18. Assessment of the skate stock complex in the Bering Sea and Aleutian Islands

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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. However, to generate the harvest recommendations the stock is divided into two units. Harvest recommendations for Alaska skate (*Bathyraja parmifera*), the most abundant skate species in 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 Changes in Assessment Inputs

Changes in the input data:

- Total catch (t) for the BSAI skate assemblage has been updated through September 28, 2012.
- Biomass estimates from the 2012 EBS shelf, EBS slope, and AI surveys were added for all species.
- Fishery length composition data have been updated through 2011.
- Survey length composition data have been updated through 2012.
- A new length-at-age dataset from the 2009 EBS shelf survey has been added.

Changes in assessment methodology:

- The Alaska skate model has been substantially revised using an updated version of the Stock Synthesis software (version 3.23).
- The 4-parameter Schnute growth function is used to model growth, instead of the von Bertalanffy growth function.
- Selectivity functions for both fisheries and the survey are dome-shaped rather than asymptotic.
- A "survivorship" function is used to model the stock-recruit relationship.
- The maximum age was raised from 25 to 30.
- The structure of the data length bins was changed to combine all smaller skates into a 0 - 19 cm length bin and all larger skates into a 110 cm plus bin.
- Four different models for Alaska skate were created and a preferred model was chosen that uses only the most recent length-at-age dataset and estimates the growth function parameters within the model.

Summary of results

Alaska skate results:

1) The revised model provides a better fit to length-at-age data relative to the previous model.
2) The revised model follows trends in the survey more closely than the previous model.
3) In the revised model, skates reach greater maximum length and weight (as a result of the better fit to the length-at-age data).
4) Because selectivity is dome-shaped, the model predicts that a small number of old, large skates are essentially unobserved by the survey or fisheries.
5) Due primarily to result (3), the revised model produces higher estimates of both total and spawning biomass than the previous model.
6) Allowable harvest rates and harvest recommendations are increased from the previous model.

Alaska skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2012	2013	As estimated or *recommended this* year for: 2013	2014
M (natural mortality rate)	0.13	0.13	0.13	0.13
Tier	3a	3a	3a	3a
Projected total (age 0+) biomass (t)	550,912	534,449	650,483	630,086
Female spawning biomass (t)				
Projected	110,278	108,638	194,072	189,811
$B_{100\%}$	184,234	184,234	266,810	266,810
$B_{40\%}$	73,692	73,692	106,724	106,724
$B_{35\%}$	64,482	64,482	93,384	93,384
F_{OFL}	0.087	0.087	0.113	0.113
$maxF_{ABC}$	0.075	0.075	0.098	0.098
F_{ABC}	0.075	0.075	0.098	0.098
OFL (t)	29,669	28,918	**36,315**	34,596
maxABC (t)	25,565	24,918	31,720	30,218
ABC (t)	25,565	24,918	**31,720**	30,218
Status	As determined *last* year for: 2010	2011	As determined *this* year for: 2011	2012
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Other skates results:

The biomass estimates for other skates on the EBS shelf and in the Aleutian Islands were down relative to the penultimate surveys, but the EBS slope biomass estimate was increased relative to 2010. As a result, the 3-survey average and the harvest recommendations for other skates are slightly higher than in the 2011 assessment.

other skate harvest recommendations				
	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2012	2013	2013	2014
M (natural mortality rate)	0.1	0.1	0.1	0.1
Tier	5	5	5	5
Biomass (t)	94,075	94,075	94,684	94,684
F_{OFL}	0.1	0.1	0.1	0.1
$maxF_{ABC}$	0.075	0.075	0.075	0.075
F_{ABC}	0.075	0.075	0.075	0.075
OFL (t)	9,408	9,408	**9,468**	9,468
maxABC (t)	7,056	7,056	7,101	7,101
ABC (t)	7,056	7,056	**7,101**	7,101
	As determined *last* year for:		As determined *this* year for:	
Status	2010	2011	2011	2012
Overfishing	No	n/a	No	n/a

BSAI skate complex aggregate harvest recommendations:

aggregate harvest recommendations for the BSAI complex				
	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2012	2013	2013	2014
OFL (t)	39,077	38,326	**45,783**	44,064
ABC (t)	32,621	31,974	**38,821**	37,319

Responses to SSC and Plan Team Comments on Assessments in General

Plan Team September 2012: "The Plan Teams recommend that assessment authors retain status quo assessment approaches for the November 2012 SAFE report but also apply the Kalman filter or random effects survey averaging methods for Tier 5 stocks and summarize the analytical results for comparison purposes only. ADMB code for implementing the random effects method will be made available."

> *Response*: Due to time limitations the Kalman filter approach was not applied to Other Skates. The Kalman filter results will be included in next year's assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC October 2012: "The Plan Team approved of the changes to the assessment and recommended that three models be developed for November/ December: the model with last year's configuration, the revised model, and an extension of the new model, in which growth parameters are estimated internally in the model. The Plan Team also recommended that the author try lowering the starting size of the plus group to 110 cm. The SSC concurs with these recommendations but also recommends an additional model with all three length-at-age datasets be considered for November/ December."

> *Response*: Four alternative models were considered in this report: 1) last year's configuration, 2) the revised model presented in September, 3) the revised model with growth estimated within the model, and 4) the revised model using all available length-at-age datasets. The starting size of the plus group was lowered to 110 cm and that approach was used in all of the alternative models

General Introduction

Contents of this report

Because two different assessment methodologies are used for skates, this report deviates somewhat from the format of other SAFE documents. The report contains the following sections:

1) General introduction for all BSAI skates
2) Description of the Tier 3 assessment for the Alaska skates
3) Description of the Tier 5 assessment for Other Skates
4) Harvest recommendations for all BSAI skates
5) Ecosystem considerations
6) Tables & Figures
7) Appendix containing supplementary catch information

Description, scientific names, and general distribution

Skates (family Rajidae) are cartilaginous fishes which are related to sharks. They are dorso-ventrally depressed animals with large pectoral "wings" attached to the sides of the head, and long, narrow whiplike tails (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 (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 (Table 2 & Fig. 7), 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 two endemic species, the recently described butterfly skate, *Bathyraja mariposa* (Stevenson et al. 2004) and the leopard skate (Fig. 8; *Bathyraja* sp. cf. *parmifera*; J. Orr, AFSC, pers. comm.) The leopard skate was previously thought to be a color morph of Alaska skate, which occurs in low numbers in the eastern AI. The most abundant species in the AI 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. 2). Aleutian 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.

<u>Management units</u>

In the North Pacific, skate species were originally managed as part of the "Other Species" management category within the BSAI Fishery Management Plan (FMP). In October 2009 the NPFMC approved amendment 95 to the BSAI FMP, which separated skates from the BSAI Other Species complex. Beginning in 2011, skates are 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.

<u>Stock structure</u>

In September 2012 a report on skate stock structure was submitted to the Plan Team. The report was an evaluation of the potential for conservation concerns arising from among-species differences in spatial distribution within the Bering Sea and Aleutian Islands (BSAI) skate complex and the distribution of fishery catches. Evaluation of spatial management concerns is seriously hampered by a lack of reliable species-level catch accounting, which is the highest priority for enhancing skate conservation and management. Although too sparse to properly evaluate the issue, the available data suggest that the current spatial management practice (i.e. BSAI-wide harvest specifications and catch accounting) is appropriate for this complex. The overall exploitation rate is low relative to natural mortality. The highest catch rates occur in the region where Alaska skate (the most abundant and data-rich of all species in the complex) is predominant. The spatial distribution of catches mirrors the spatial distribution of the various species. Biomass trends for all species in all areas appear to be stable, although biomass timeseries are too short and estimates too variable for proper evaluation.

It is important to note that the difference in species composition among the different BSAI subareas likely violates the requirement, under the current National Standard guidelines, that stock complexes should only include those stocks that are “sufficiently similar in geographic distribution”.

Life history

Skates have 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). As a result they can be considered “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). 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 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.

Known life history parameters of Alaskan skate species are presented in Table 1. Considerable research has been directed at skates in the Bering Sea within recent years. Graduate students at the University of Washington and California State University (Moss Landing Marine Laboratories) have completed several 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 completed in 2006 (Matta 2006). 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) examined 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 discernible 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 egg-case development time of over 3 years, possibly due to the cold ocean temperatures in the EBS (Fig. 10; Hoff 2007). Captive studies are at the Alaska Sealife Center (Seward, AK) have provided preliminary data that validate this conclusion (J. Guthridge, ASLC, pers. comm.). The field observations are also 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 egg-case development stage at warmer temperatures than those found in the EBS (Berestovskii 1994 cited 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.

Fishery

Directed fishery

In the BSAI, there is no directed fishery for skates at present but there is some interest in developing skate fisheries in Alaska. A directed skate fishery developed in federal waters of the Gulf of Alaska in 2003 (Gaichas et al. 2003), and despite the closure of that fishery interest remains. A small state-waters fishery was conducted in Prince William Sound in 2009 and 2010. Retention of large skates occurs, indicative of their market value.

Bycatch and discards

Skates are caught incidentally in substantial numbers in BSAI fisheries (Tables 3 & 4). At present the Alaska regional office's Catch Accounting System (CAS) only reports species-specific catch for selected skate species, and these estimates are complicated by limitations of observer data (see below). For the purposes of the age-structured model, the fraction of Alaska skates in the total skate catch is estimated by applying the average species composition encountered during trawl surveys (see Data section below).

Skates are caught in almost all fisheries and areas of the Bering Sea shelf, but most of the skate bycatch is in the hook and line fishery for Pacific cod. Trawl fisheries for pollock, rock sole, flathead sole, and yellowfin sole also catch significant amounts (Table 5a). 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. In 2011, 24% of captured skates were retained. Data from Gulf of Alaska fisheries suggests that larger skates are preferentially retained.

Historically, skates were almost always recorded as "skate unidentified", with very few exceptions between 1990 and 2002. Beginning in 2005, additional training greatly increased observers' ability to identify skates to species. However, many skates are still only identified to the genus level because most skates are caught in longline fisheries, and if the animal drops off the longline it cannot be identified to species by the observer. Changes made to the observer manual at the author's request have resulted in a large increase in skate length measurements beginning in 2008.

The NMFS reporting areas encompassing the EBS outer shelf (521 and 517) have consistently experienced the highest incidental skate catch rates in the BSAI (Table 5b & Fig. 12). However a qualitative analysis of catches by area suggests that the proportion of the catch in area 521 is declining relative to area 509, where catches are increasing. Area 509 includes the part of the middle shelf domain immediately north of the Alaska Peninsula. As skates are caught incidentally, this change likely reflects a change in the fishing behavior of the target Pacific cod and flatfish fisheries where most skate are caught.

ALASKA SKATE – Tier 3 assessment

Overview

The first age-structured model for BSAI Alaska skates was created in 2007 and approved in 2008 for use in making harvest recommendations for 2009 (Ormseth and Matta 2008). Since 2008 the initial model (referred to here as the "previous model") has seen only minor revisions and updates with new data. During this time the modeling software (Stock Synthesis) has been upgraded extensively and the availability of data on Alaska skates has increased. Therefore, the stock assessment author felt it necessary to conduct a more thorough revision of the Alaska skate assessment model. The revised model was presented to the BSAI Plan Team in September 2012. The author was requested to proceed using the revised model but to include several alternative models for comparison. The four models considered in this assessment are:

Model 1	previous (2011) model using updated catch and survey data
Model 2	revised model using only the most recent length-at-age dataset & growth parameters fixed
Model 3	revised model using only the most recent length-at-age dataset, but with growth parameters estimated within the model
Model 4	revised model using all available length-at-age datasets, and growth parameters estimated within the model

The author concludes that model 3 provides the best fit to the data. Therefore, this report summarizes the results from the various models and uses model 3 to produce harvest recommendations for Alaska skate.

The three alternative versions of the revised model (models 2 - 4) all begin in 1980, in contrast to the previous model that began in 1992. The original rationale for a 1992 start year was the uncertainty in catch and survey data prior to 1992, as well as a short history of fishery length composition data. For these reasons, in the previous model the population was 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. While this rationale still holds true, it was decided that the model would benefit from a short "burn-in period" that includes no survey data but does include a constant reduced level of estimated catch.

As in the previous model, the revised model includes some characteristics designed to accommodate life history features unique to skates. All skate species have an extended embryonic period during which they develop within protective egg-cases 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 egg-case development time of approximately 3.6 years, possibly due to the cold ocean temperatures in the EBS (Hoff 2007; Fig. 10). Incorporating this information in the model is complicated by the possibility that embryo development times may be temperature-dependent, which is also supported by the preliminary captive-study data (G. Hoff, pers. comm.).

The timing of Alaska skate reproduction is also uncertain. While most females appear to deposit egg-cases during the summer, with emergence of young skates occurring during the winter, some level of skate reproduction seems to occur year-round. In the model, the first three age classes of Alaska skates (0-2) are assigned to an embryonic period where growth differs from older age classes and individuals are not available to either the fishery or survey. Thus, free-swimming skates in their first year are considered to be 3½ years old. In addition parameters of the length model and age selectivity are adjusted to accommodate the developmental delay and the uncertainty in its duration. This approach permits a more accurate representation of skate population dynamics and ensures that characteristics of the spawning population correspond to the appropriate year class. Finally, the nature of an equilibrium life history strategy is considered in specifying recruitment parameters and evaluating model results.

Data

summary of data used in the Alaska skate model

source	data	years
AKRO Catch Accounting System	Nontarget catch	2003-2012
Improved Pseudo Blend (AFSC)	Nontarget catch	1997-2002
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	Biomass Index	1992- 2012
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	Length composition	2000-2012
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	Length-at-age	2003, 2007, 2009
NMFS Fishery Monitoring & Analysis program- observed skate catch	Length composition	2007-2011
NMFS Fishery Monitoring & Analysis program- observed skate catch	Length-at-age	2005

Total catch

Incidental catches of skates in the BSAI occur in several target fisheries but can be broken down into catches by two gear types: longline and trawl. These fisheries have different selectivities and the majority of catches occur in the longline fisheries. The revised model includes catch data from two distinct eras, 1980 - 1991 and 1992 - 2012. No catch data are available for the years 1980-1991, so catch in those years was set at 10,000 t for the longline fishery and 2,000 t for the trawl fishery. These values are identical to the initial equilibrium catch level used in the previous model.

For the 1992 - 2012 period, independent estimates of BSAI skate catch were made by the Blend system and AKRO CAS as described in the 2008 BSAI skate assessment (Ormseth et al. 2008). Catches were broken down by habitat area (EBS shelf, EBS slope, and AI) and by fishery gear type from 1992 - 2012 (Table 6). 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 - 2011 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 - 2011 bottom trawl surveys (Fig. 13) were utilized to further partition the catch into Alaska skates and Other Skates. 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 - 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 6 and Fig. 14).

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. Fishery length data from 2007 - 2011 were 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 7).

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 - 2012) 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 (Fig. 13). Biomass estimates from 1992 - 2012 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 - 2007 surveys (Table 8). The modeling software 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 8).

Survey length composition

Total length (TL) data from the EBS shelf survey were available from 2000 - 2011 (Table 9). The survey takes length measurements for every skate in each haul. Length data were aggregated into 4 cm bins with 3 exceptions: a 0 - 19 cm bin, 104 - 109 cm bin, and a 110+ cm bin that included all skates 110 cm and larger. An N of 100 for each length composition was used in the model.

Length at age (LAA)

Mean LAA data were obtained from production ageing of skate vertebrae collected during the several EBS shelf surveys and from the longline fishery in 2005. Age was determined through examination of annual growth rings which are deposited on the vertebra following hatching from the egg-case (viewed through histological examination of vertebral thin sections). 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. In the previous model, three LAA datasets were used: one from the 2003 EBS shelf survey (n = 182), one from the 2005 longline fishery (n = 208), and one from the 2007 EBS shelf survey (n = 243). For all four alternative models, a new LAA dataset from 2009 (N = 337; Fig. 15) was introduced. Models 1 & 4 used all of the available datasets; models 2 & 3 used only the most recent (2009) dataset. The rationale for the inclusion of only one dataset is 1) that the most recent data is most indicative of current growth conditions for skates and 2) the most recent dataset is also the highest quality, with the greatest sample size and collected according to a completely randomized sampling design.

Weight at length

Parameters from the allometric length-weight relationship ($W = a\mathrm{TL}^b$, where W is weight in kg and TL is total length in cm) were obtained from Matta (2006) for the Alaska skate. For sexes combined, *a* was estimated as $4.01*10^{-6}$ and *b* was estimated as 3.149 (n = 526; Fig. 16).

Analytic Approach

Model structure

The 2012 revised model was created using the Stock Synthesis 3 (SS3) assessment program[1] (Methot 2005, 2007). The Stock Synthesis application allows the flexibility to incorporate both age- and size-structured information in an age-structured 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 SS3 to convert the size-based information into age-specific values that can be used to model the population through time.

Stock Synthesis 3 is comprised of three submodels. A population submodel captures the dynamics of an age-structured population, while 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 SS3 uses to maximize the overall likelihood by altering the parameters that govern the population dynamics model. SS3 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 SS3 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. 17. 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 user-defined recruitment functions. 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

[1] NOAA Fisheries Toolbox Version 3.23b, 2011. Stock Synthesis 3, Richard Methot, Northwest Fisheries Science Center, Seattle, WA. [Internet address: http://nft/nefsc.noaa.gov]

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.

The revised model continues a number of simplifications and assumptions used in the existing model. 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 10 and described in more detail below.

Parameters estimated outside the assessment model

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). Previous runs of the model have demonstrated that this value of *M* provides the best model fit, so *M* in the model continues to be fixed at 0.13 (Table 10).

Growth parameters

An analysis by Matta (2006) suggested that a Gompertz growth model best fit the length-at-age data for Alaska skate. For the revised model, the Gompertz growth function was approximated in SS3 by choosing the Schnute 4-parameter growth model option (Schnute 1981), rather than the von Bertalanffy curve used in the existing model. The Schnute model takes the form:

$$Y(t) = \left\{ y_1^\gamma + \left(y_2^\gamma - y_1^\gamma\right) \frac{1 - exp[-\kappa(t - \tau_1)]}{1 - exp[-\kappa(\tau_2 - \tau_1)]} \right\}^{1/\gamma}$$

where Y(t) is length at age t; y_1 and y_2 are the length at ages $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$, respectively; and κ and γ are parameters that control the shape of the growth curve. In SS3, κ is referred to as the von Bertalanffy *k* parameter and γ is referred to as the Richards coefficient. In model 2, all growth parameters are fixed except for the two uncertainty parameters (CV of y_1 and y_2). In models 3 & 4 all of the growth parameters are estimated within the model (Table 10).

Length at maturity

SS3 incorporates female maturity parameters into the model using the following equation:

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

where L_{50} is the length at 50% maturity and *b* is a slope parameter. Maturity parameters were obtained from Matta (2006), where b = -0.548 and L_{50} = 93.28 cm TL (Table 10 & Fig. 18). 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

The approach to survey catchability remains unchanged from the existing model. Survey catchability was fixed at 1 (Table 10). The EBS shelf survey appears to sample Alaska skates very reliably, with CVs of approximately 0.05. 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 and surveys from the other areas are infrequent. It was considered a precautionary measure not to account for the small amount of Alaska skate biomass on the slope and in the AI.

Age selectivity

The uncertainty surrounding the embryonic development period for the Alaska skate poses some problems in the model, 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, it was assumed that no skates were available to either fisheries or the surveys before age 3.5, and were fully available (in terms of age) beyond age 3.5 (Table 10). Length-based selectivity was then used to model the selective behavior of the fleet and surveys for skate older than age 3.5.

Parameters estimated inside the assessment model

Length selectivity

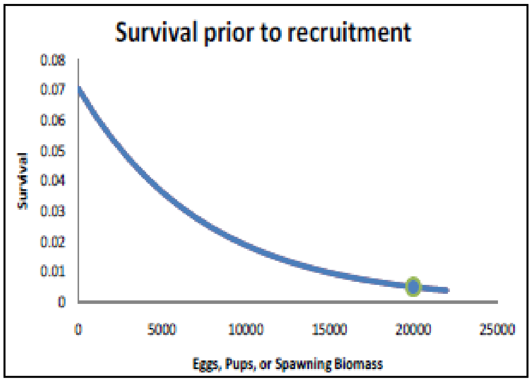
In contrast to the previous model, for the revision most of the selectivity parameters were estimated within the model (Table 10). The rationale for this approach is that the selectivity patterns of the fisheries and survey have the least prior information in the model. Therefore, the selectivity functions in the model were relatively unconstrained relative to the existing model. The main difference in the selectivity patterns in the revised model is that all three patterns have a descending limb, whereas in the previous model they are all asymptotic. Skate reproductive activity is thought to peak during the summer and at least some portion of old, large, and mature skates are likely to be in nursery grounds outside of the survey area during that time (G. Hoff, AFSSC, pers. comm.). This was the main rationale for introducing dome-shaped selectivity.

The changes described above required the abandonment of the logistic selectivity pattern for the EBS shelf survey. The previous model relied on an independent field assessment of trawl survey capture probability using a logistic function (Kotwicki and Weinberg 2005). While this study provided valuable information regarding gear selectivity of the trawl gear, the assessment author felt this was likely to be an incomplete representation of survey selectivity. In the revised model, fishery and survey selectivity are modeled using a double-normal function that is the recommended function for use in SS3. The double-normal is defined by six parameters for each fishery or survey, where p1 is the peak or ascending inflection size, p2 is the width of the plateau, p3 is the ascending width, p4 is the descending width, p5 is the selectivity at the first length bin, and p6 is the selectivity at the last length bin. All bounds were the default values specified in the SS3 documentation.

Spawner-recruit parameters

The previous model used a Beverton-Holt function to describe the spawner-recruit relationship of the Alaska skate, with steepness fixed at 1.0 to create a mean level of recruitment. In the revised model, an SS3-specific “survivorship” function was instead used to model recruitment. The survivorship function was designed explicitly for use with low-fecundity species. Details of the survivorship function are given elsewhere (Taylor et al. in press). Briefly, the function relies on two parameters that describe the number of offspring that survive to recruit into the adult population: “S fraction” that defines the level of survivorship at low population densities, and “beta’ that describes the effect of increasing population density on the level of survivorship. Based on Taylor et al. (in press) and Gertseva and Taylor (2012), an

S-frac of 0.5 and a beta of 1 were fixed in the model. The plot below shows the resulting survivorship curve:



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

Results

Model Evaluation

Alternative model evaluation criteria
The four alternative models (described in the overview section) were evaluated using several different criteria. Results of the evaluation can be found in Table 11. The criteria included:

1) Overall and component likelihoods, as well as AIC.
2) Reasonable estimates of unfished recruitment and recruitment variability.
3) Consistency with results from the previous model and surveys.

