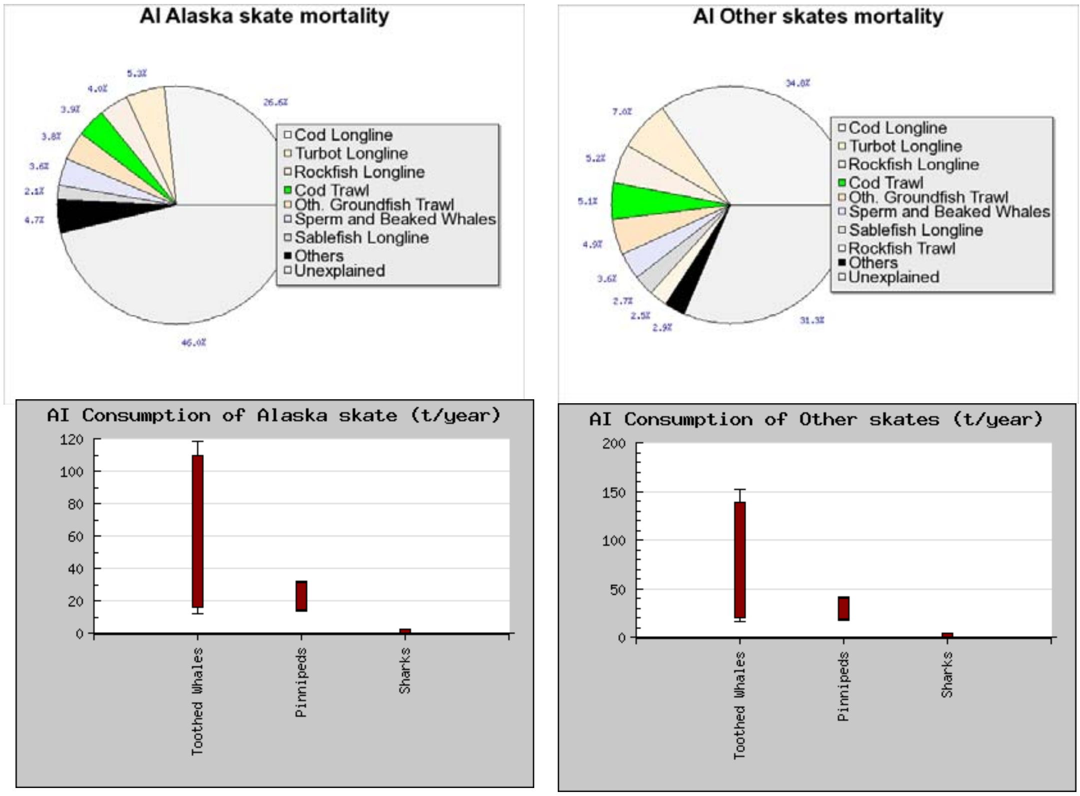


Figure 36. Mortality sources and consumption of skates in the AI—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for AI (former) Alaska skate (left panels) and AI Other Skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