Evaluation of the alternative models

1) Due to differences in model configuration and data, there was limited ability to compare likelihood values among all of the models. Model 1 was sufficiently different that it was not included in this part of the analysis. Of models 2 - 4, only the length composition component of the likelihood can be compared directly (Table 11). Of the three, model 3 had the highest likelihood. As models 2 & 3 had the same data, the likelihood values could be compared directly. Model 3 had the highest likelihood (68.66). Analysis of Akaike's information criterion (AIC) confirmed that model 3 provided the best fit to the data.
2) All of the models produced reasonable estimates of recruitment (Table 11). Model 1 had the highest recruitment, and recruitment was similar among models 2 - 4. The revised model estimate of unfished recruitment was consistent with the amount of spawning biomass and our limited knowledge of skate fecundity.
3) Models 2 - 4 all produced higher estimates of total and spawning biomass than model 1 (and relative to the 2011 estimate), likely as a result of a better fit to the length-at-age data and a higher estimated length and weight at age for skates. For models 2 & 3, the estimates were reasonable given the survey biomass estimates and survey selectivity. The estimates in model 4, however, seem unreasonably high. For example, the model 5 estimate of 2012 total biomass (859,058 t) is more than twice as high as the 2012 survey biomass estimate.

Conclusion: based on these three criteria, model 3 is preferred for assessing the Alaska skate stock and providing harvest recommendations.

Preferred model evaluation criteria:

Model 3 was further evaluated using additional criteria:

1) Model fit to survey biomass estimates.
2) Model fit to length-at-age data.
3) Model fit to length compositions.
4) Reasonable estimates of fishery length selectivity parameters.

Preferred model evaluation:

1) The expected survey biomass produced by the model provided a good fit to the observed biomass (Fig. 19). Relative to the existing model, the revised model does a much better job of fitting annual variability in the biomass estimates (the existing model provided a very flat fit).
2) The revised model provides good fits to the length composition data from the EBS shelf survey (Fig. 20), longline fishery (Fig. 21), and trawl fishery (Fig. 22).
3) The model provides excellent fit to the length-at-age (LAA) data (Fig. 23, upper panel), as should be expected since fitting the LAA data was a primary goal in the model construction. Because the previous model underestimates LAA (Fig. 23, lower panel), the improved fit results in larger and heavier skates in the model. Along with the change in the selectivity, this is likely the cause of the increased total and spawning biomass relative to the existing model.
4) Estimates of selectivity parameters (Table 10) and selectivity at length (Figs. 24 - 26) for the fisheries and survey were reasonable. Longline fisheries (Fig. 24) displayed higher 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. It may also be a result of the nature of the longline fishery, where smaller skates are often removed from the groundline before being landed on the vessel. While fishery observers identify these dropped skates to genus and include them in counts, they are unable to take length measurements and it is likely that the longline length data are biased towards larger skates. The estimate of trawl selectivity (Fig. 25) also seems reasonable, as the trawl fisheries occur in areas where small skates are more abundant and the observer measurements are less likely to have the length bias described earlier. Both fisheries and the survey (Fig. 26) have a descending limb that suggests the very oldest skates are relatively unavailable to the different gears. This is consistent with the hypothesis that mature skates spend a portion of the year (peaking in summer) engaging in spawning activities inside highly localized nursery areas on the upper continental slope, where they are not encountered by the EBS shelf survey and are less likely to encounter fisheries.

Time series results

Results presented below are from the preferred 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 1980-2011 are reported in Table 12 and in Fig. 27, respectively. The estimate of total biomass (about 600,000 t) is higher relative to the previous model, and the estimate of female spawning biomass (~ 200,000 t) is not only much higher but also represents a greater fraction of the total biomass.

Recruitment

Time series of age 0 recruitment are reported in Table 12 and Fig. 28. The model suggests that recruitment peaked in the early 1990s and has since declined. Although the data are noisy, the survey length compositions also suggest a diminution of year classes since the 1990s (Fig. 29). The model's fit to this pattern results in a flattening of the population size composition in the model (Fig. 30).

Exploitation rate

A time series of exploitation (catch/total biomass) is given in Table 13. Despite the changes in the model, the exploitation rates estimated in the 2012 assessment are similar to those of previous years.

OTHER SKATES – Tier 5 assessment

Data

Survey biomass

The biomass of the skate assemblage as a whole has increased since the early 1980s (Table 14 & Fig. 31). 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 (Tables 14 - 19 and Figs. 31 - 34). 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. The Alaska skate 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. To generate harvest recommendations, we used the 3 most recent survey biomass estimates for each area to calculate average biomass.

Analytic Approach

Parameter Estimates

Natural Mortality (*M*)

As in previous years, *M* was estimated based on 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 big skate and longnose skate for California, British Columbia and the GOA (Table 20) (Zeiner and Wolf 1993,McFarlane and King 2006, Gburski et al. 2007). These species are rare in the BSAI, but provide the best available information for skates and estimation of *M*. 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 accepted M = 0.10 (derived from the California big and longnose skates) as a reasonable approximation of "aggregate skate" *M* for the Other Skates group. Recent work (i.e. McFarlane and King 2006, Gburski et al. 2007) estimated *M* to be similar to the accepted value. Considering the uncertainty inherent in applying this method to the multi-species Other Skates group, we continue to recommend the accepted value of *M* (M=0.10), 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 to promote skate conservation while still allowing for historical levels of incidental catch in target groundfish fisheries.

Results

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.

Harvest recommendations – entire BSAI skate complex

Reference points and tier assignment – Alaska skate

This assessment using the base model provides 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 – Alaska skate

The 2012 estimate of female spawning biomass for BSAI Alaska skates is 194,072 t. The estimate of $B_{40\%}$ is 106,724 t, so $B/B_{40\%}$ is 1.82 and 2013-2014 Alaska skate harvest levels can be assigned according to subtier 3a. Therefore, $F_{OFL}= F_{35\%} = 0.113$ and maximum $F_{ABC}= F_{40\%} = 0.098$. The corresponding 2013 OFL is 36,315 t and maximum allowable ABC is 31,720 t. For 2013, OFL is projected to be 34,596 t and maximum allowable ABC is 30,218 t.

Specification of OFL and ABC – Other Skates

other skates biomass estimates			
	EBS shelf	AI	EBS slope
2006		40,643	
2007			
2008			33,033
2009			
2010	18,902	48,307	33,882
2011	17,771		
2012	16,664	33,951	40,901
3-survey average biomass	17,779	40,967	35,938
total BSAI other skates average biomass			94,684

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 94,684 t) = 0.075 * 94,684 t = 7**,101 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 94,684 t) = 0.1 * 94,684 t = **9,468 t**.

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.

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 35; 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. 36 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. 36 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. 36 distinguish predation from fishing mortality, and further distinguish these measured sources of mortality from sources that are not explained within the ecosystem models. The models 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. 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. 37, 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. 37, 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 (e.g. Steller sea lions) and sharks also contributed to Alaska skate mortality in the AI, averaging less than 50 tons annually (Fig. 38, 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. 38, 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. 39, 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 - 350,000 tons of pollock annually (Fig. 39, 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 - 70,000 tons of pollock annually (Fig. 39, 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. 39, 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 (now identified as the leopard 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. 40 upper left panel). Diets of Other Skates in the AI are more dominated by benthic invertebrates, especially shrimp (42% of diet), but include more pelagic prey such as juvenile pollock, adult Atka mackerel, adult pollock and squids (totaling 45% of diet; Fig. 40 upper right panel). Estimated annual consumption of Atka mackerel by AI leopard skates in the early 1990s ranged from 7,000 to 15,000 tons, while pollock consumption was below 5,000 tons (Fig. 40 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. 40 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. 41), 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 leopard skates in the AI.

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 - 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

- The most important data gap for BSAI skates is the lack of reliable species-specific catch reporting. Species identification by fishery observers has vastly improved in recent years but 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. Species-specific accounting is essential for monitoring catch vs. biomass for species in the Other Skates group and to ensure that individual species within the complex are not being overfished.

- 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.

- Biomass indices from the EBS slope and AI are critical pieces of information for managing BSAI skates. The survey efforts in these regions need to continue and should have a high priority.

- We have conducted a tagging program for Alaska skates on the EBS shelf since 2008. Any additional information regarding movement of skates would be valuable.

- 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. Reliable fecundity estimates for Alaska skates are a research priority.

- Skate habitat is only beginning to be described in detail. Current efforts to protect eggcase-containing nursery areas should be supported and additional research is required to gauge the importance of the known nursery areas to skate populations. In addition, the defining characteristics of these nursery habitats need to be described.

- Additional information is required regarding the mortality rate of early life stages of skates, both inside their eggcases and when they emerge as free-swimming juveniles.

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Literature Cited

Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. 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

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.

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.

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.

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.

Gertseva, V. and I.G. Taylor. 2012. Status of the spiny dogfish shark resource off the continental U.S. Pacific Coast in 2011. Pacific Fishery Management Council, Portland, OR. Online at: http://www.pcouncil.org/groundfish/stock-assessments/by-species/spiny-dogfish/

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.

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

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.

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.

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.

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.

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. 2008. 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.

Schnute, J. 1981 A versatile growth model with statistically stable parameters. Can. J. Fish. Aquat. Sci. 38: 1128-1140.

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.

Taylor, I.G., Gertseva, V., Methot., R.D., and M.N. Maunder. *In press*. A stock recruitment relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fish. Res.

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

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.

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 2012, when all BSAI areas were surveyed.

species	EBS shelf		EBS slope		AI		BSAI total	
	biomass estimate	CV	biomass estimate	CV	biomass estimate	CV	biomass estimate	CV
Alaska	369,881	0.06	19,829	0.27	1,503	0.31	391,213	0.06
Aleutian	4,565	0.37	22,657	0.12	6,072	0.18	33,293	0.10
whiteblotched	342	1.00	5,820	0.19	15,360	0.20	21,522	0.16
Bering	10,190	0.16	3,465	0.16	109	0.17	13,764	0.13
misc. skates					10,865	0.23	10,865	0.23
commander			4,378	0.13			4,378	0.13
mud	286	1.00	842	0.31	1,277	0.15	2,405	0.18
roughtail			2,324	0.15	2	0.86	2,326	0.15
whitebrow			1,325	0.15	72	0.69	1,397	0.15
big skate	1,161	0.70			195	0.65	1,356	0.61
longnose	120	1.00					120	1.00
Bathyraja sp			90	1.00			90	1.00
all skates	386,545	0.06	60,730	0.10	35,454	0.12	482,729	0.05

Table 3. Time series of OFL, ABC, TAC, catch, and retention for the BSAI skate complex. All values are in metric tons except for retention rate. *2012 data are incomplete; retrieved September 28, 2012. Prior to 2011 skates were managed as part of the Other Species complex; data regarding catch in that era can be found in previous BSAI skate assessments.

Year	**skate complex OFL**	**skate complex ABC**	**skate complex TAC**	**skate complex catch**	**skate retention rate**
2011	37800	31500	16500	23135	24%
*2012**	*39100*	*32600*	*24700*	*19592*	*27%*

Source: Alaska Regional Office.

Table 4. Estimated catch (t) of all skate species combined by BSAI area, 1997 - 2012. *2012 data are incomplete; retrieved September 28, 2012.

	EBS	AI	total
1997	16,890	857	17,747
1998	18,189	1128	19,317
1999	13,277	802	14,079
2000	17,068	1808	18,876
2001	18,061	2510	20,571
2002	20,583	695	21,278
2003	18,501	655	19,156
2004	21,415	885	22,300
2005	22,388	696	23,084
2006	19,283	966	20,249
2007	17,608	1007	18,615
2008	20,254	1419	21,673
2009	19,389	1206	20,595
2010	16,374	1337	17,711
2011	22,414	721	23,135
*2012**	*18,724*	*868*	*19,592*

Table 5a. Estimated catch (t) of all skate species combined by target fishery, 2003 - 2012. Source: AKRO CAS. *2012 data incomplete; retrieved September 28, 2012.

target fishery	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	***2012****
Pacific cod	14,950	18,336	19,450	15,109	13,459	14,313	12,698	11,442	16,710	*14,165*
walleye pollock	471	841	732	1,308	1,287	2,758	3,856	1,887	2,348	*1,950*
yellowfin sole	1,513	596	942	1,133	1,405	1,301	1,799	1,906	2,123	*1,611*
rock sole	530	509	423	931	1,000	559	947	1,211	711	*640*
Greenland turbot	221	136	168	121	174	69	209	357	370	*326*
Atka mackerel	91	143	140	141	153	179	185	246	269	*368*
arrowtooth flounder	103	64	127	281	81	297	192	179	122	*203*
flathead sole	627	1,184	844	851	769	664	362	301	112	*74*
rockfish	73	23	30	37	72	63	96	53	104	*69*
sablefish	57	13	26	123	61	40	99	76	103	*37*
Kamchatka flounder	0	0	0	0	0	0	0	0	93	*101*
Alaska plaice	0	0	0	1	0	1	1	5	36	*8*
IFQ halibut	265	282	130	84	18	1,364	25	38	12	*38*
other flatfish	26	78	43	7	64	2	14	2	3	*3*
BSAI total	**19,156**	**22,300**	**23,084**	**20,249**	**18,615**	**21,673**	**20,595**	**17,711**	**23,135**	***19,592***

Table 5b. Estimated catch (t) of all skate species combined by reporting area, 2003 - 2012. Source: AKRO CAS. *2012 data incomplete; retrieved September 28, 2012.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	***2012****
					AI					
541	302	466	487	563	337	497	452	465	488	*637*
542	234	278	126	336	394	577	335	445	203	*200*
543	118	141	83	67	276	345	419	427	30	*31*
AI total	**655**	**885**	**696**	**966**	**1,007**	**1,419**	**1,206**	**1,337**	**721**	***868***
					EBS					
508	0	0	0	0	0	0	0	0	6	*0*
509	1,968	2,160	3,267	3,537	3,577	4,041	5,009	2,792	6,090	*4,695*
512	25	205	15	0	0	29	16	13	7	*118*
513	2,757	2,821	4,010	2,667	2,360	2,049	2,502	1,859	3,075	*1,285*
514	279	67	196	221	445	84	134	78	150	*1,528*
516	132	408	239	253	398	490	576	662	243	*309*
517	2,863	2,946	3,669	2,399	2,139	2,468	3,201	2,831	2,622	*2,447*
518	25	6	16	11	5	480	56	41	18	*18*
519	184	139	104	69	109	189	55	80	104	*95*
521	8,946	10,313	8,478	8,351	7,105	7,626	6,182	6,618	8,692	*6,515*
523	306	325	243	283	334	242	262	396	266	*1,026*
524	1,016	2,025	2,151	1,493	1,137	2,558	1,396	1,003	1,141	*687*
530	0	0	0	0	0	0	1	0	0	*0*
EBS total	**18,501**	**21,415**	**22,388**	**19,283**	**17,608**	**20,254**	**19,389**	**16,374**	**22,414**	***18,724***
BSAI total	**19,156**	**22,300**	**23,084**	**20,249**	**18,615**	**21,673**	**20,595**	**17,711**	**23,135**	***19,592***

Table 6. 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 Alaska skate model. *2012 catch is as reported through September 28, 2012.

year	EBS shelf longline	EBS shelf trawl	EBS slope longline	EBS slope trawl	AI longline	AI trawl	BSAI longline	BSAI trawl
1992	12,204	2,690	23	8	169	94	12,396	2,792
1993	8,797	1,939	16	6	122	68	8,935	2,013
1994	10,234	2,256	19	7	142	79	10,394	2,341
1995	10,715	2,362	20	7	148	83	10,883	2,451
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	10,129	2,233	19	7	141	78	10,288	2,318
2000	13,020	2,870	24	9	317	177	13,362	3,055
2001	13,778	3,037	26	9	440	245	14,244	3,291
2002	15,702	3,461	119	42	122	68	15,943	3,571
2003	13,944	3,271	30	7	115	64	14,088	3,342
2004	16,104	3,777	26	22	155	86	16,285	3,886
2005	17,498	3,333	40	4	122	68	17,660	3,405
2006	14,710	3,243	27	10	169	94	14,907	3,346
2007	13,432	2,961	25	9	177	98	13,634	3,068
2008	15,449	3,405	29	10	249	139	15,726	3,554
2009	14,796	3,262	28	10	211	118	15,035	3,389
2010	12,493	2,754	23	8	234	131	12,750	2,892
2011	17,099	3,769	32	11	126	70	17,257	3,851
*2012**	*14,284*	*3,149*	*27*	*9*	*152*	*85*	*14,463*	*3,243*

Table 7. Alaska skate length compositions from the BSAI longline and trawl fisheries, 2007 - 2011. Bin number is the lower limit of length interval in cm.

	2007		2008		2009		2010		2011	
bin	**trawl**	**longline**	**trawl**	**longline**	**trawl**	**longline**	**trawl**	**longline**	**trawl**	**longline**
0	0.001	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.000
20	0.008	0.000	0.004	0.000	0.003	0.000	0.003	0.000	0.002	0.000
24	0.017	0.000	0.022	0.000	0.011	0.000	0.010	0.000	0.012	0.000
28	0.013	0.000	0.035	0.000	0.024	0.000	0.018	0.000	0.020	0.000
32	0.023	0.000	0.043	0.000	0.035	0.001	0.031	0.001	0.026	0.000
36	0.030	0.000	0.062	0.001	0.053	0.001	0.037	0.001	0.034	0.001
40	0.040	0.002	0.056	0.002	0.065	0.002	0.054	0.002	0.049	0.003
44	0.054	0.005	0.047	0.004	0.066	0.005	0.055	0.006	0.059	0.007
48	0.061	0.006	0.049	0.014	0.056	0.009	0.051	0.014	0.052	0.014
52	0.053	0.016	0.046	0.020	0.051	0.017	0.042	0.024	0.047	0.020
56	0.046	0.027	0.037	0.027	0.044	0.023	0.041	0.032	0.040	0.027
60	0.061	0.046	0.039	0.030	0.041	0.032	0.043	0.045	0.038	0.041
64	0.067	0.062	0.037	0.053	0.048	0.043	0.048	0.056	0.039	0.050
68	0.049	0.054	0.038	0.074	0.048	0.058	0.057	0.068	0.053	0.064
72	0.053	0.072	0.039	0.062	0.048	0.063	0.054	0.070	0.060	0.077
76	0.059	0.055	0.037	0.072	0.040	0.069	0.050	0.062	0.059	0.074
80	0.045	0.059	0.041	0.072	0.054	0.069	0.054	0.071	0.059	0.077
84	0.048	0.060	0.044	0.073	0.045	0.069	0.054	0.067	0.053	0.076
88	0.059	0.065	0.052	0.078	0.061	0.083	0.055	0.072	0.060	0.082
92	0.052	0.089	0.056	0.082	0.061	0.098	0.069	0.091	0.069	0.095
96	0.060	0.117	0.075	0.110	0.058	0.129	0.068	0.103	0.068	0.112
100	0.051	0.137	0.075	0.132	0.050	0.124	0.054	0.104	0.058	0.106
104	0.035	0.096	0.048	0.081	0.032	0.086	0.035	0.072	0.031	0.060
110	0.017	0.033	0.016	0.012	0.005	0.019	0.014	0.038	0.011	0.013
N	2,911	858	1,369	2,930	18,081	8,174	17,168	9,545	6,600	22,156

Table 8. EBS shelf bottom trawl survey estimates of Alaska skate biomass (t). Line indicates the first year (1992) that the data are included in the model. Estimates and CVs in bold (1999 - 2012) 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 - 2007.

year	biomass	CV
1982	167,826	0.10
1983	163,970	0.10
1984	190,037	0.10
1985		
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	**349,571**	**0.16**
2000	**311,970**	**0.06**
2001	**414,539**	**0.06**
2002	**410,016**	**0.06**
2003	**372,257**	**0.05**
2004	**433,660**	**0.05**
2005	**547,031**	**0.05**
2006	**437,737**	**0.05**
2007	**478,872**	**0.07**
2008	**361,298**	**0.06**
2009	**350,233**	**0.06**
2010	**366,116**	**0.06**
2011	**410,340**	**0.05**
2012	**369,881**	**0.06**

Table 9. Alaska skate EBS shelf survey length compositions, 2000 - 2012. Bin number is the lower limit of each length bin (in cm); data are proportions of each bin. N = number of hauls.

	year												
bin	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
0	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.001	0.001
20	0.005	0.009	0.008	0.007	0.003	0.004	0.005	0.008	0.004	0.010	0.005	0.005	0.004
24	0.032	0.031	0.025	0.027	0.015	0.019	0.026	0.030	0.017	0.021	0.018	0.015	0.009
28	0.042	0.047	0.035	0.024	0.027	0.023	0.026	0.021	0.019	0.020	0.018	0.021	0.016
32	0.037	0.046	0.047	0.040	0.028	0.030	0.031	0.028	0.026	0.033	0.019	0.025	0.016
36	0.048	0.042	0.048	0.039	0.031	0.038	0.033	0.038	0.037	0.042	0.027	0.028	0.020
40	0.048	0.046	0.052	0.044	0.048	0.044	0.041	0.052	0.047	0.053	0.036	0.039	0.028
44	0.046	0.051	0.057	0.050	0.051	0.059	0.046	0.051	0.057	0.055	0.049	0.054	0.043
48	0.052	0.045	0.053	0.076	0.058	0.056	0.054	0.062	0.058	0.059	0.042	0.065	0.049
52	0.061	0.051	0.064	0.049	0.065	0.054	0.050	0.052	0.065	0.067	0.049	0.063	0.056
56	0.059	0.046	0.052	0.040	0.053	0.058	0.054	0.054	0.064	0.068	0.054	0.064	0.059
60	0.059	0.054	0.048	0.045	0.051	0.066	0.058	0.048	0.061	0.067	0.055	0.065	0.059
64	0.048	0.051	0.042	0.041	0.046	0.050	0.056	0.058	0.064	0.057	0.061	0.066	0.064
68	0.044	0.054	0.053	0.062	0.059	0.050	0.054	0.058	0.052	0.054	0.070	0.064	0.064
72	0.049	0.056	0.049	0.053	0.054	0.051	0.057	0.056	0.058	0.060	0.063	0.068	0.075
76	0.033	0.044	0.047	0.048	0.055	0.042	0.054	0.047	0.051	0.045	0.057	0.051	0.073
80	0.039	0.032	0.029	0.048	0.040	0.040	0.038	0.044	0.045	0.044	0.054	0.045	0.061
84	0.028	0.026	0.024	0.036	0.040	0.038	0.043	0.035	0.040	0.039	0.057	0.045	0.045
88	0.033	0.034	0.044	0.042	0.043	0.050	0.038	0.040	0.042	0.041	0.054	0.044	0.064
92	0.049	0.061	0.053	0.050	0.057	0.049	0.058	0.060	0.052	0.045	0.065	0.050	0.060
96	0.071	0.068	0.067	0.074	0.070	0.060	0.066	0.057	0.054	0.052	0.067	0.055	0.062
100	0.062	0.066	0.058	0.057	0.065	0.065	0.062	0.056	0.051	0.043	0.045	0.045	0.047
104	0.046	0.035	0.036	0.043	0.035	0.046	0.044	0.036	0.029	0.023	0.029	0.020	0.022
110	0.008	0.007	0.010	0.005	0.005	0.006	0.007	0.007	0.005	0.002	0.004	0.003	0.003
N	316	354	333	332	380	370	352	362	346	334	348	343	337

Table 10. Final parameter values of the preferred 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)	23.6	-10	30	
	length at A2 (L2)	115	70	150	
	von Bertalanffy coefficient (κ)	0.2	0.05	0.2	
	Richards coefficient (γ)	-0.31	-1	2	
	CV of L1	0.174	0.05	0.25	
	CV of L2	0.05	0.05	0.25	
length-weight relationship	coefficient (a)	2.44×10^{-6}			X
	exponent (b)	3.35			X
length at maturity	length at 50% maturity (a)	93.28			X
	slope (b)	-0.548			X
length-fecundity relationship	intercept	-14.7			X
	slope	0.214			X
survivorship function (recruitment)	ln virgin recruitment level (R0)	10.25	5	15	
	survivorship S fraction	0.5			X
	survivorship beta parameter	1			X
	SD of R0 (σR)	0.4			X
EBS shelf survey catchability	ln catchability (Q)	0			X
longline length selectivity	peak (p1)	90			X
	top (p2)	-0.985	-6	4	
	ascending width (p3)	6.48	-1	9	
	descending width (p4)	2.66	-1	9	
	selectivity at first size bin (p5)	-4.99	-5	9	
	selectivity at last size bin (p6)	-2.21	-5	9	
trawl length selectivity	peak (p1)	49			X
	top (p2)	0.496	-6	4	
	ascending width (p3)	4.95	-1	9	
	descending width (p4)	2.47	-1	9	
	selectivity at first size bin (p5)	-0.682	-5	9	
	selectivity at last size bin (p6)	-2.17	-5	9	
survey length selectivity	peak (p1)	49			X
	top (p2)	0.645	-6	4	
	ascending width (p3)	3.025	-1	9	
	descending width (p4)	-0.255	-1	9	
	selectivity at first size bin (p5)	0.5			X
	selectivity at last size bin (p6)	-3.02	-5	9	
age selectivity (logistic) for all fisheries and survey	(p1)	3.5			X
	(p2)	0.1			X
initial fishing mortality	longline fishery F	0.032	0	1	
	trawl fishery F	0.005	0	1	

Table 11. Comparison of model results. "*" indicates author's preferred model.

		model 1	model 2	model 3*	model 4
likelihood					
total		269.4	100.2	68.66	205.0
survey		-21.36	-17.17	-20.20	-20.90
length composition		118.5	92.27	78.16	101.57
length at age		219.7	43.26	30.50	141.95
recruitment		-35.50	-21.26	-22.68	-21.21
forecasted recruitment		-11.91	3.04	2.87	3.57
# of estimated parameters		63	62	66	66
total parameters		76	104	104	104
key parameters					
ln(R0)		10.5929	10.2528	10.2474	10.3391
length at A1		19.93	23.00	23.58	24.26
length at A2		101.47	115.00	115.02	125.13
LVB k parameter		0.14	0.15	0.20	0.20
Richards coefficient		n/a	0.10	-0.31	-0.54
recruitment (1000s)	unfished	39,849	28,363	28,209	30,917
	2006	32,194	13,837	14,564	14,392
	mean	39,410	28,076	28,218	31,572
total biomass (t)	unfished	696,597	765,130	808,063	1,056,550
	2012	519,877	552,916	608,287	859,058
female spawning biomass (t)	unfished	188,903	235,098	261,455	347,910
	2012	116,339	168,584	194,289	287,634
AIC (active parameters)		664.85	324.34	269.32	541.99

Table 12. 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)**
1980	624,861	187,812	28,501
1981	624,861	187,812	26,955
1982	624,862	187,812	25,378
1983	624,846	187,812	24,314
1984	624,775	187,812	24,169
1985	624,588	187,812	25,160
1986	624,198	187,812	27,195
1987	623,501	187,811	29,457
1988	622,395	187,810	30,637
1989	620,813	187,804	31,049
1990	618,762	187,792	34,325
1991	616,361	187,764	40,873
1992	613,888	187,741	47,230
1993	608,489	186,593	38,197
1994	608,407	186,278	35,465
1995	608,055	184,921	33,111
1996	609,120	182,829	27,813
1997	614,707	181,034	37,436
1998	618,096	178,077	30,821
1999	622,560	175,368	25,744
2000	633,793	174,864	29,508
2001	642,408	174,442	25,923
2002	650,146	174,902	25,495
2003	655,239	176,454	24,210
2004	661,048	180,675	22,030
2005	662,133	185,352	18,069
2006	659,960	189,835	14,564
2007	658,096	194,047	14,031
2008	655,172	196,755	15,079
2009	646,826	197,656	29,091
2010	636,533	197,590	29,426
2011	626,444	197,191	29,770
2012	608,287	194,289	30,154

Table 13. Time series of exploitation rates (catch/total biomass) as estimated by the model.

	longline	trawl	total
1980	0.032	0.005	0.037
1981	0.032	0.005	0.037
1982	0.032	0.005	0.037
1983	0.032	0.005	0.037
1984	0.032	0.005	0.037
1985	0.032	0.005	0.037
1986	0.032	0.005	0.037
1987	0.032	0.005	0.037
1988	0.032	0.005	0.037
1989	0.032	0.005	0.037
1990	0.032	0.005	0.037
1991	0.032	0.005	0.037
1992	0.040	0.008	0.048
1993	0.029	0.006	0.035
1994	0.035	0.006	0.041
1995	0.037	0.007	0.043
1996	0.031	0.006	0.037
1997	0.044	0.008	0.052
1998	0.047	0.008	0.055
1999	0.034	0.006	0.040
2000	0.042	0.008	0.050
2001	0.043	0.008	0.051
2002	0.046	0.008	0.055
2003	0.040	0.008	0.048
2004	0.045	0.009	0.054
2005	0.048	0.008	0.056
2006	0.041	0.008	0.049
2007	0.038	0.007	0.045
2008	0.044	0.009	0.053
2009	0.044	0.008	0.052
2010	0.038	0.007	0.045
2011	0.053	0.010	0.064
2012	0.047	0.009	0.056

Table 14. 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 - 2012.

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	175,643	0.09	2,723	0.10		
1983	171,607	0.08			9,750	0.12
1984	198,888	0.09				
1985			3,329	0.10		
1986	267,306	0.15			15,515	0.19
1987	356,519	0.09				
1988	416,029	0.11	3,271	0.21		
1989	413,909	0.08				
1990	540,502	0.11				
1991	448,054	0.09	4,031	0.25	15,013	0.17
1992	399,358	0.09				
1993	388,950	0.07				
1994	414,054	0.08			25,051	0.10
1995	404,460	0.08				
1996	446,036	0.06				
1997	422,974	0.07			29,021	0.14
1998	369,330	0.05				
1999	382,446	0.15				
2000	336,713	0.05			29,129	0.09
2001	428,591	0.06				
2002	428,664	0.06	69,275	0.50	34,471	0.11
2003	404,639	0.05				
2004	448,316	0.05	33,156	0.08	53,242	0.16
2005	563,846	0.05				
2006	452,685	0.05			53,922	0.12
2007	496,108	0.07				
2008	380,915	0.05	37,548	0.08		
2009	370,395	0.06				
2010	385,018	0.06	35,177	0.12	51,988	0.11
2011	428,111	0.05				
2012	386,545	0.06	60,730	0.10	35,454	0.12

Table 15. Total BSAI biomass estimates by species for the 4 years since 2000 when surveys were conducted in each area (EBS shelf, EBS slope, AI) in the same year. The “other skates” row in the first part of the table includes all the species listed in the second part of the table.

	2002		2004		2010		2012	
	biomass	CV	biomass	CV	biomass	CV	biomass	CV
Alaska	456,687	0.09	450,830	0.05	371,093	0.06	391,213	0.06
other skates	75,723	0.08	83,884	0.10	101,091	0.08	91,516	0.06
all skates	532,410	0.08	534,714	0.04	472,183	0.05	482,729	0.05
other skates:								
Aleutian	26,261	0.18	29,000	0.20	30,775	0.15	33,293	0.10
whiteblotched	20,892	0.15	29,697	0.22	28,339	0.17	21,522	0.16
Bering	15,848	0.13	13,310	0.10	14,828	0.12	13,764	0.13
misc skates	37	0.84	140	0.39	13,196	0.21	10,865	0.23
commander	3,662	0.16	4,194	0.15	3,393	0.15	4,378	0.13
mud	2,706	0.15	2,509	0.14	2,122	0.17	2,405	0.18
roughtail	1,656	0.14	1,678	0.12	2,103	0.16	2,326	0.15
whitebrow	1,570	0.23	1,789	0.20	1,908	0.19	1,397	0.15
big skate	1,692	0.53	1,373	0.52	4,081	0.57	1,356	0.61
longnose	915	0.71					120	1.00
Bathyraja sp	69	0.59	21	0.49	1	1.00	90	1.00
Okhotsk	415	0.56	8	1.00				
deepsea			164	0.73	345	0.64		

Table 16. Survey biomass estimates for Alaska skate, other skates, and total skates by area and year.

		Alaska		other skates		all skates	
		biomass	CV	biomass	CV	biomass	CV
EBS slope	2002	35,932	0.95	33,344	0.14	69,275	0.50
	2004	4,248	0.33	28,909	0.08	33,156	0.08
	2008	4,516	0.32	33,033	0.08	37,548	0.08
	2010	1,296	0.32	33,882	0.12	35,177	0.12
	2012	19,829	0.27	40,901	0.08	60,730	0.10
AI	1980	643	0.80	3,615	0.25	4,257	0.25
	1983	322	0.25	9,428	0.13	9,750	0.12
	1986	259	0.53	15,257	0.19	15,515	0.19
	1991	1,624	0.50	13,388	0.18	15,013	0.17
	1994	7,133	0.20	17,917	0.11	25,051	0.10
	1997	7,862	0.17	21,159	0.18	29,021	0.14
	2000	9,578	0.15	19,551	0.12	29,129	0.09
	2002	10,739	0.20	23,732	0.13	34,471	0.11
	2004	12,923	0.22	40,319	0.21	53,242	0.16
	2006	13,279	0.19	40,643	0.14	53,922	0.12
	2010	3,681	0.20	48,307	0.12	51,988	0.11
	2012	1,503	0.31	33,951	0.12	35,454	0.12
EBS shelf	1982	733	0.37	72,736	0.19	73,469	0.18
	1983	48,512	0.13	58,023	0.12	106,535	0.09
	1984	88,017	0.11	98,767	0.15	186,783	0.10
	1985	66,786	0.30	105,465	0.10	172,251	0.13
	1986	58,043	0.30	78,590	0.26	136,633	0.20
	1987	127,686	0.12	114,953	0.16	242,639	0.10
	1988	107,323	0.21	180,544	0.12	287,867	0.11
	1989	767	1.00	370,237	0.08	371,004	0.08
	1990			540,502	0.11	540,502	0.11
	1991			384,972	0.09	384,972	0.09
	1992	18,597	0.22	380,198	0.09	398,794	0.09
	1993			388,950	0.07	388,950	0.07
	1994			433,979	0.08	433,979	0.08
	1995			404,460	0.08	404,460	0.08
	1996	374,406	0.06	69,017	0.19	443,423	0.06
	1997	336,930	0.07	86,044	0.21	422,974	0.07
	1998	357,095	0.05	7,063	0.34	364,158	0.05
	1999	349,571	0.16	18,600	0.37	368,171	0.15
	2000	311,970	0.06	24,743	0.21	336,713	0.05
	2001	414,539	0.06	17,405	0.15	431,944	0.06
	2002	410,016	0.06	18,647	0.14	428,664	0.06
	2003	372,257	0.05	32,381	0.25	404,639	0.05
	2004	433,660	0.05	14,656	0.13	448,316	0.05
	2005	547,031	0.05	16,815		563,846	0.06
	2006	437,737	0.05	18,515	0.15	456,252	0.05
	2007	478,872	0.07	17,236	0.22	496,108	0.07
	2008	361,298	0.06	19,617	0.22	380,915	0.05
	2009	350,233	0.06	20,162	0.17	370,395	0.06
	2010	366,116	0.06	18,902	0.16	385,018	0.06
	2011	410,340	0.05	17,771	0.24	428,111	0.05
	2012	369,881	0.06	16,664	0.15	386,545	0.06

Table 17. Survey biomass estimates for miscellaneous, Aleutian, Bering, and whiteblotched skates by area and year (part of the "other skates" category in Table 16). Miscellaneous skates includes skates not identified to species; in the AI in 2010 and 2012 it also includes the leopard skate.

		misc skates		Aleutian		Bering		whiteblotched	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			18,658	0.24	2,873	0.18	3,927	0.23
	2004			14,987	0.14	1,953	0.11	3,450	0.16
	2008			17,160	0.15	2,520	0.16	4,574	0.17
	2010			18,721	0.22	2,780	0.16	4,055	0.14
	2012			22,657	0.12	3,465	0.16	5,820	0.19
AI	1980	3,044	0.30	86	1.00	91	1.00		
	1983	5,556	0.16	1,651	0.36	307	0.83	1,560	0.30
	1986	8,703	0.29	3,434	0.36	119	0.91	1,886	0.22
	1991	6,274	0.31	2,423	0.21	39	0.71	142	0.64
	1994	2,685	0.19	3,376	0.22	938	0.36	7,989	0.19
	1997	1,171	0.80	4,455	0.30	42	0.33	13,379	0.26
	2000	153	0.54	3,329	0.19	2	1.00	13,721	0.15
	2002	37	0.84	4,711	0.17	229	0.93	16,728	0.18
	2004	139	0.39	11,519	0.45	147	0.75	26,247	0.25
	2006	598	0.42	6,592	0.23	186	0.55	29,715	0.19
	2010	13,196	0.21	8,721	0.21	56	0.45	24,151	0.20
	2012	10,865	0.23	6,072	0.18	109	0.17	15,360	0.20
EBS shelf	1982	72,478	0.19	257	0.52				
	1983	38,491	0.14	16,410	0.21	2,710	0.51		
	1984	88,299	0.16	8,759	0.57	254	0.69		
	1985	95,400	0.10	6,495	0.46	1,121	0.45		
	1986	53,669	0.16	2,971	0.58	1,580	0.83		
	1987	69,548	0.22	5,096	0.44	31,089	0.26		
	1988	166,540	0.12	6,566	0.68	6,443	0.39		
	1989	370,237	0.08						
	1990	540,502	0.11						
	1991	384,972	0.09						
	1992	380,181	0.09			16	1.00		
	1993	388,950	0.07						
	1994	433,979	0.08						
	1995	404,460	0.08						
	1996	2,195	0.91	56,580	0.22	9,018	0.22		
	1997	12,880	0.60	65,427	0.25	7,738	0.19		
	1998	2,868	0.57	794	0.37	1,760	0.33		
	1999	2,159	0.55			9,949	0.20		
	2000	66	1.00	2,232	0.54	16,842	0.16		
	2001			1,232	0.61	14,263	0.14		
	2002			2,893	0.47	12,746	0.16	237	1.00
	2003			18,253	0.43	13,602	0.12		
	2004	1	1.00	2,494	0.41	11,209	0.12		
	2005								
	2006			5,568	0.41	11,674	0.13	182	1.00
	2007			2,718	0.43	9,480	0.14	3,234	0.92
	2008			6,278	0.57	9,943	0.16	238	1.00
	2009			2,171	0.49	13,274	0.18	216	1.00
	2010			3,332	0.35	11,992	0.14	133	1.00
	2011			2,525	0.54	9,795	0.17		
	2012			4,565	0.37	10,190	0.16	342	1.00

Table 18. Survey biomass estimates (t) for big, mud, roughtail, commander, and whitebrow skates (part of the "other skates" category in Table 16) by area and year.

		big skate		mud		roughtail		commander		whitebrow	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			927	0.32	1,656	0.14	3,662	0.16	1,539	0.23
	2004			702	0.20	1,677	0.12	4,194	0.15	1,755	0.20
	2008			1,018	0.22	2,213	0.14	3,437	0.15	1,934	0.17
	2010			576	0.25	2,103	0.16	3,393	0.15	1,908	0.19
	2012			842	0.31	2,324	0.15	4,378	0.13	1,325	0.15
AI	1980	376	0.23			17	0.43				
	1983	26	0.72			318	0.51			10	0.71
	1986	127	0.71			976	0.58				
	1991	26	1.00	90	0.39	749	0.36				
	1994	973	0.40	885	0.17	69	1.00			36	1.00
	1997	381	0.51	952	0.25	45	0.86			25	0.77
	2000	1,049	0.56	1,296	0.13	0	1.31				
	2002	203	0.62	1,779	0.16					30	0.71
	2004	422	0.53	1,807	0.17	1	0.98			34	1.00
	2006	568	0.72	2,971	0.28						
	2010	637	0.83	1,546	0.22	0	1.21				
	2012	195	0.65	1,277	0.15	2	0.86			72	0.69
EBS shelf	1982										
	1983	412	1.00								
	1984	1,387	1.00								
	1985	2,449	0.77								
	1986	20,370	0.91								
	1987	9,220	0.62								
	1988	995	1.00								
	1989										
	1990										
	1991										
	1992										
	1993										
	1994										
	1995										
	1996	988	1.00								
	1997										
	1998	1,642	1.00								
	1999	6,492	1.00								
	2000	5,155	0.83	448	0.48						
	2001	1,811	0.78								
	2002	1,489	0.59								
	2003			526	0.37						
	2004	951	0.71								
	2005										
	2006	1,036	0.68	55	1.00						
	2007	1,804	0.76								
	2008	2,870	0.63	125	1.00						
	2009	4,500	0.50								
	2010	3,445	0.66								
	2011	5,263	0.72	189	0.70						
	2012	1,161	0.70	286	1.00						

Table 19. Survey biomass estimates for longnose, Okhotsk, and deepsea skates and skates identified only to the genus *Bathyraja* (part of the "other skates" category in Table 16), by area and year.

		longnose		Okhotsk		*Bathyraja* sp		deepsea	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			47	0.59	54	0.74		
	2004			8	1.00	19	0.54	164	0.73
	2008	12	1.00					165	0.62
	2010					1	1.00	345	0.64
	2012					90	1.00		
AI	1980								
	1983								
	1986					12	0.63		
	1991	97	0.99			3,549	0.39		
	1994	28	1.00			939	0.40		
	1997	368	1.00			341	0.32		
	2000					1	0.97		
	2002					15	0.46		
	2004					3	0.76		
	2006					13	0.98		
	2010								
	2012								
EBS shelf	1982								
	1983								
	1984							68	1.00
	1985								
	1986								
	1987								
	1988								
	1989								
	1990								
	1991								
	1992								
	1993								
	1994								
	1995								
	1996	236	1.00						
	1997								
	1998								
	1999								
	2000								
	2001			98	1.00				
	2002	915	0.71	368	0.62				
	2003								
	2004								
	2005								
	2006								
	2007								
	2008	162	1.00						
	2009								
	2010								
	2011								
	2012	120	1.00						

Table 20. 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.

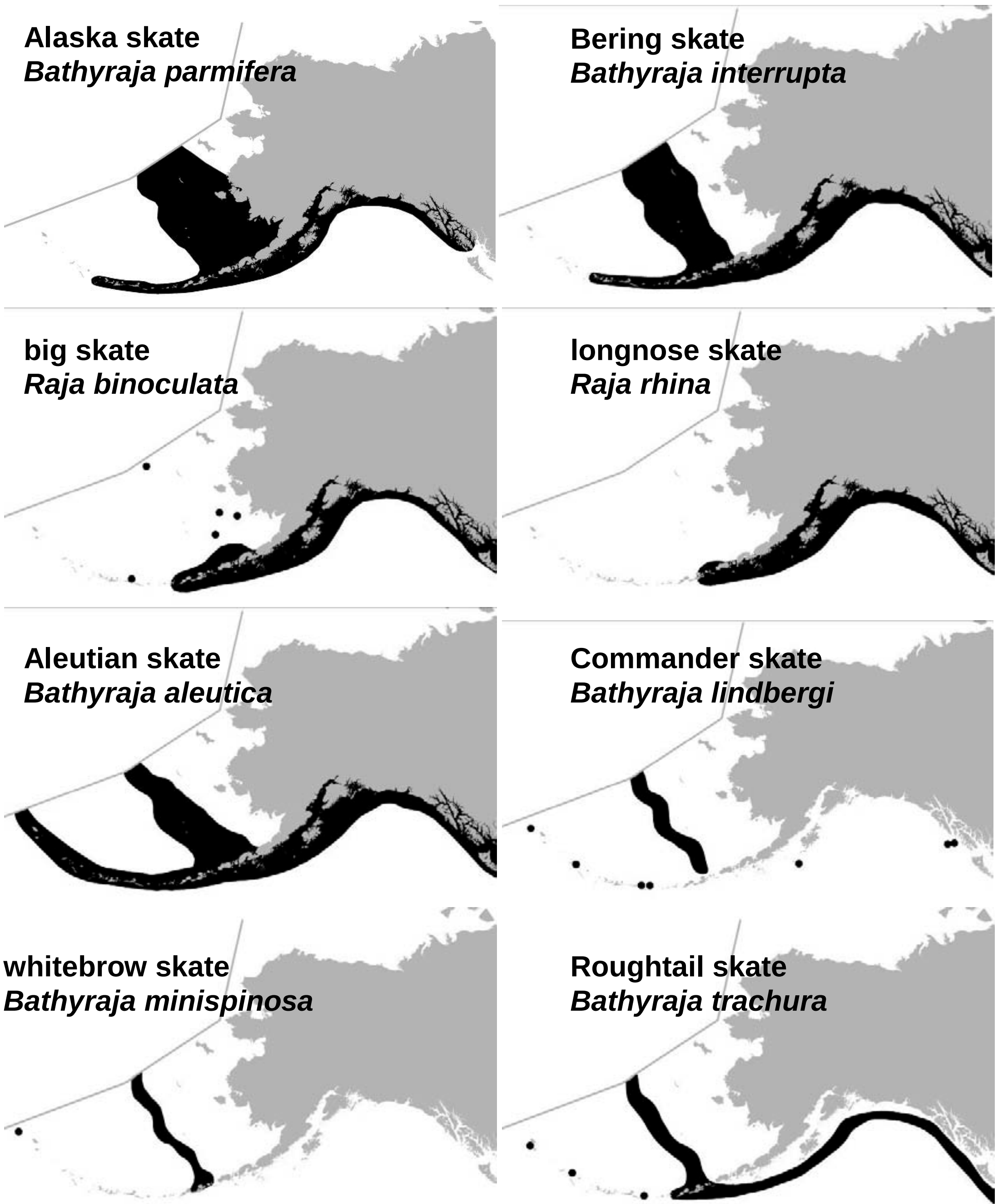


Figure 2. Distribution of skate species in Alaskan waters. These maps were created primarily using survey data, although observer records were included whenever positive species identification was possible (through voucher specimens or photographs). (Source: Stevenson et al. 2007)