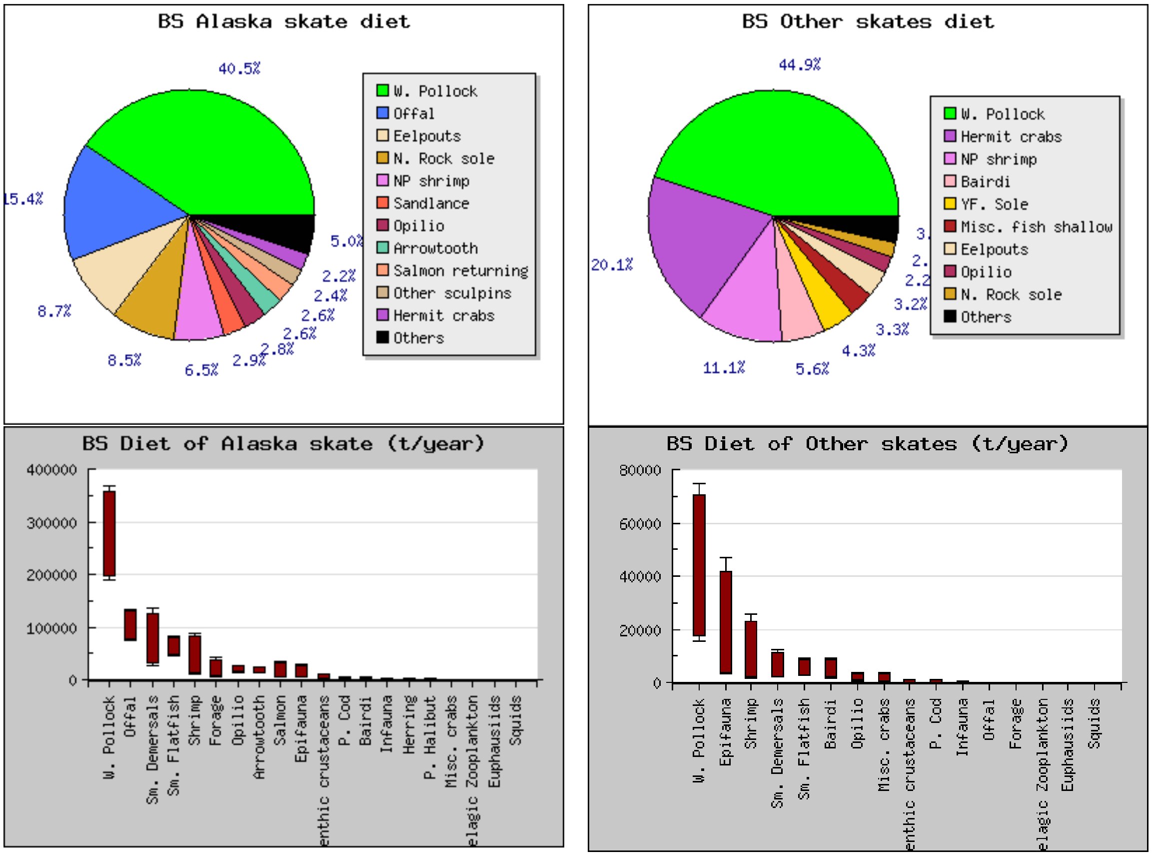


Figure 37. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for EBS Alaska skates (left panels) and Other Skates (right panels). Results were generated from stomach content collections occurring during RACE trawl surveys.