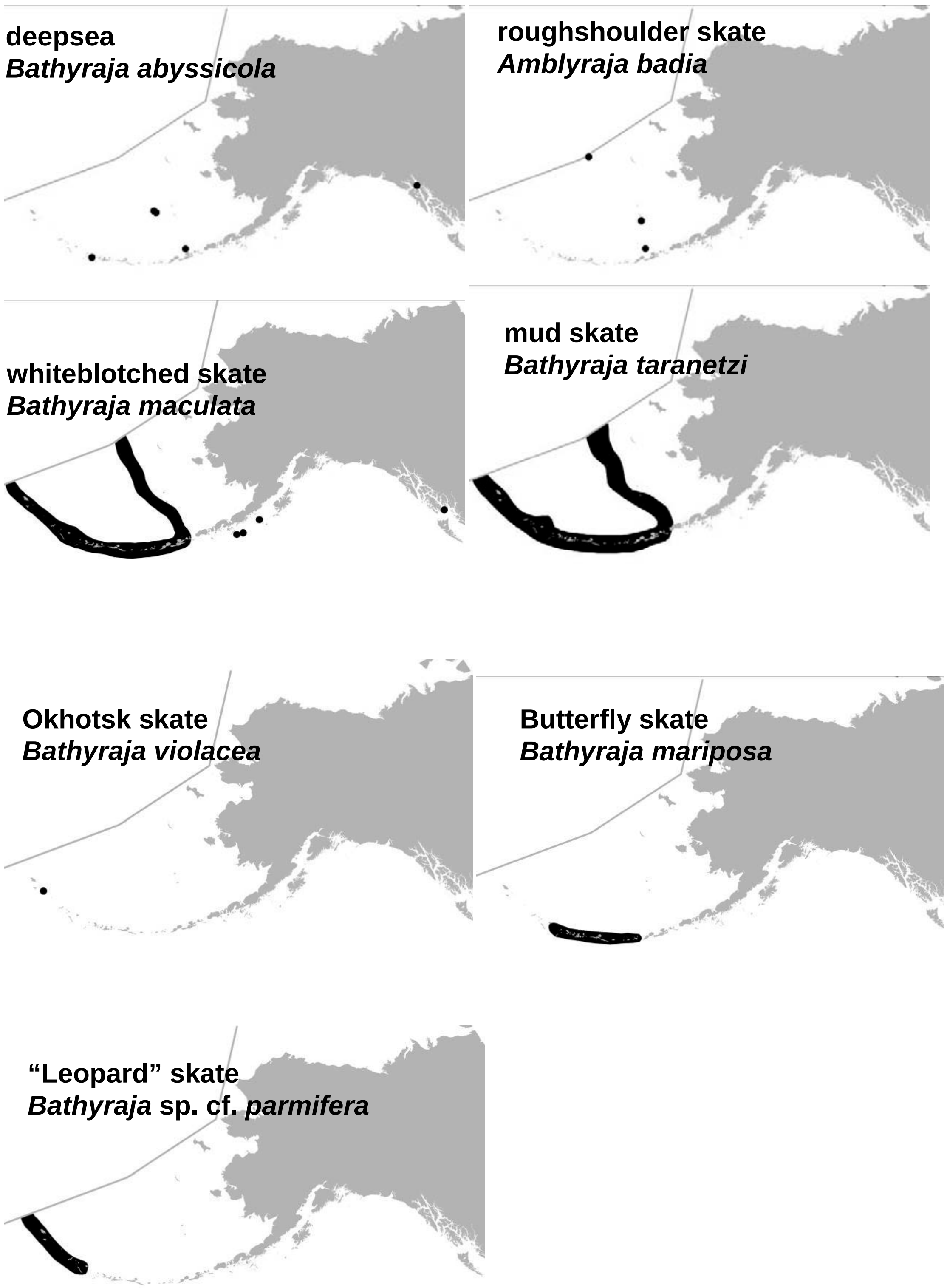


Figure 2 continued. Distribution of skate species in Alaskan waters. (Source: Stevenson et al. 2007)

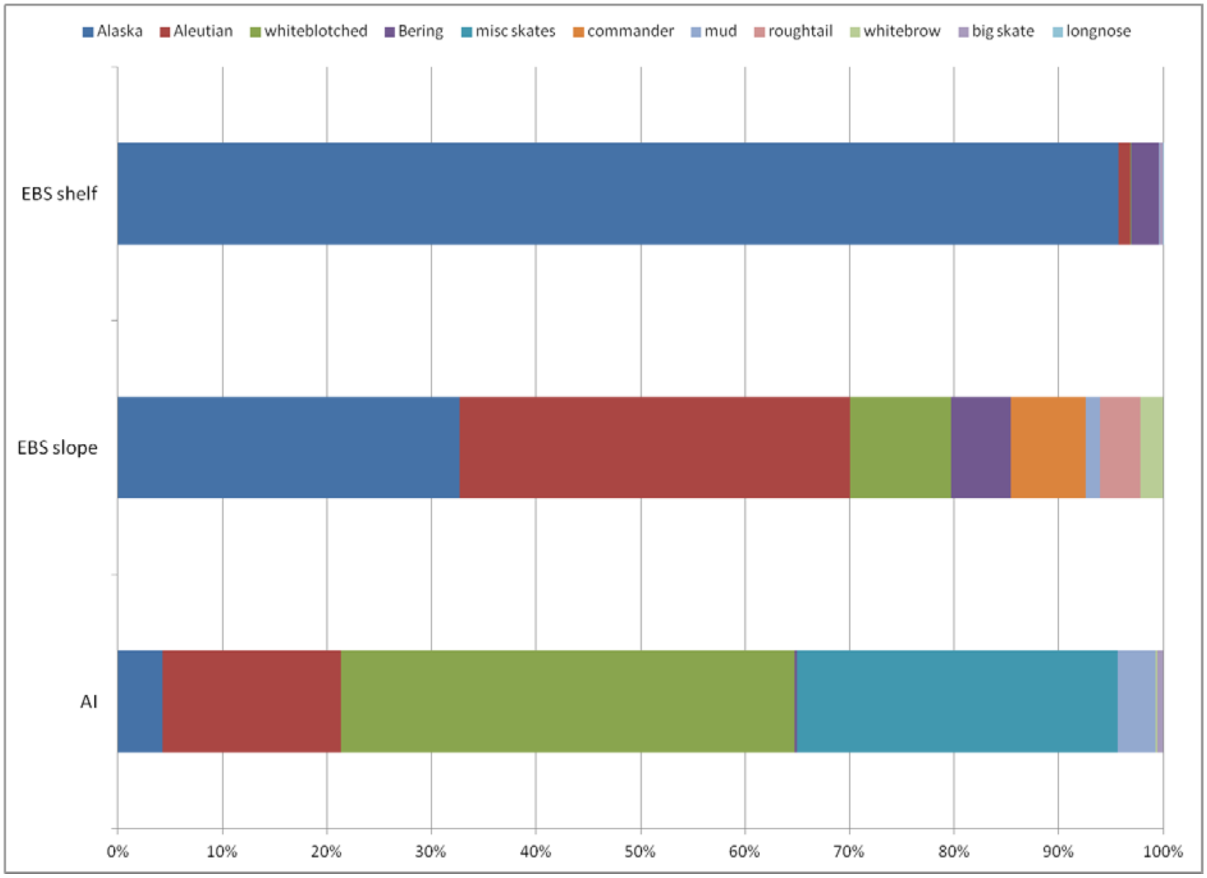


Figure 3. Skate species composition (by weight) by BSAI subregion, from surveys conducted in each region in 2012. In the AI, “misc skates” includes leopard skates.

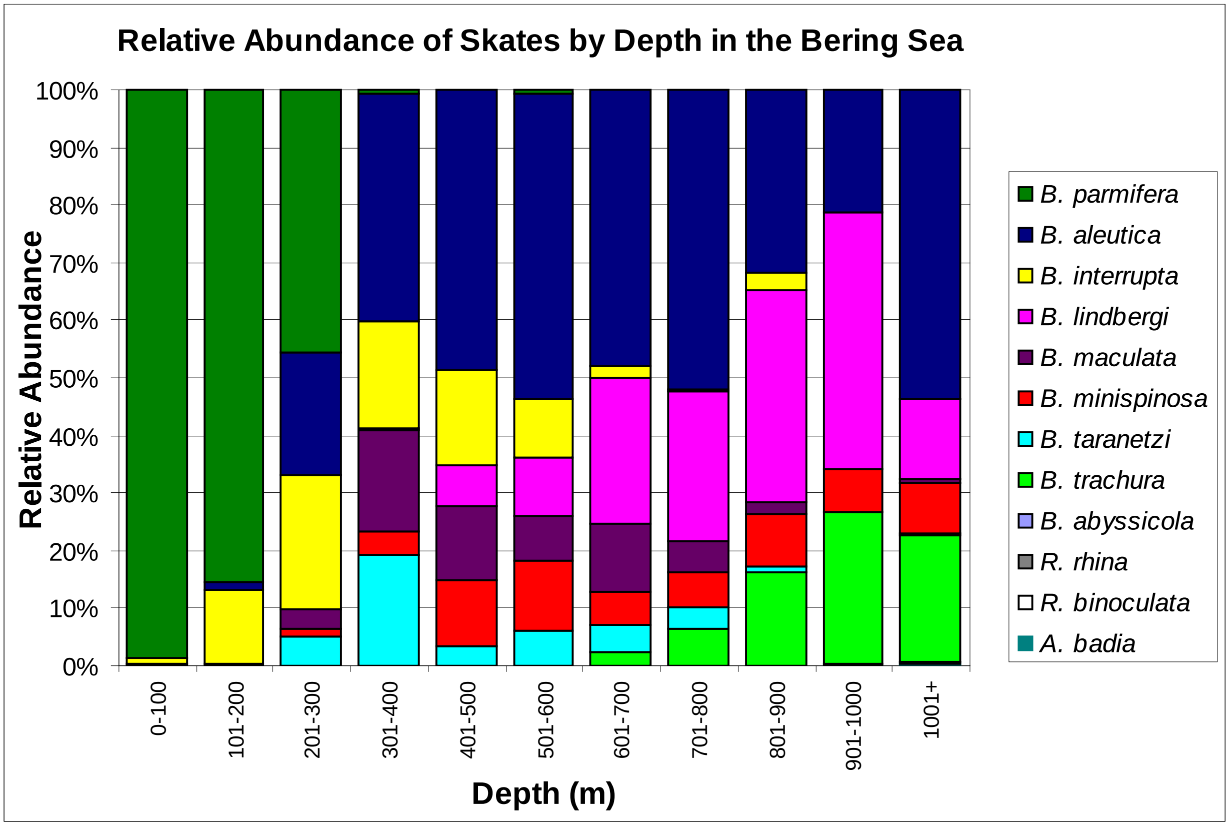


Figure 4. Relative abundance of skate species in the EBS by depth. (Source: Stevenson et al. 2006.)

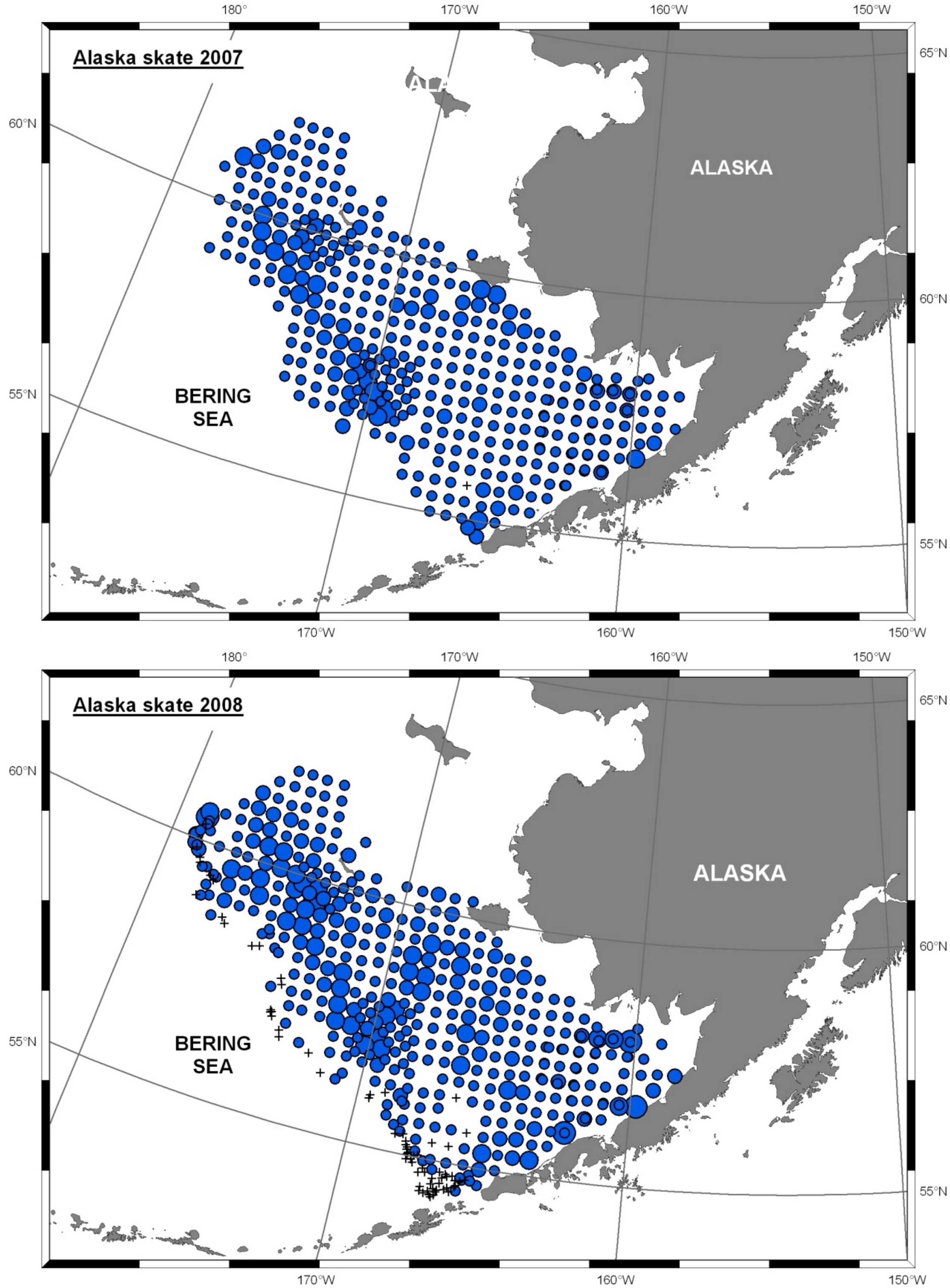


Figure 5. AFSC bottom trawl survey catches of Alaska skate in 2007 & 2008. Symbol size is proportional to total catch at each survey station. Data from 2008 include the 2008 slope survey. Crosses indicate no catch of Alaska skate at that station.

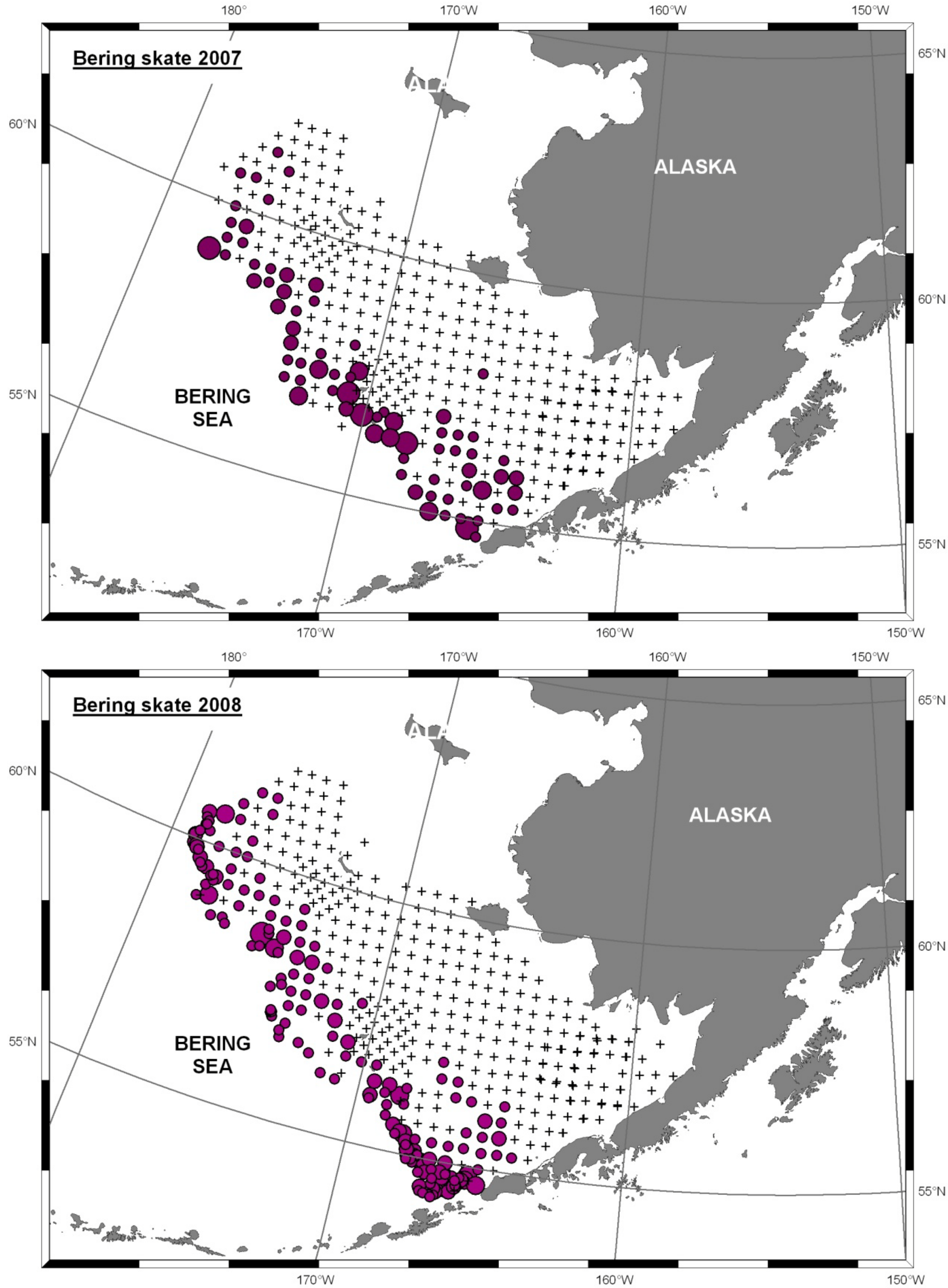


Figure 6. AFSC bottom trawl survey catches of Bering skate in 2007 & 2008. Symbol size is proportional to total catch at each survey station. Data from 2008 include the 2008 slope survey. Crosses indicate no catch of Bering skate at that station.

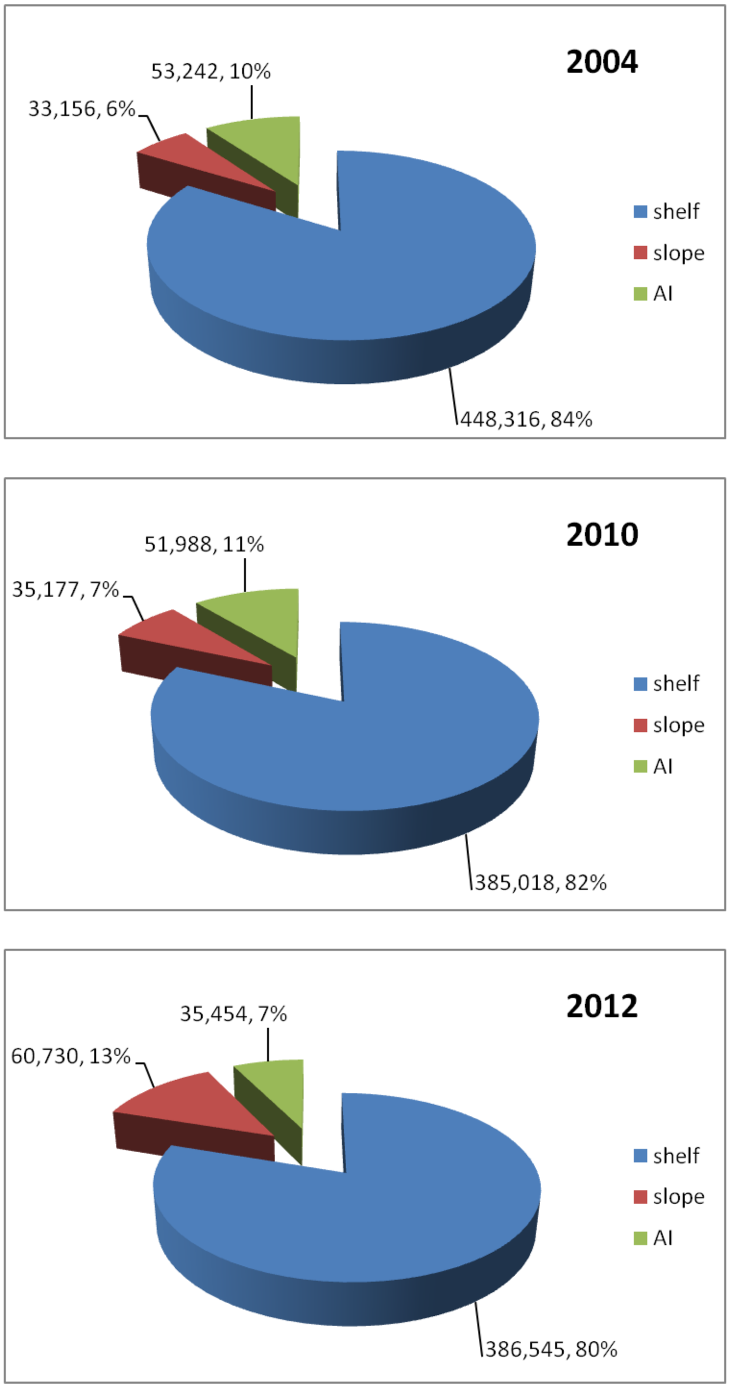


Figure 7. Distribution of skate biomass in the 3 subregions of the BSAI, 2004 and 2010. Data are biomass estimates (t) and relative proportions from AFSC groundfish surveys.

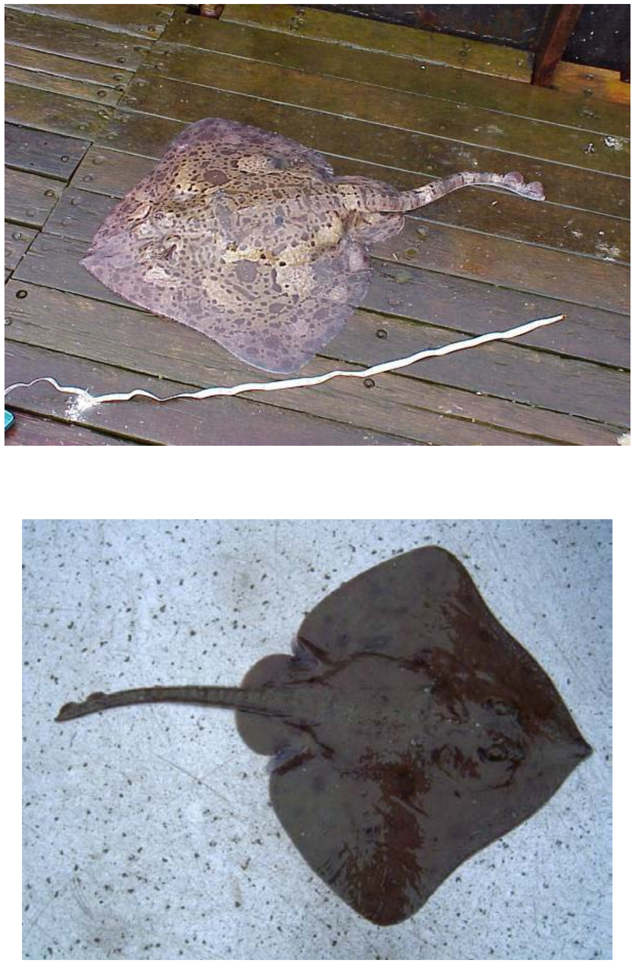


Figure 8. Skate diversity in the Aleutians: a new species, the leopard skate, from the Aleutian Islands (top) formerly thought to be the same species as the extremely common Alaska skate, *B. parmifera* (from the EBS, bottom). Photo credits: leopard skate, Richard MacIntosh; Alaska skate, Beth Matta.

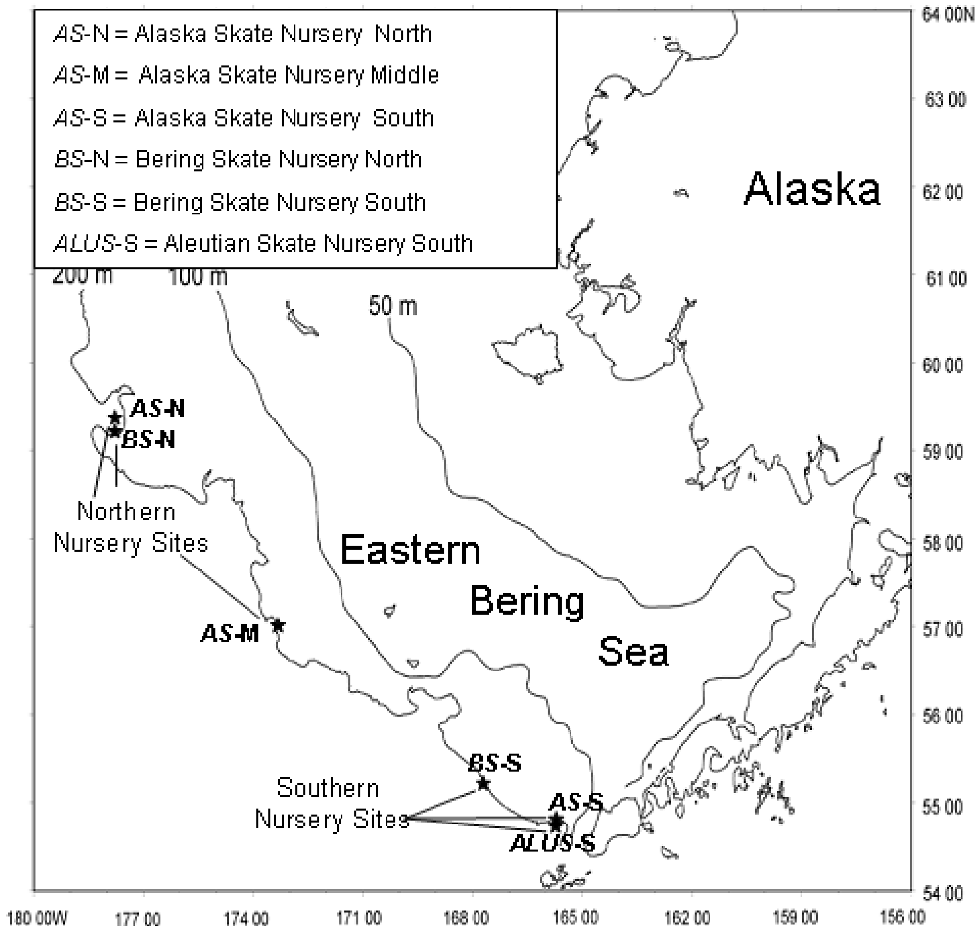


Figure 9. Map of the eastern Bering Sea with the six known skate nursery site locations and designations as a northern or southern nursery site. (See the legend for nursery site designation.) Source: Gerald Hoff, AFSC, unpublished data.

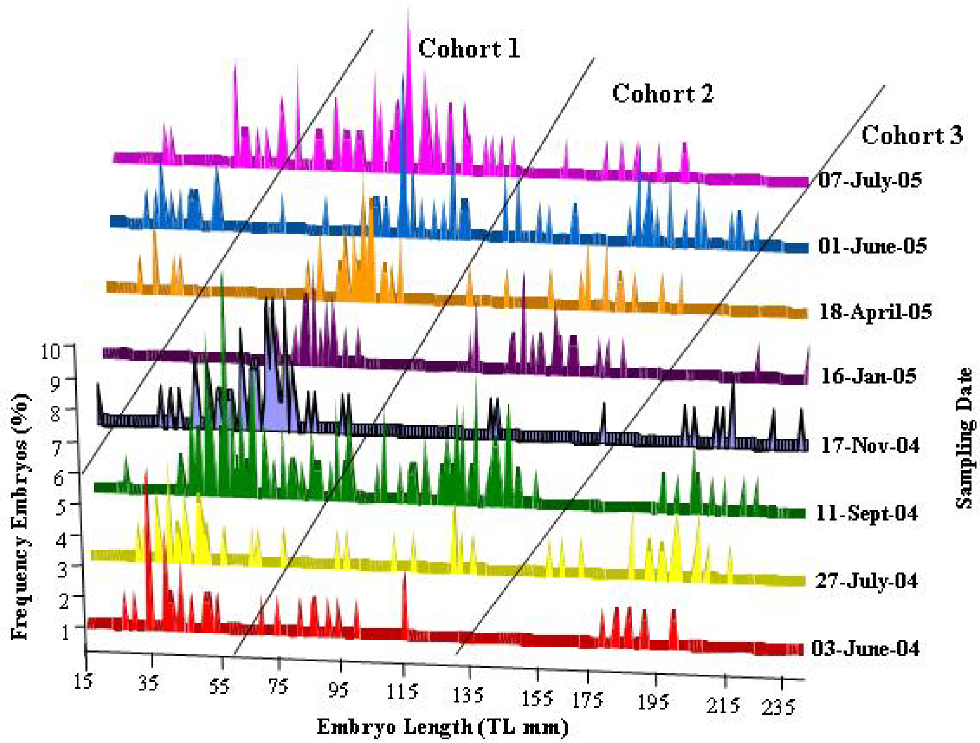


Figure 10. Embryo length composition data used in a cohort analysis of embryo development time. Figure is from G. Hoff (pers. comm.).

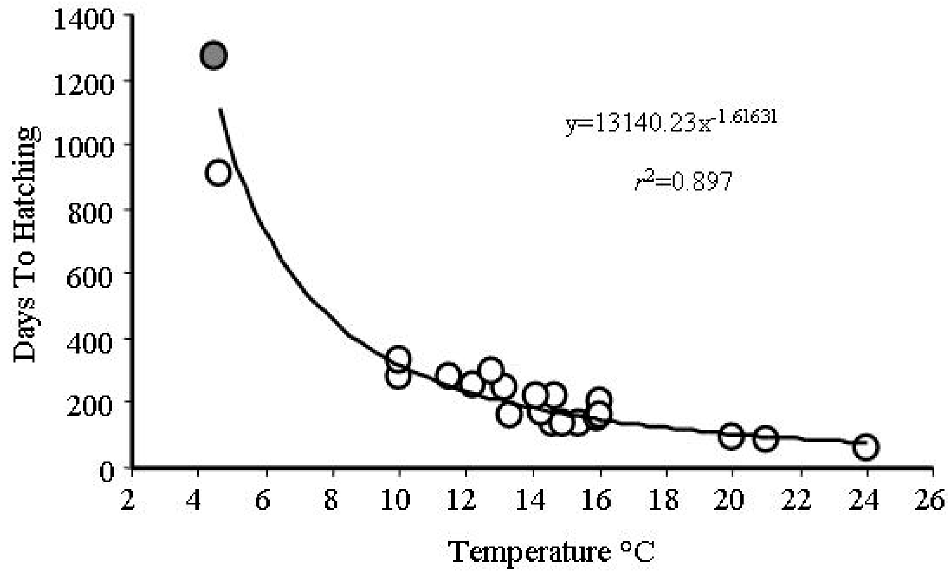


Figure 11. Ocean temperature versus embryo development time for 21 skate species. Dark grey circle is the Alaska skate. Equation and R^2 are the values of the fitted relationship. Figure is from G. Hoff, AFSC, pers. comm.

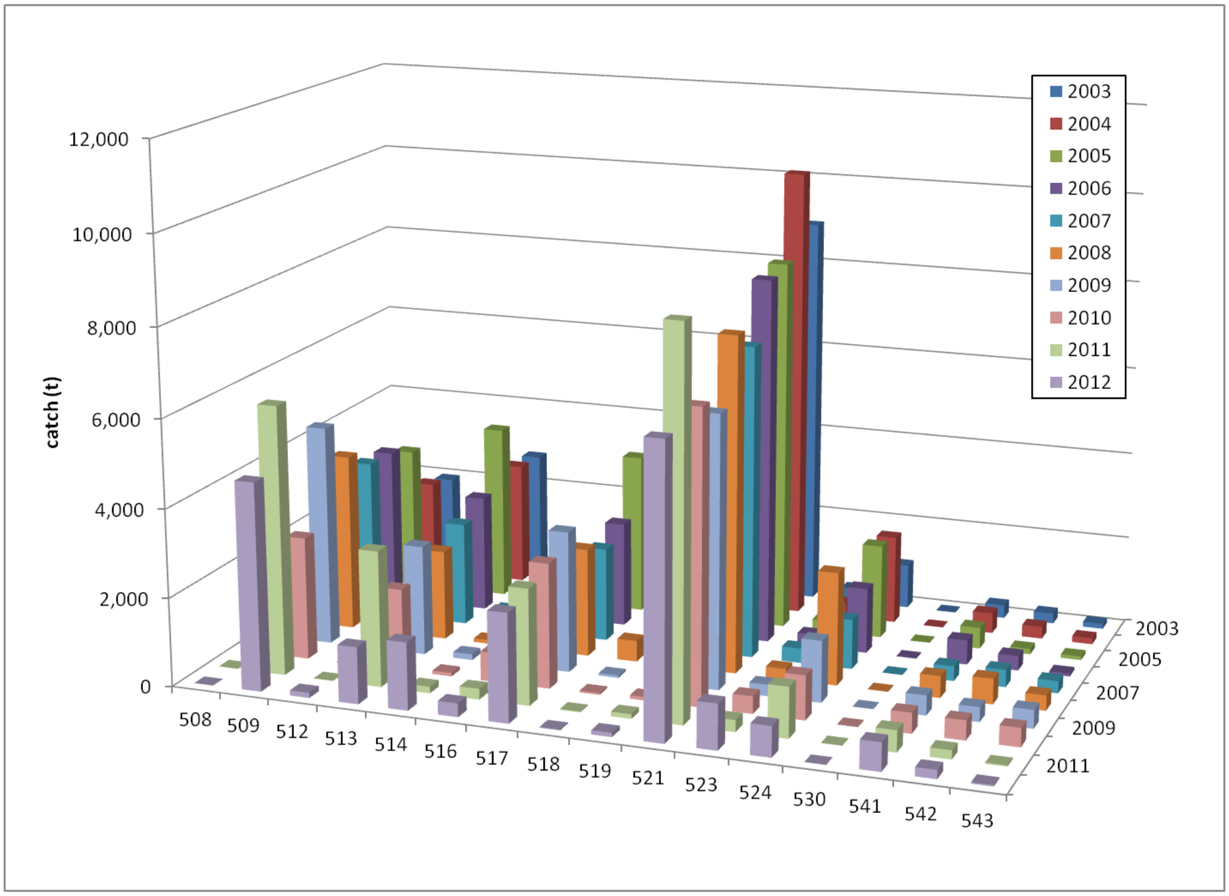


Figure 12. Total skate catch (all species combined) by FMP reporting area for both the EBS and the AI, 2003 - 2012. Source: AKRO CAS. 2012 data incomplete; retrieved September 28, 2012.

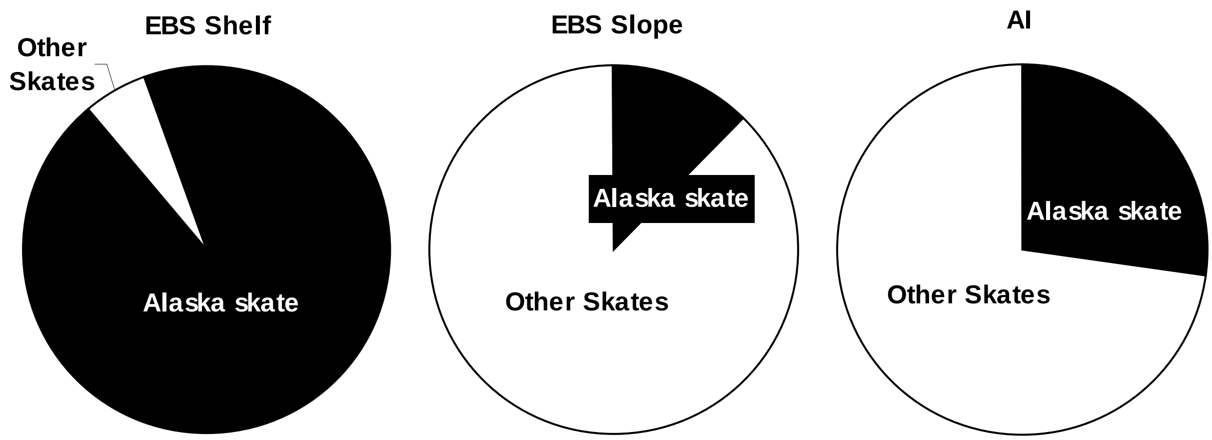


Figure 13. Relative proportion of Alaska skates and Other Skates in each habitat area. Graphs represent weighted averages from 1999 - 2012 trawl survey biomass estimates. These data were used to reconstruct catch data for the Alaska skate for use in the assessment model.

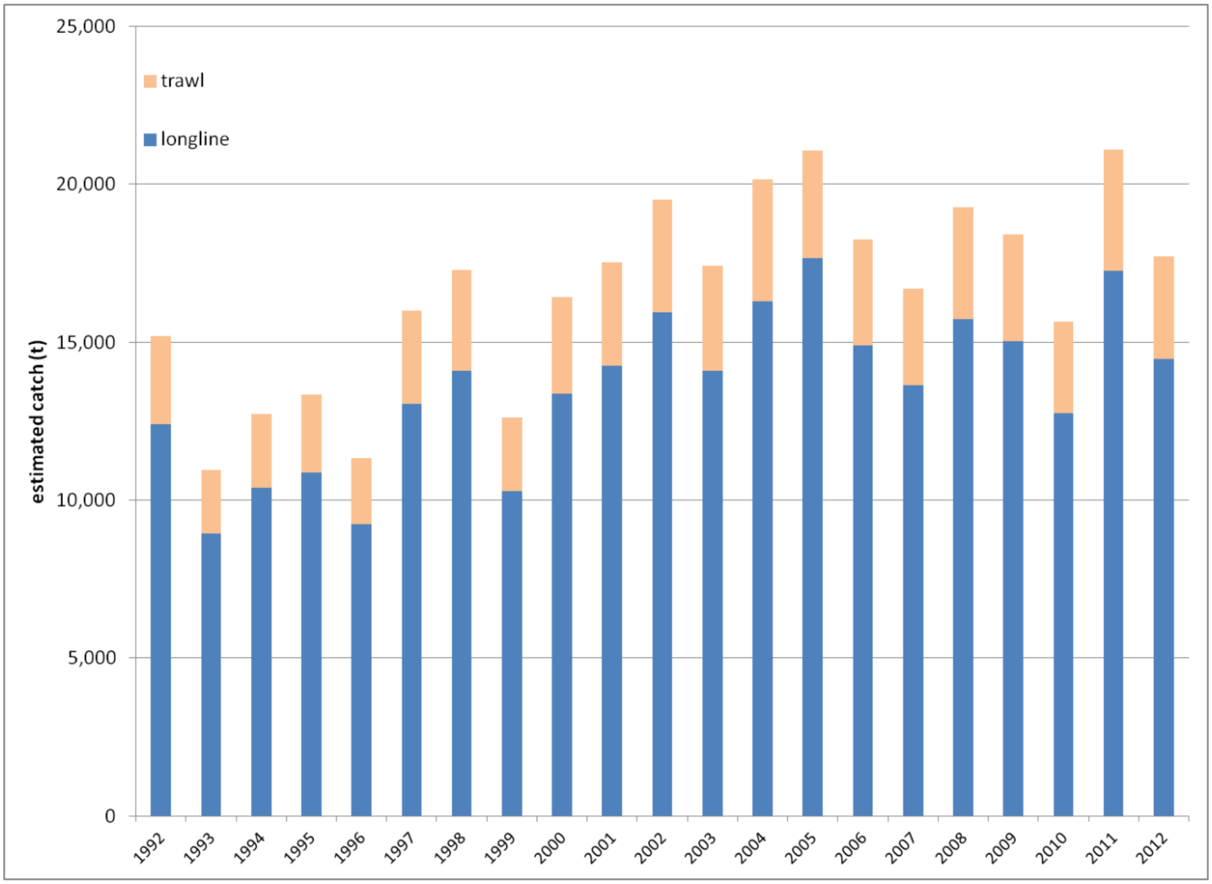


Figure 14. Estimated catch of Alaska skates (t) in the BSAI used in the model, 1992 - 2012. Data were obtained from the Blend system and AKRO CAS. 2012 catch is as reported through September 28, 2012.

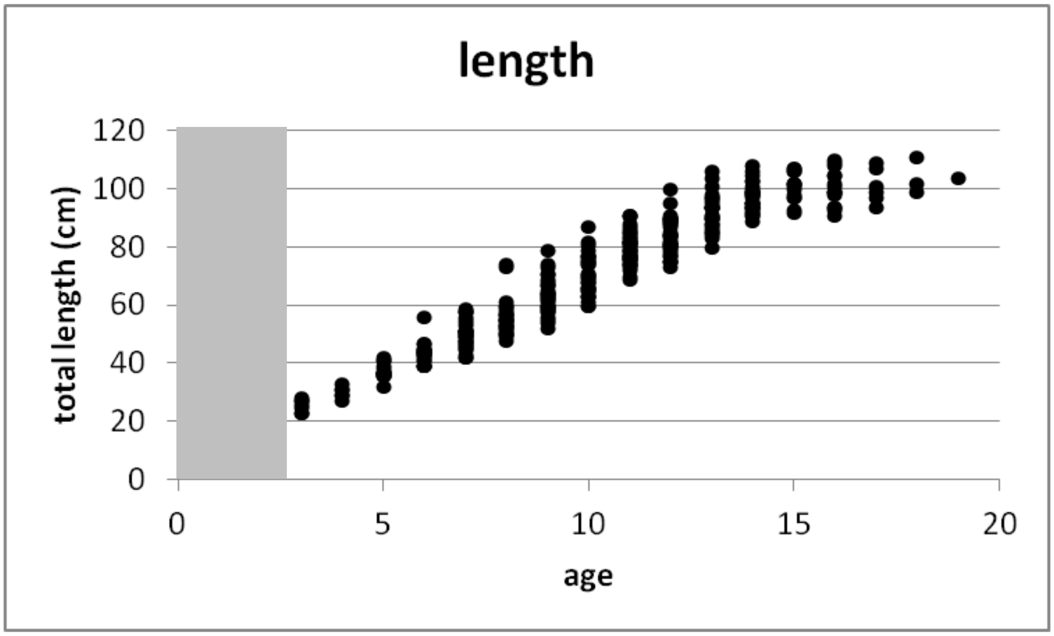


Figure 15. Observed size at age data from Alaska skates collected in the 2009 EBS shelf trawl survey, sexes combined (N = 337). The three year embryonic development period included in the base model is represented by the shaded area.

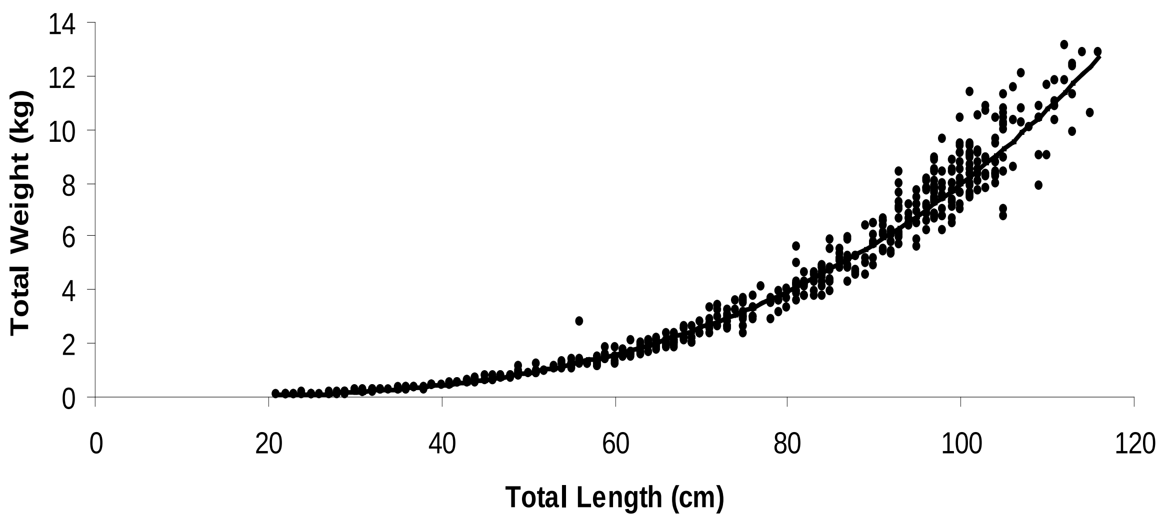


Figure 16. The relationship between total length (TL) and total body weight (W) for the Alaska skate, both sexes combined (n = 526).