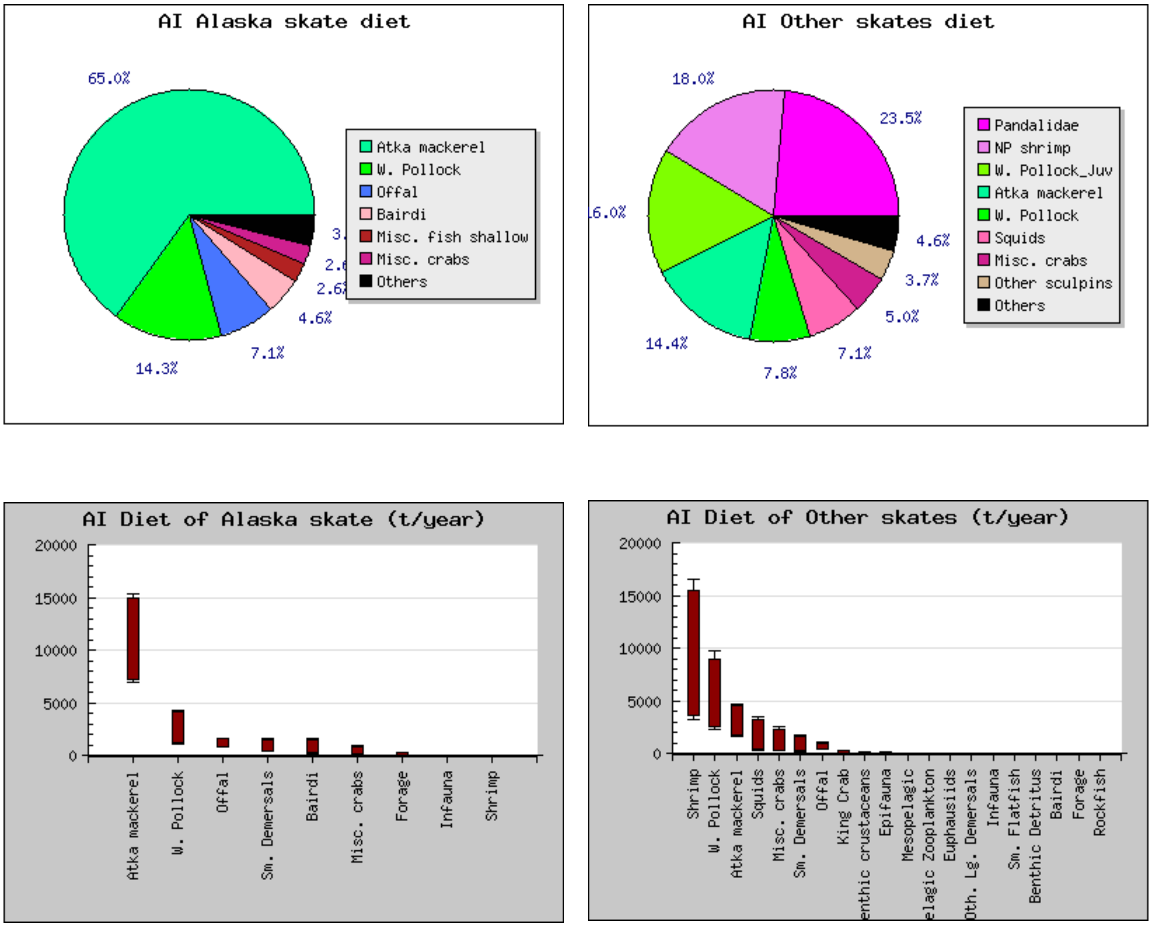


Figure 38. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for AI Alaska skates (left panels) and Other Skates (right panels). Consumption rates were estimated using published diet data from the Kuril Islands (Orlov 1998, 1999) and estimated prey densities.

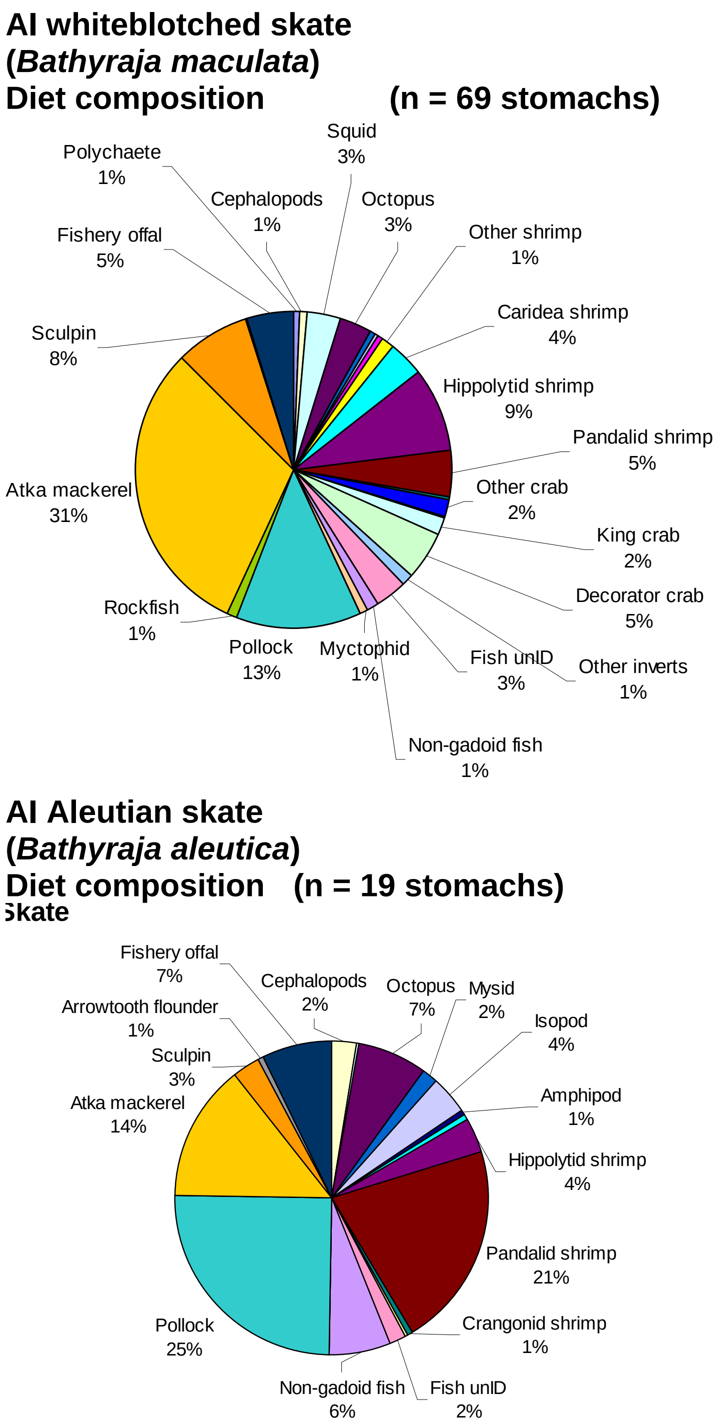


Figure 39. Diet composition (by weight) for the other two biomass-dominant skate species in the Aleutian Islands (which are included in the "Other Skates" group in the previous figure): whiteblotched skate (top) and Aleutian skate (bottom). Results were generated from stomach content collections occurring during trawl surveys, and are described in more detail in Yang (2007).