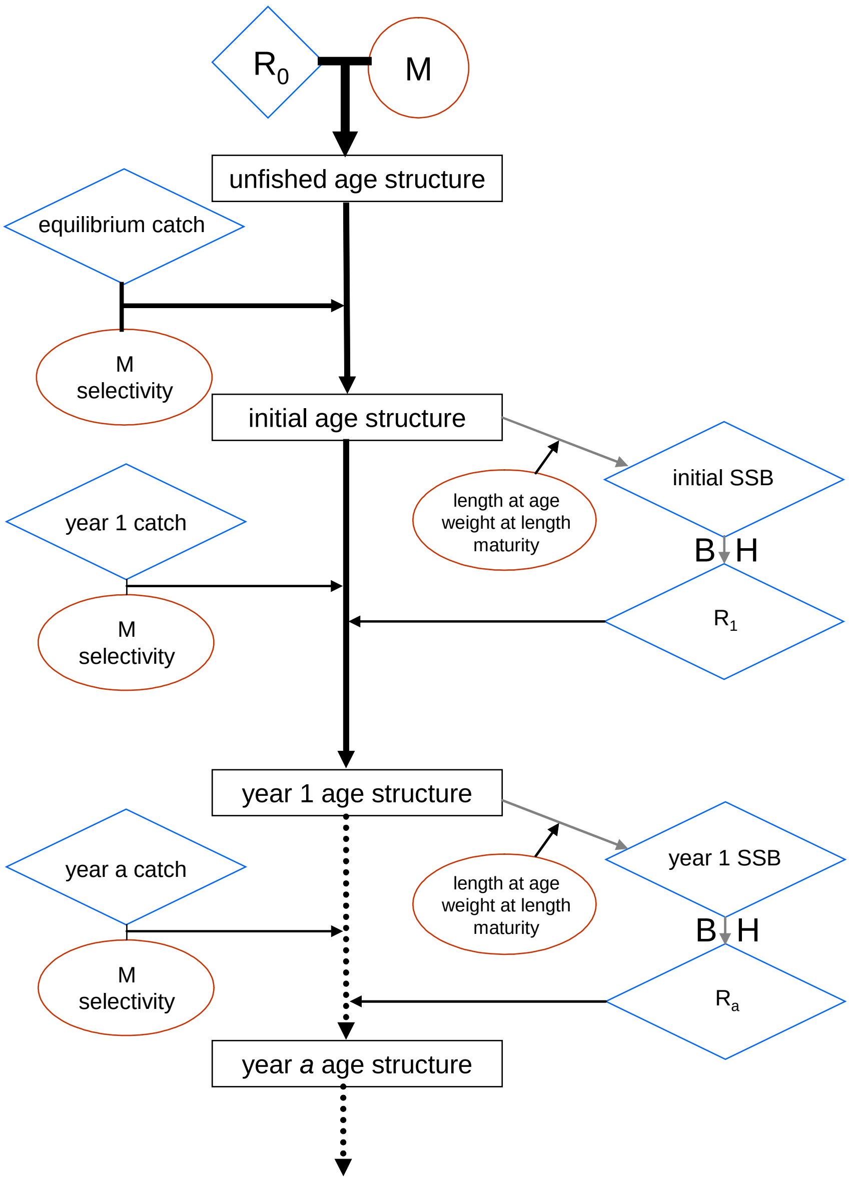


Figure 17. Simplified schematic depiction of population dynamics model used in the Alaska skate assessment. Blue diamonds indicate physical quantities, red circles indicate rates. R_a = recruitment in year a, *M* = natural mortality, SSB = spawning biomass, BH indicates that a Beverton-Holt stock-recruit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

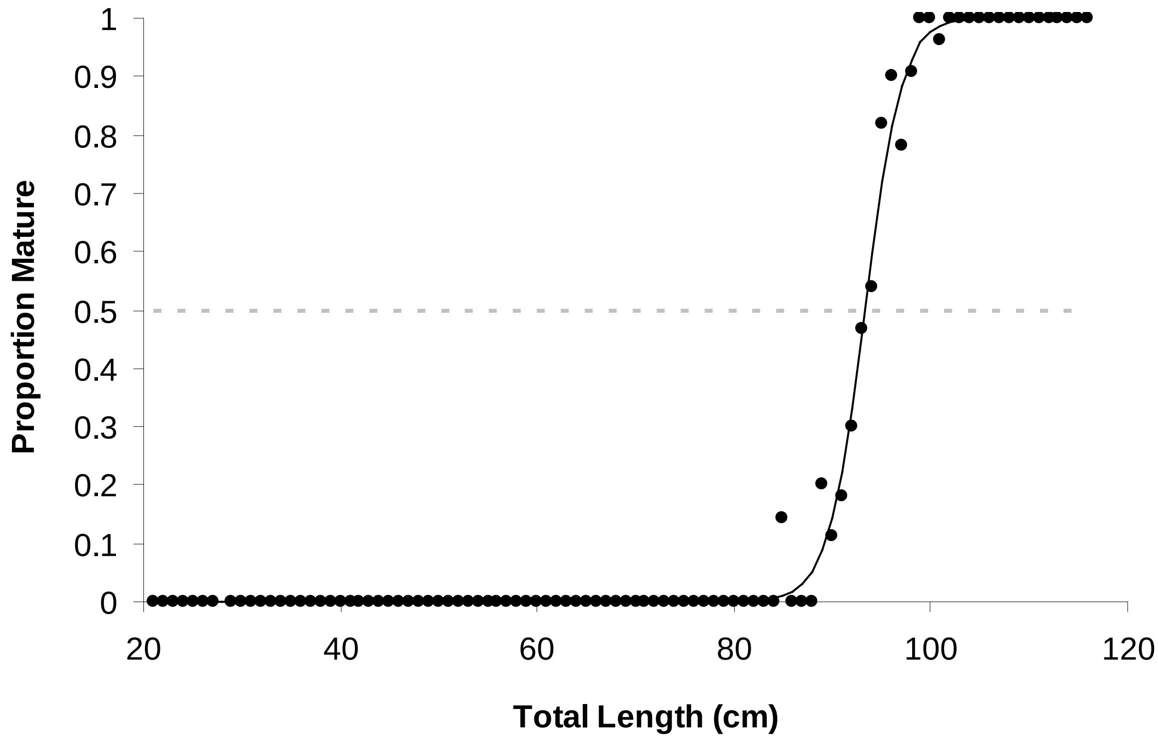


Figure 18. Female Alaska skate maturity-at-length data shown with fitted logistic curve from Matta (2006) (n = 642).

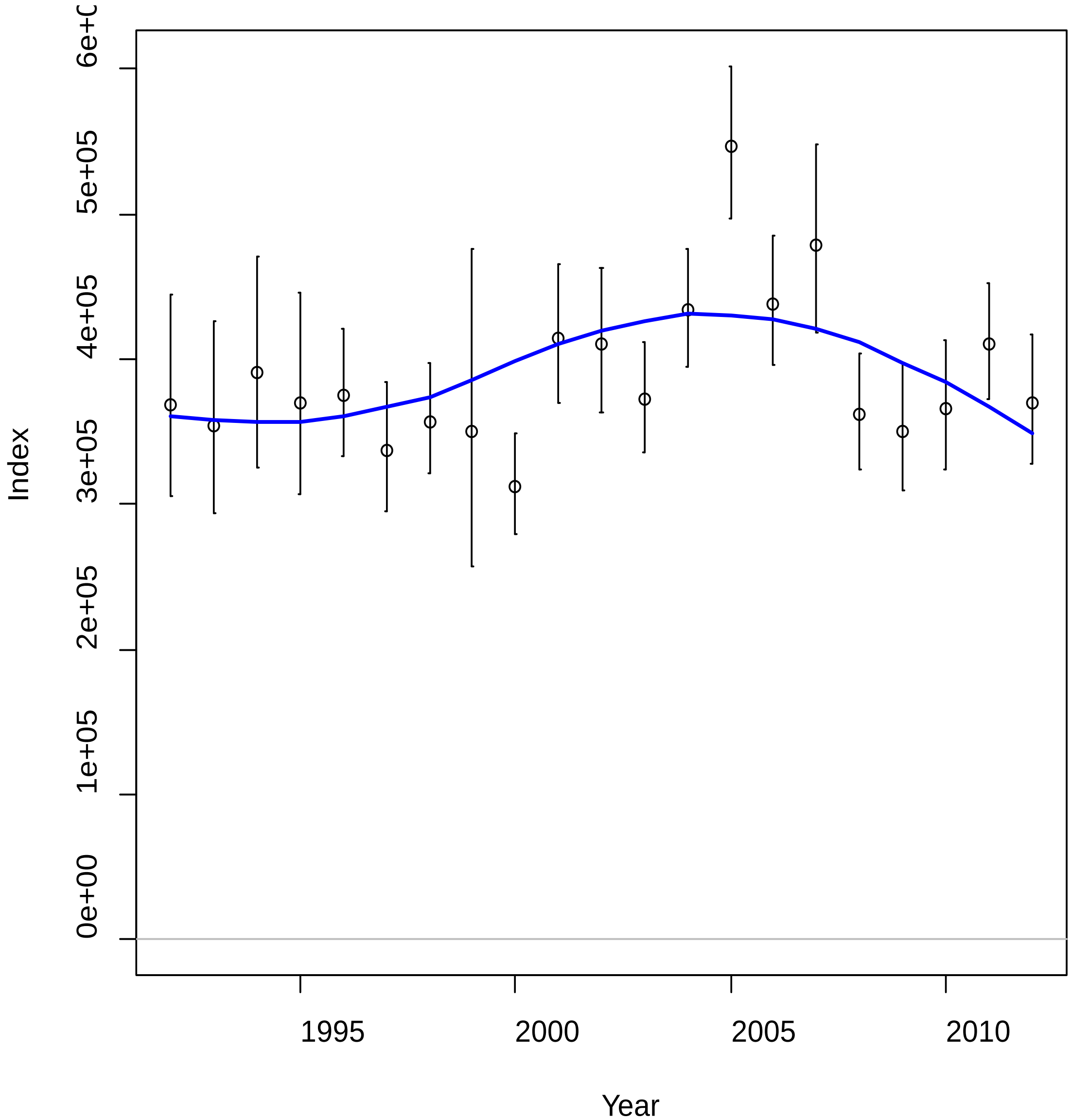


Figure 19. Observed biomass (circles) from EBS shelf surveys 1992 - 2012, with 95% confidence intervals, and predicted survey biomass from the model (blue line).

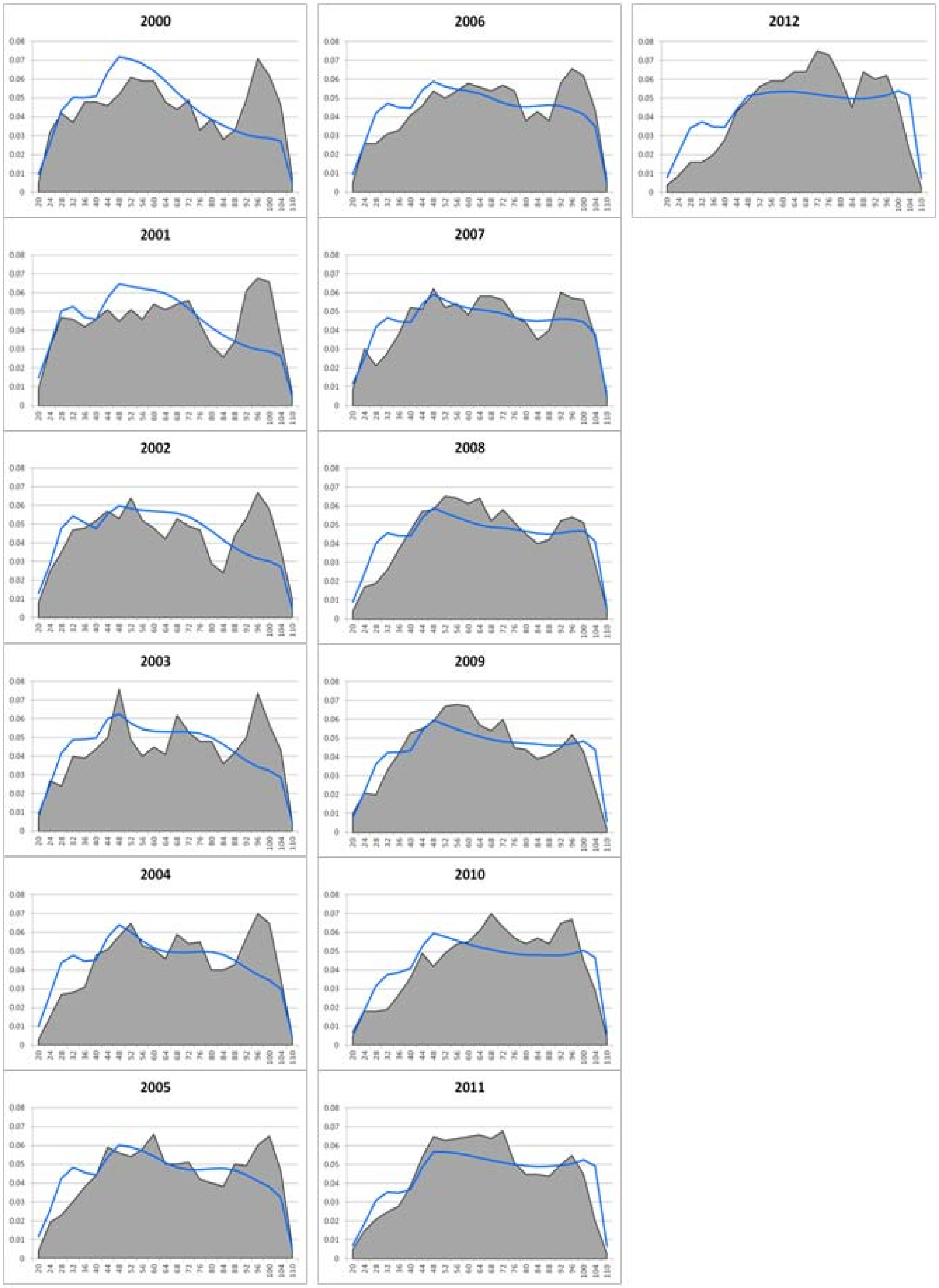


Figure 20. EBS shelf survey length compositions from 2000 - 2012. Grey shaded area = observed proportions; blue line = model predictions.

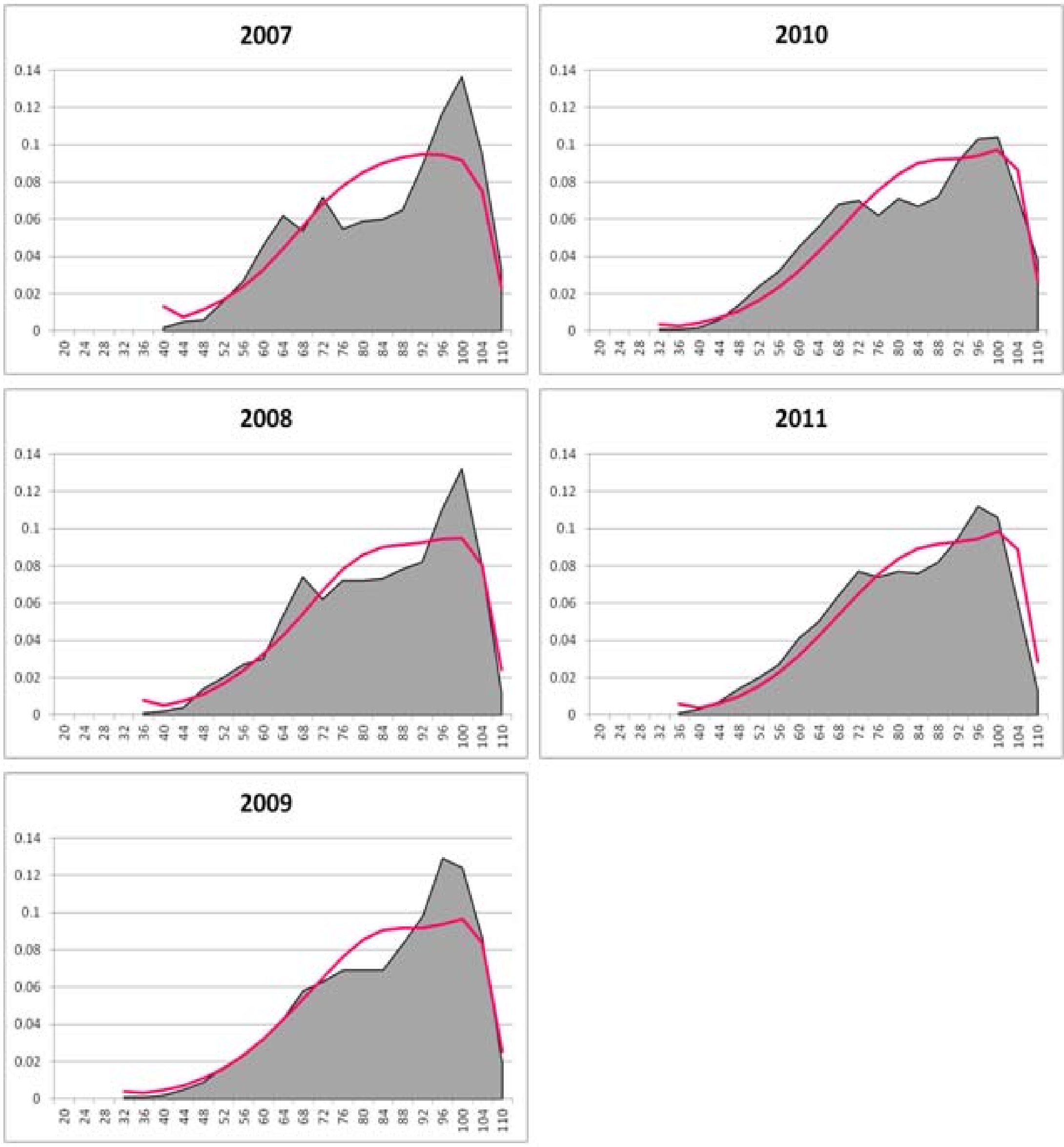


Figure 21. Observed and model-predicted length compositions from the 2007 - 2011 longline fisheries, with model predictions. Grey shaded area = observed proportions; purple line = model predictions.

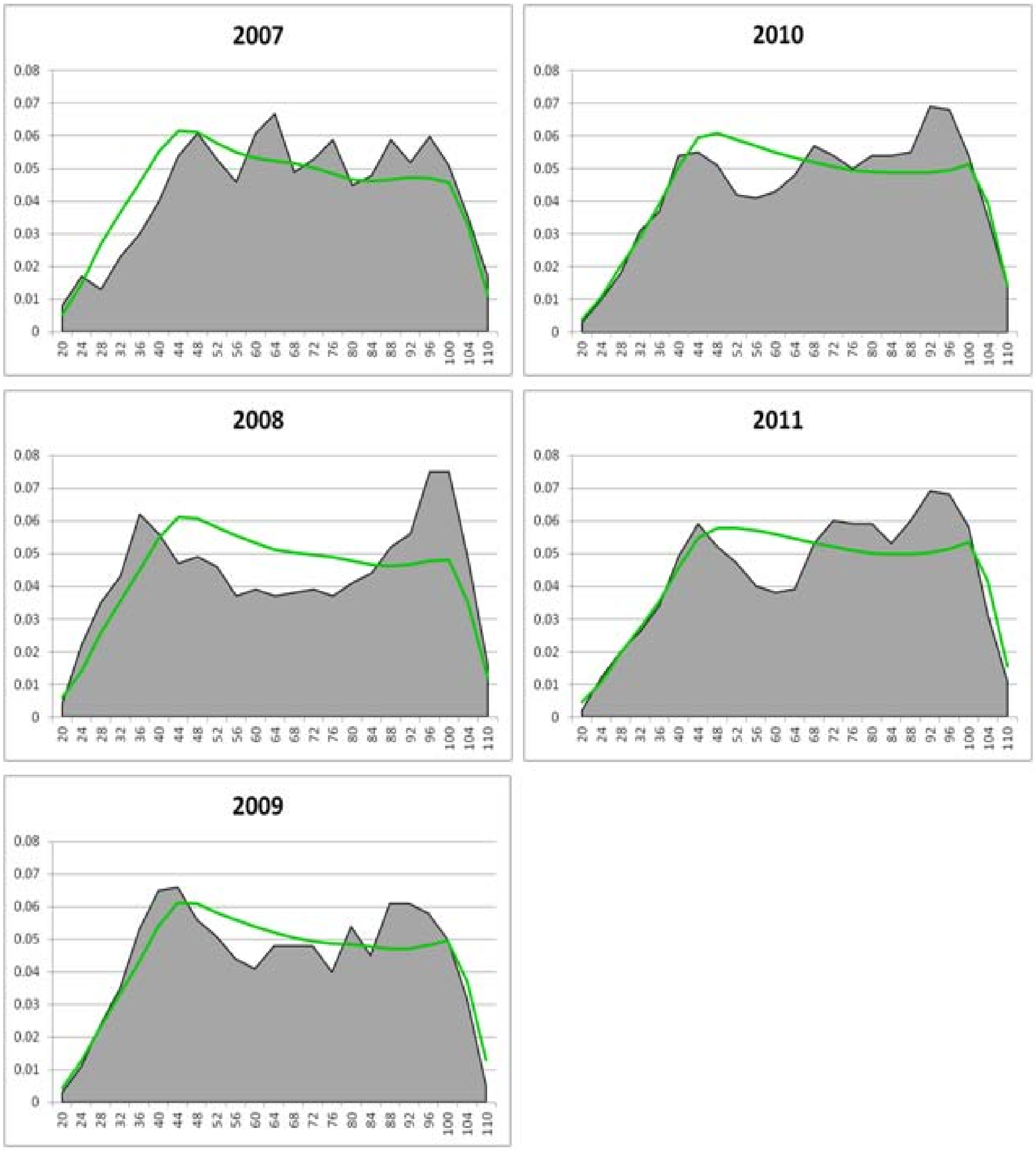


Figure 22. Observed and model-predicted length compositions from the 2007 - 2009 trawl fisheries, with model predictions. Grey shaded area = observed proportions; green line = model predictions.

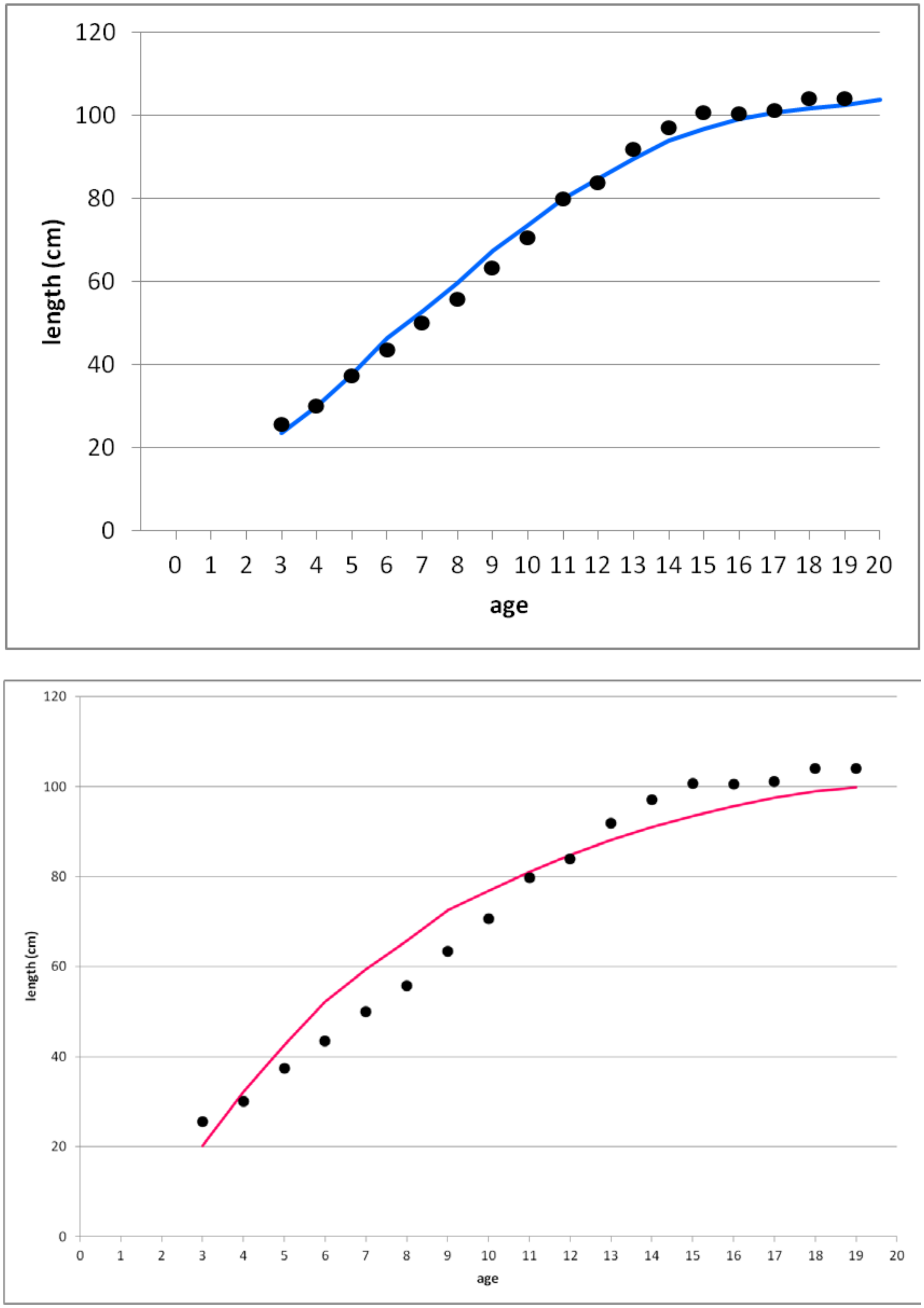


Figure 23. Observed and model-predicted length-at-age from the 2009 EBS shelf survey. Upper panel shows the fit from the preferred model (Model 3); bottom panel shows the fit from the previous model (Model 1).

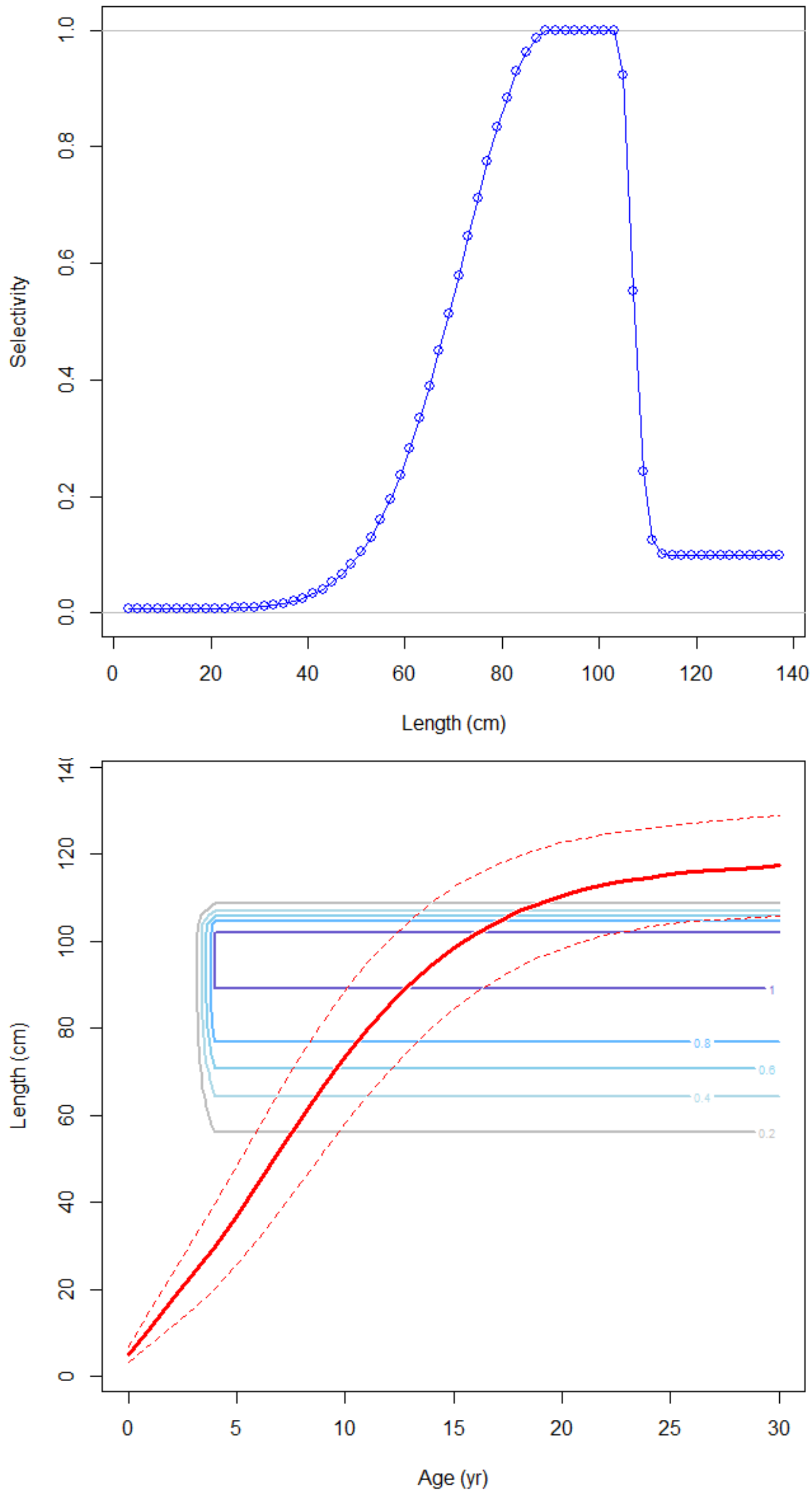


Figure 24. Length-based selectivity for the longline fishery. Upper plot shows selectivity at length; lower plot shows the selection surface imposed on the function for length at age.

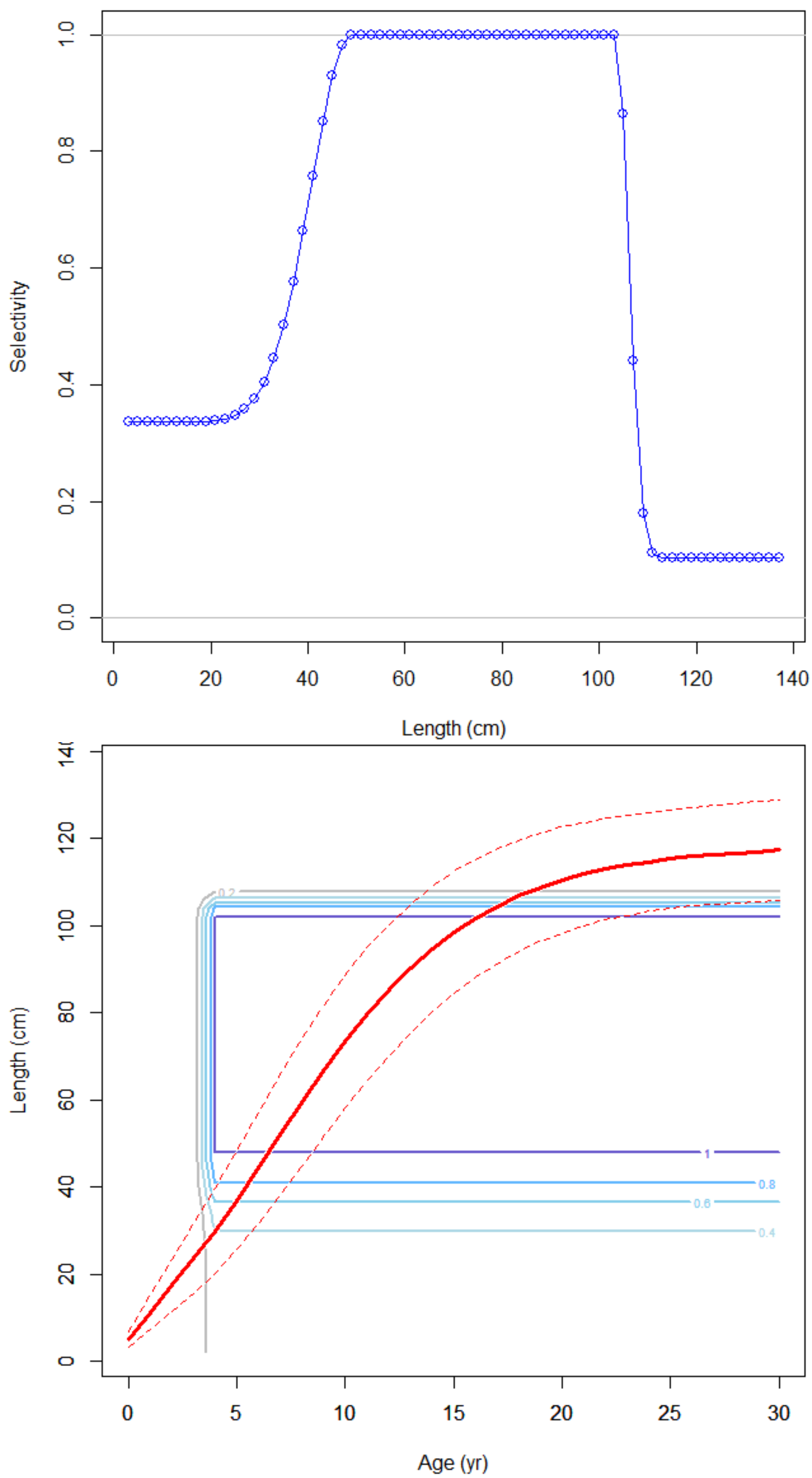


Figure 25. Length-based selectivity for the trawl fishery. Upper plot shows selectivity at length; lower plot shows the selection surface imposed on the function for length at age.

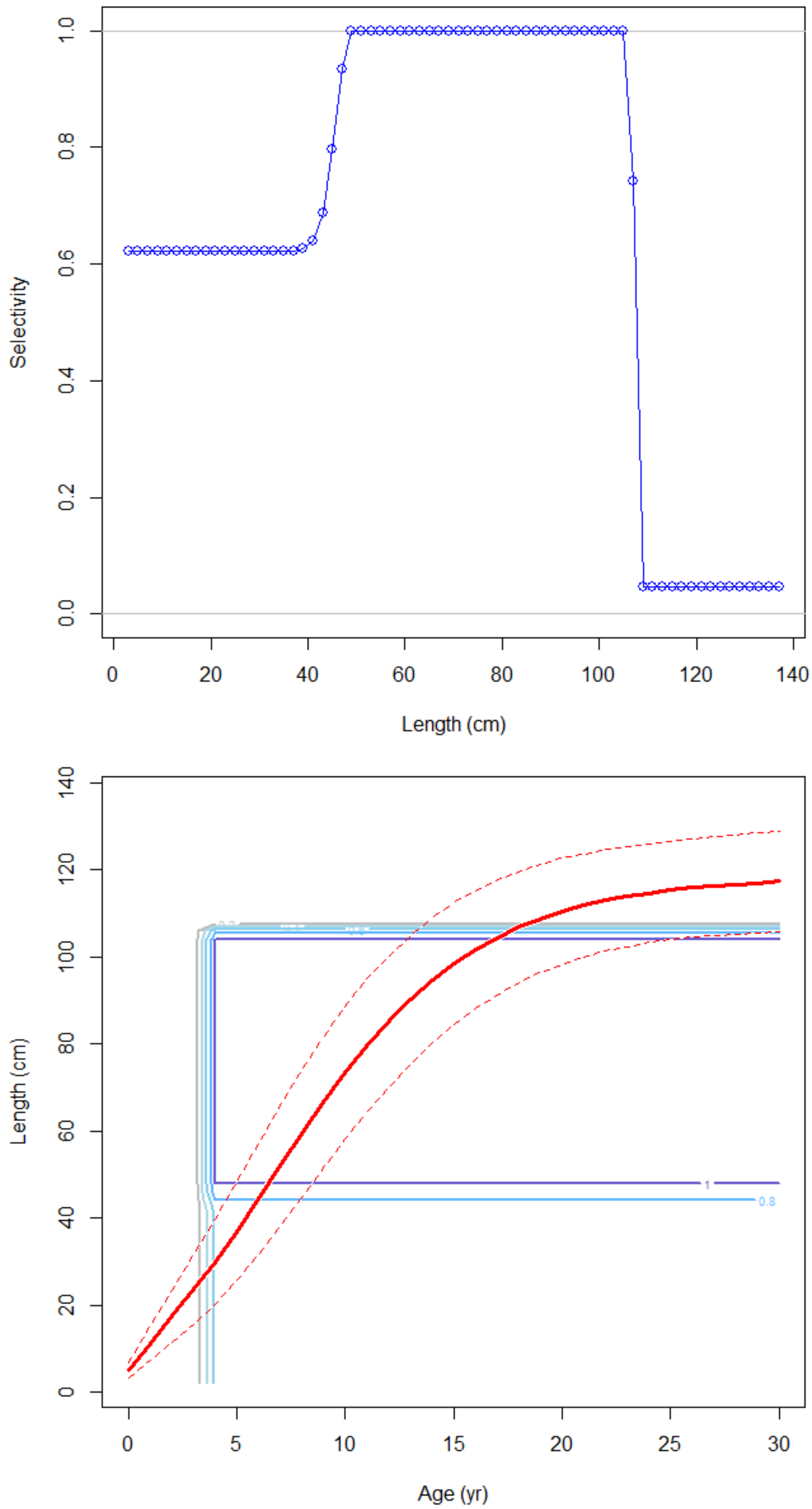


Figure 26. Length-based selectivity for the EBS bottom trawl survey. Upper plot shows selectivity at length; lower plot shows the selection surface imposed on the function for length at age.

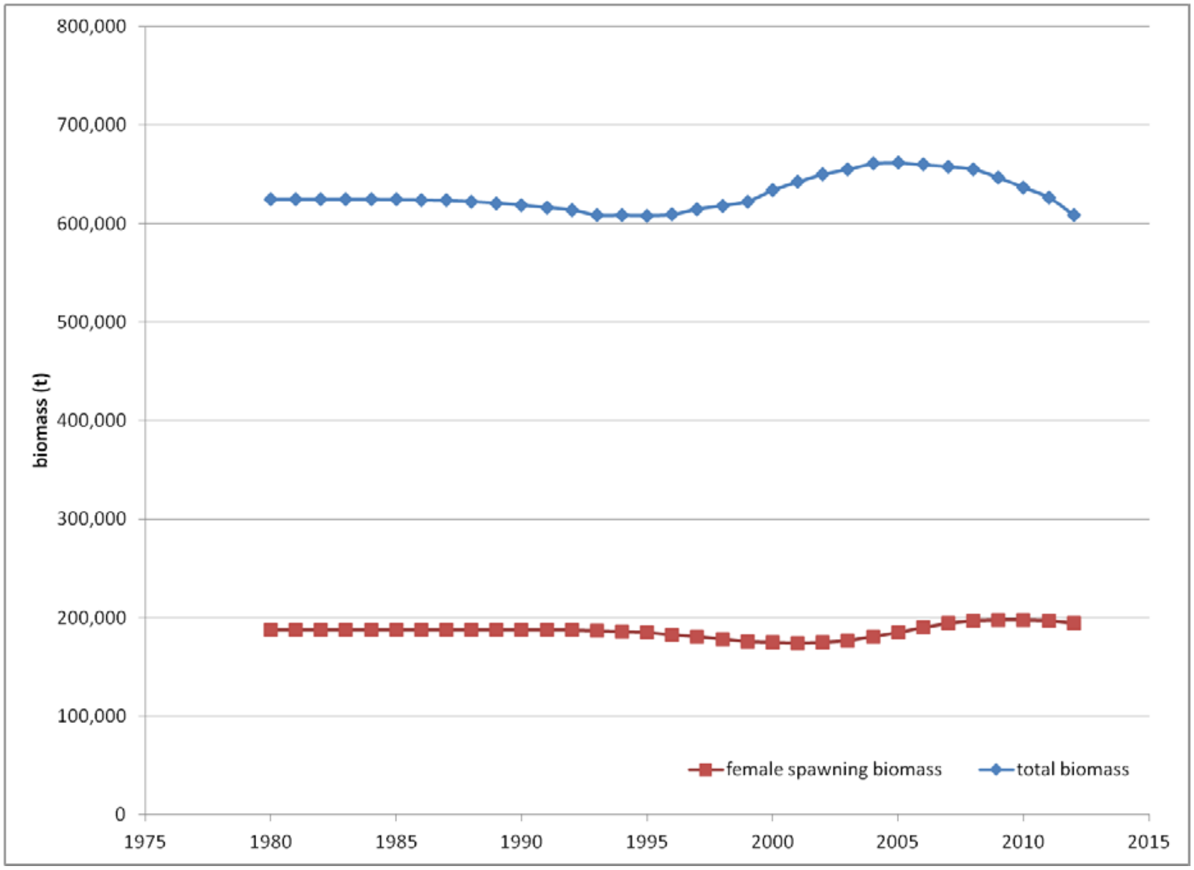


Figure 27. Time series of model estimates for total (age 0+) biomass (t) and female spawning biomass (t).

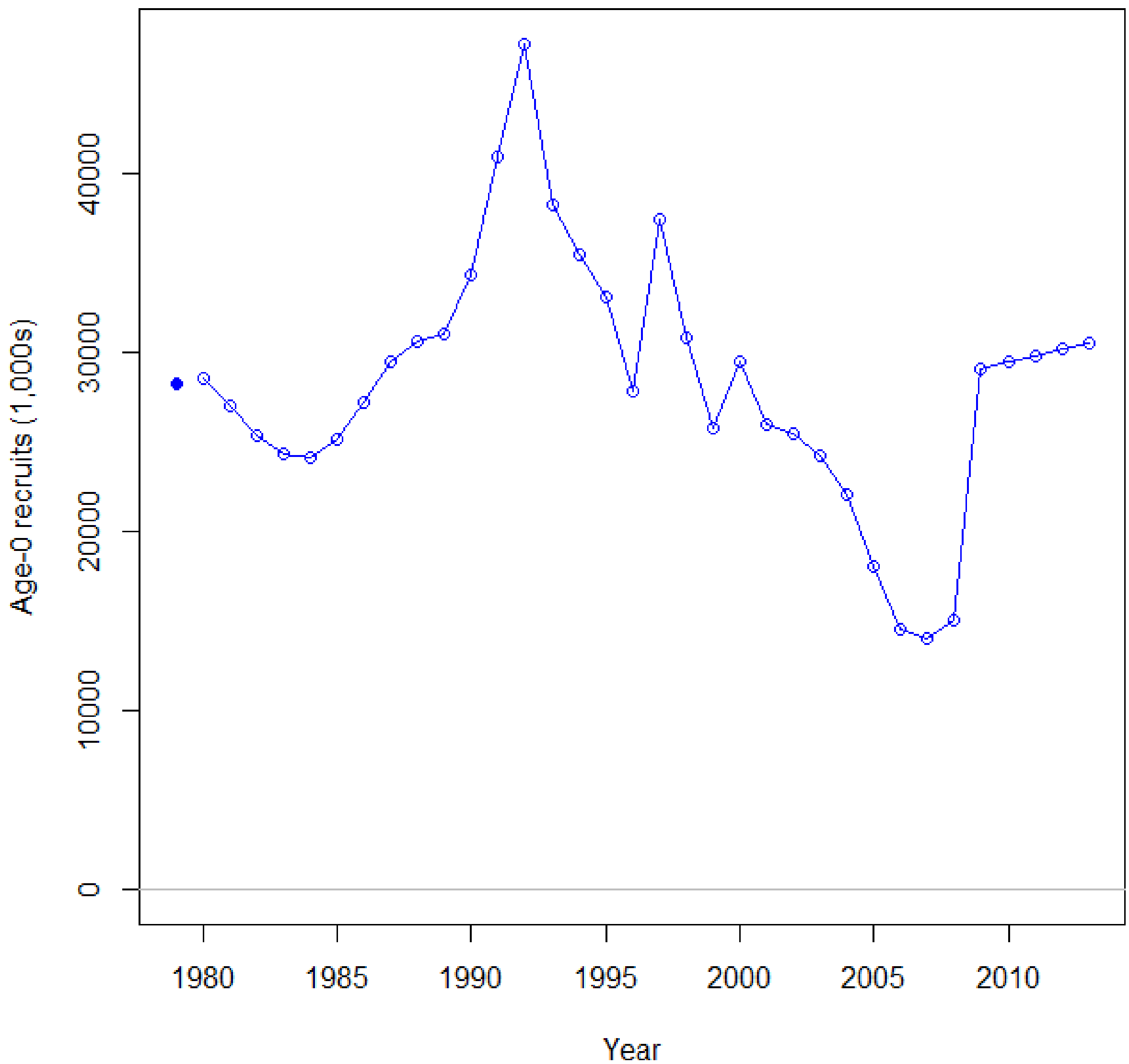


Figure 28. Time series of recruitment (in thousands of age 0 fish) estimated by the model.

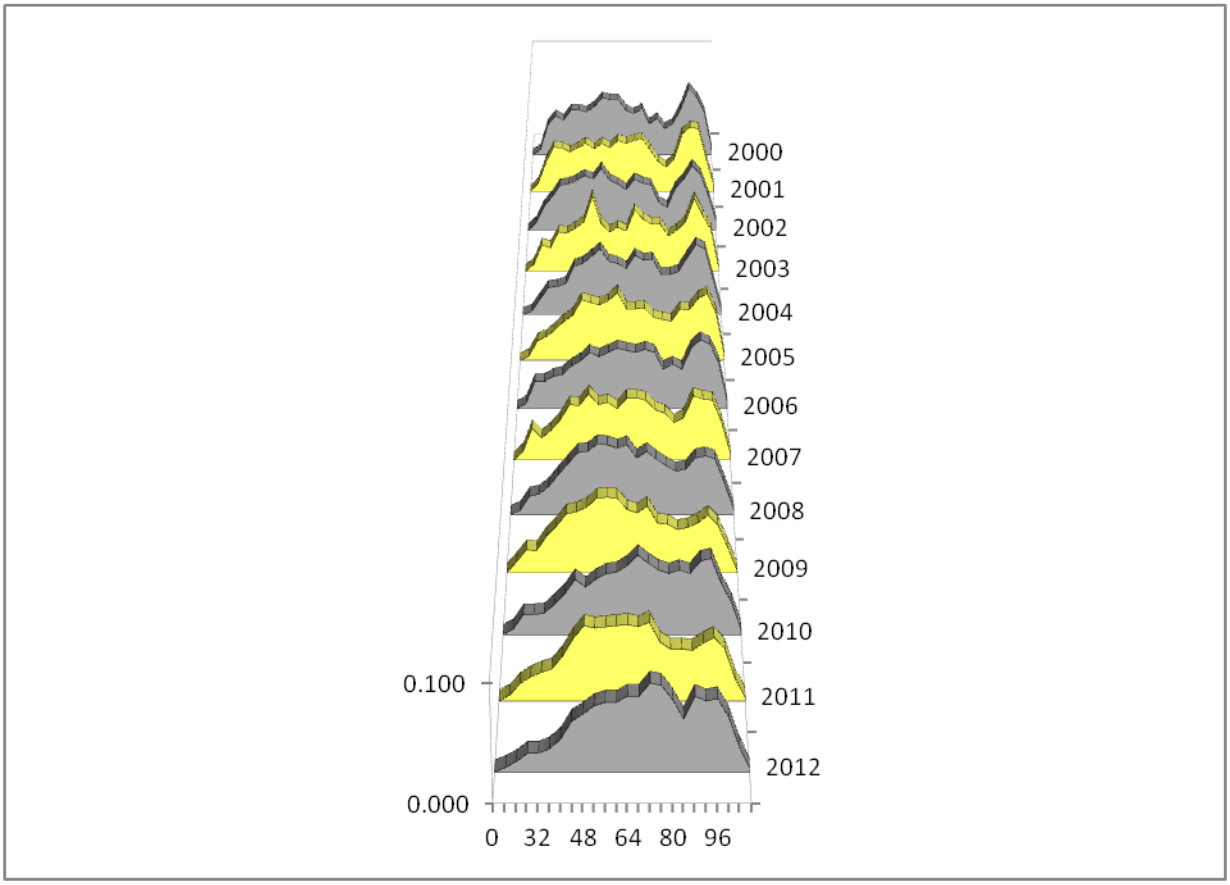


Figure 29. Timeseries of survey length compositions for Alaska skate on the EBS shelf.

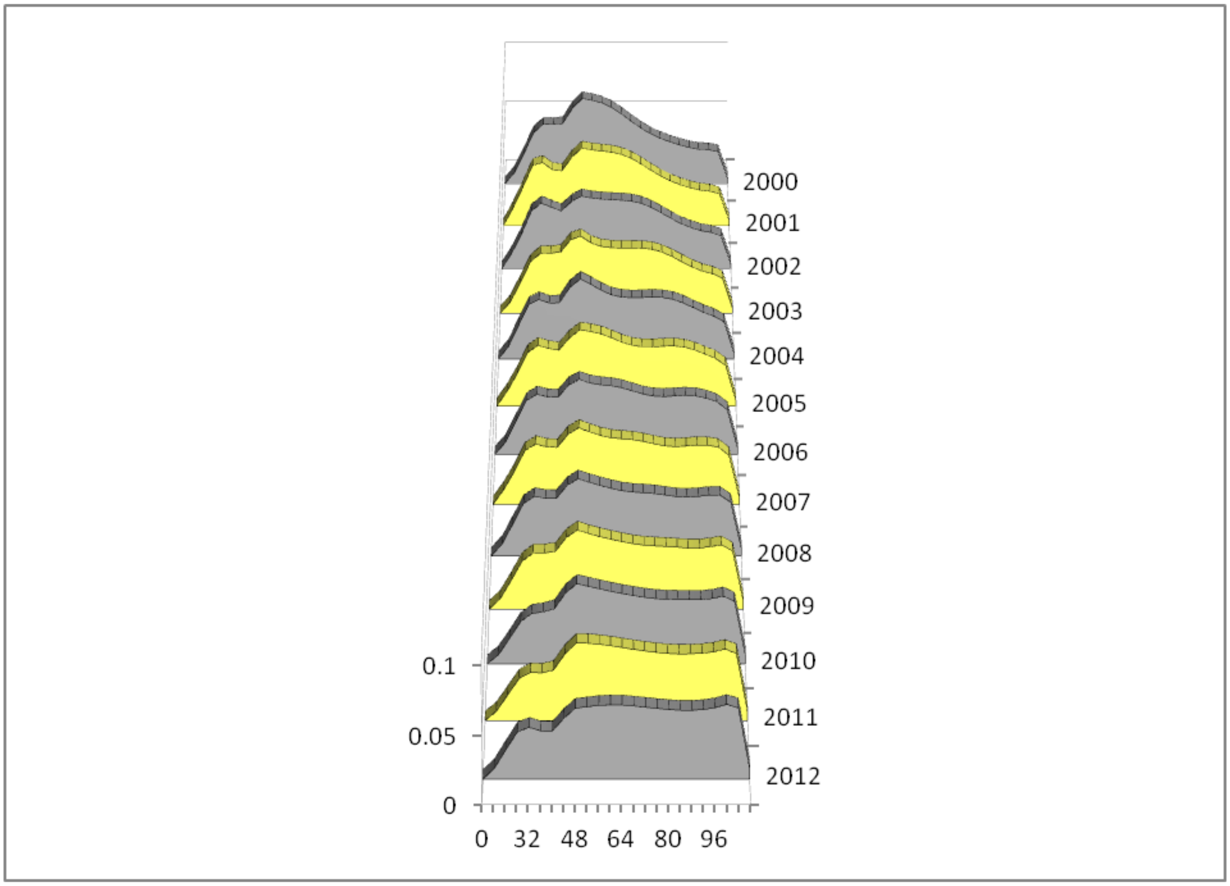


Figure 30. Timeseries of model fits to the survey length compositions for Alaska skate on the EBS shelf.

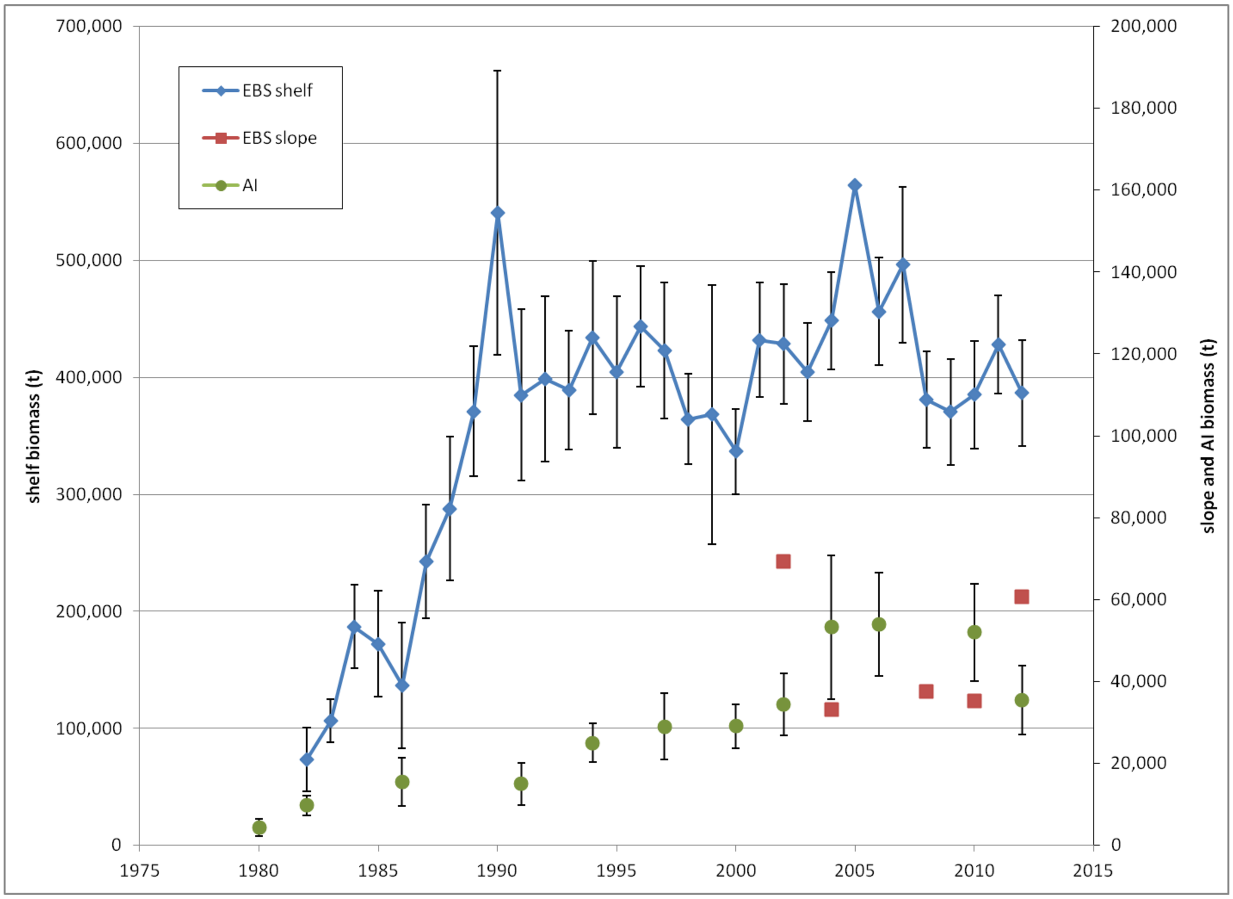


Figure 31. Aggregated skate biomass (t) and 95% confidence intervals estimated from RACE bottom trawl surveys in each of the three major habitat areas (1975 – 2012). Note that slope and AI estimates are much smaller and pertain to the secondary y-axis.

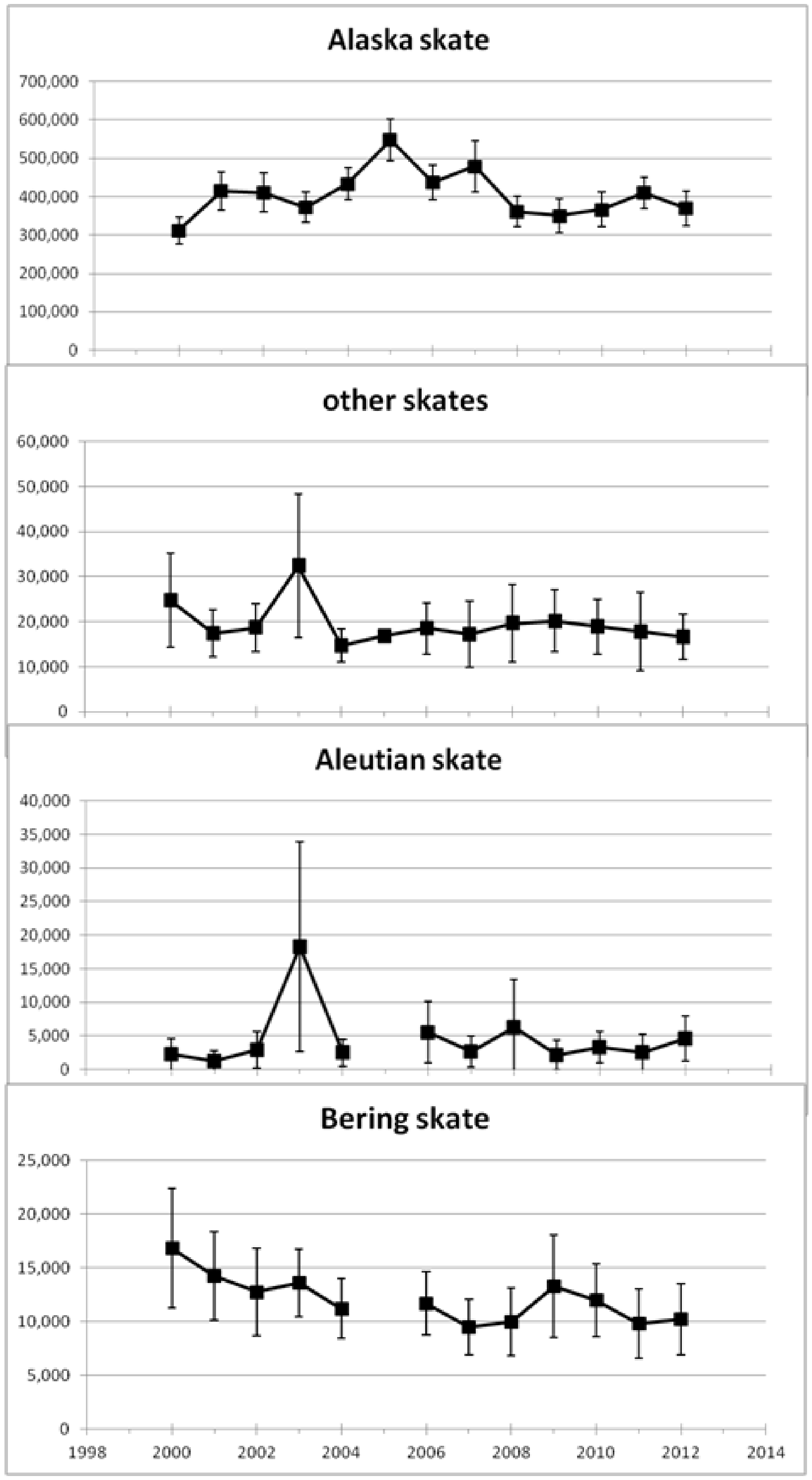


Figure 32. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS shelf. "Other skates" includes Aleutian and Bering skates and is included here to complement the skate management units. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass.

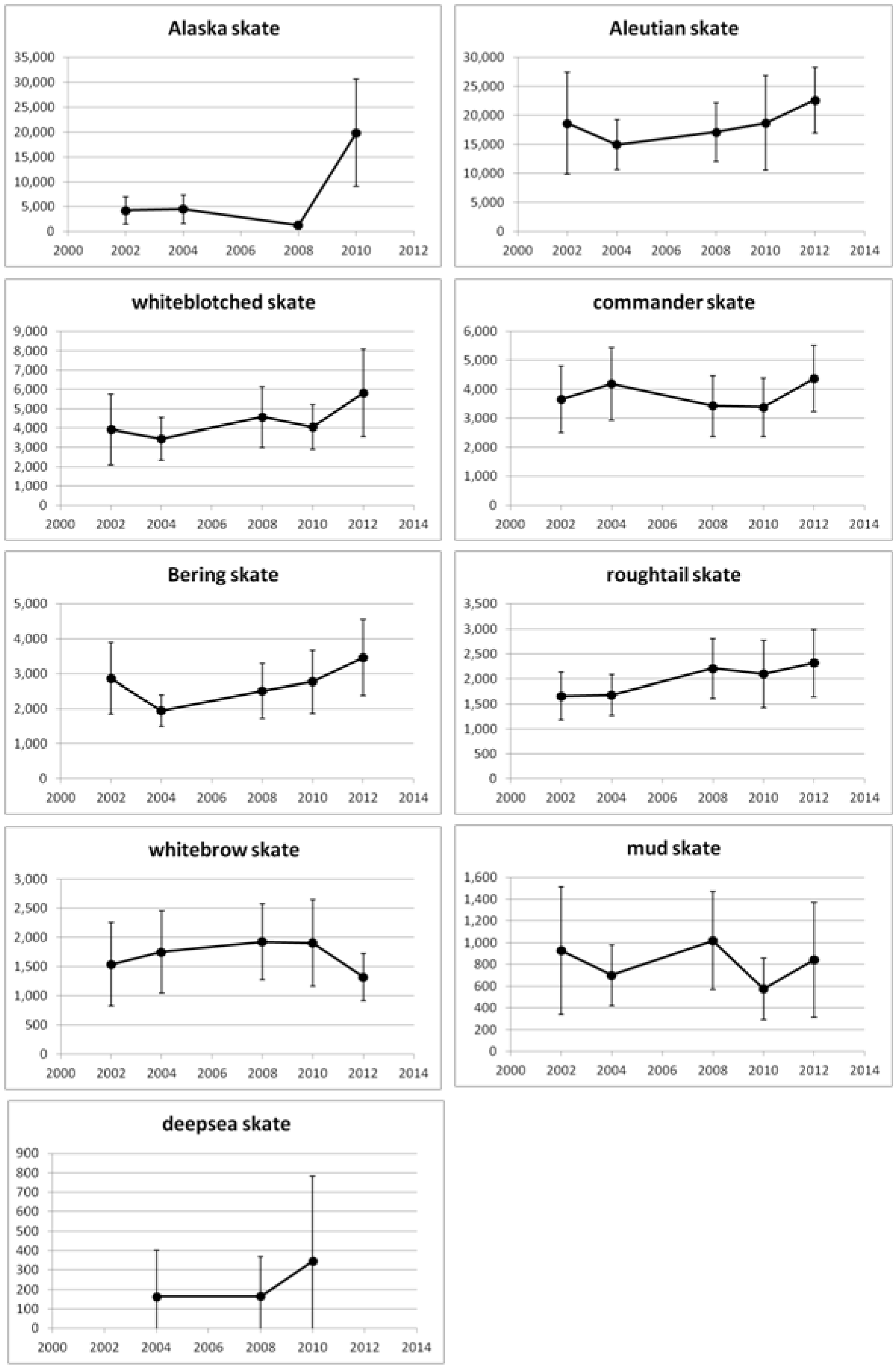


Figure 33. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS slope. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass.

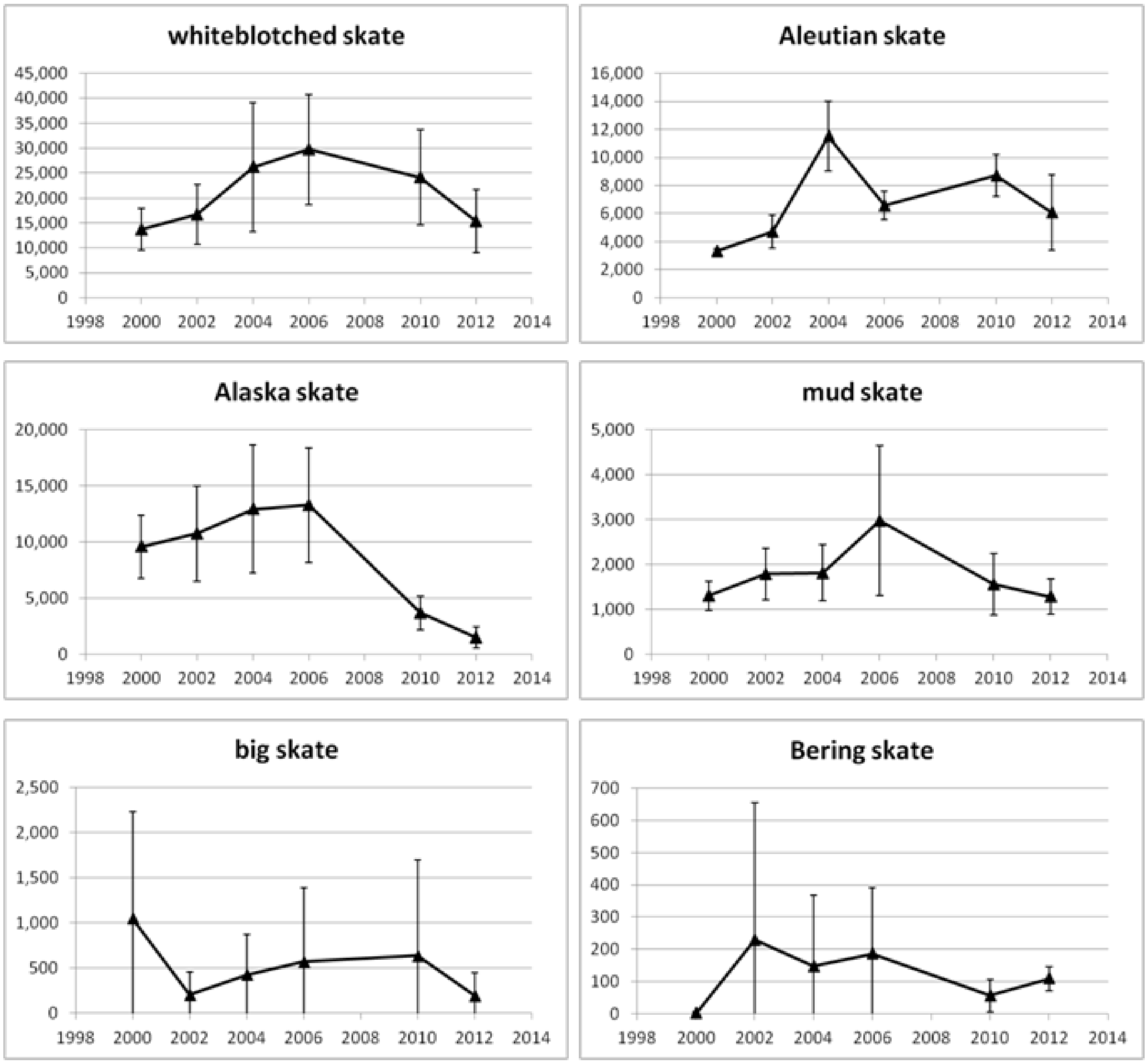


Figure 34. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates in the Aleutian Islands. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass.

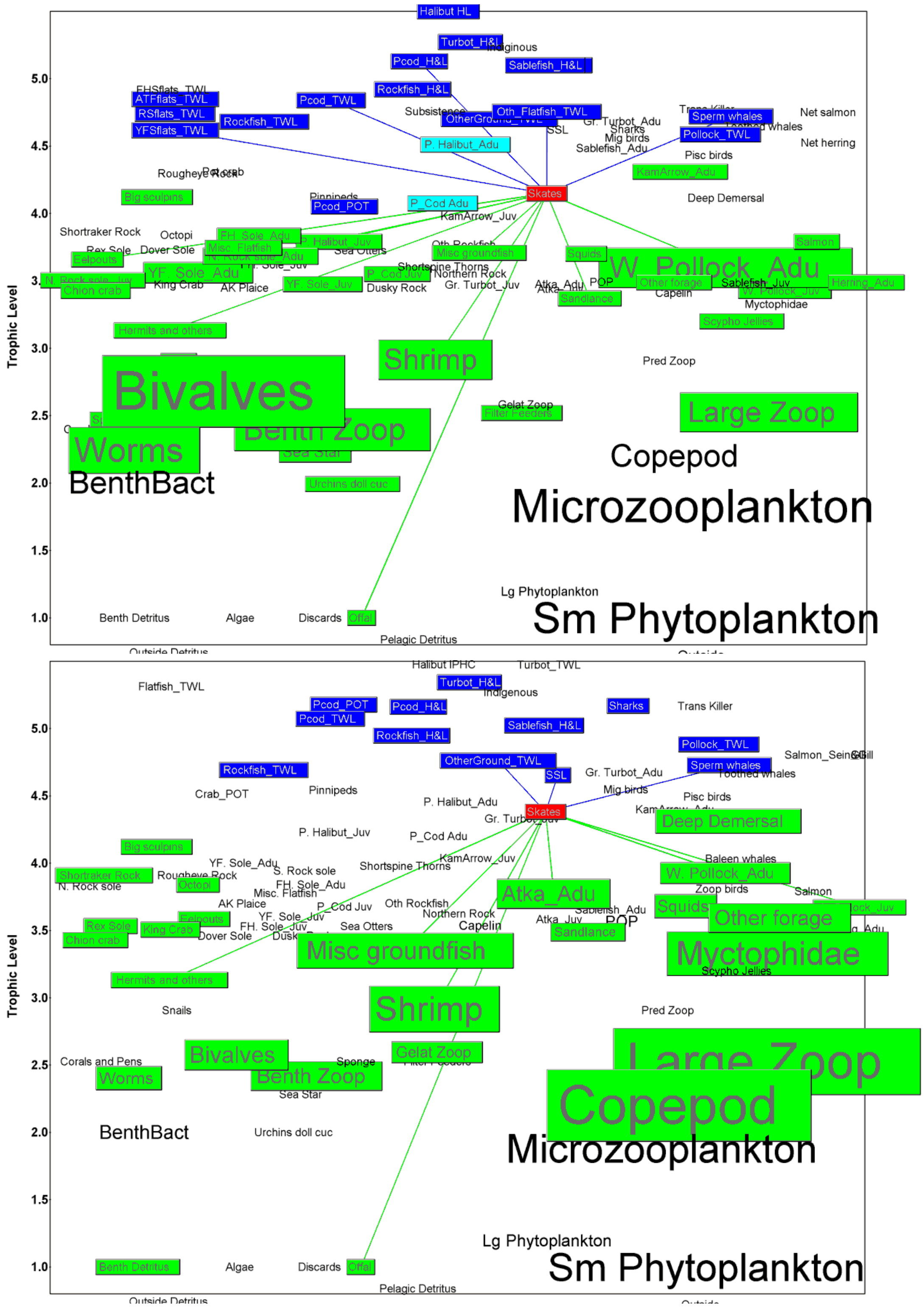


Figure 35. EBS (upper panel) and AI (lower panel) skate food webs derived from mass balance ecosystem models, with skate species aggregated in each area. Source: K. Aydin, AFSC, code available upon request.

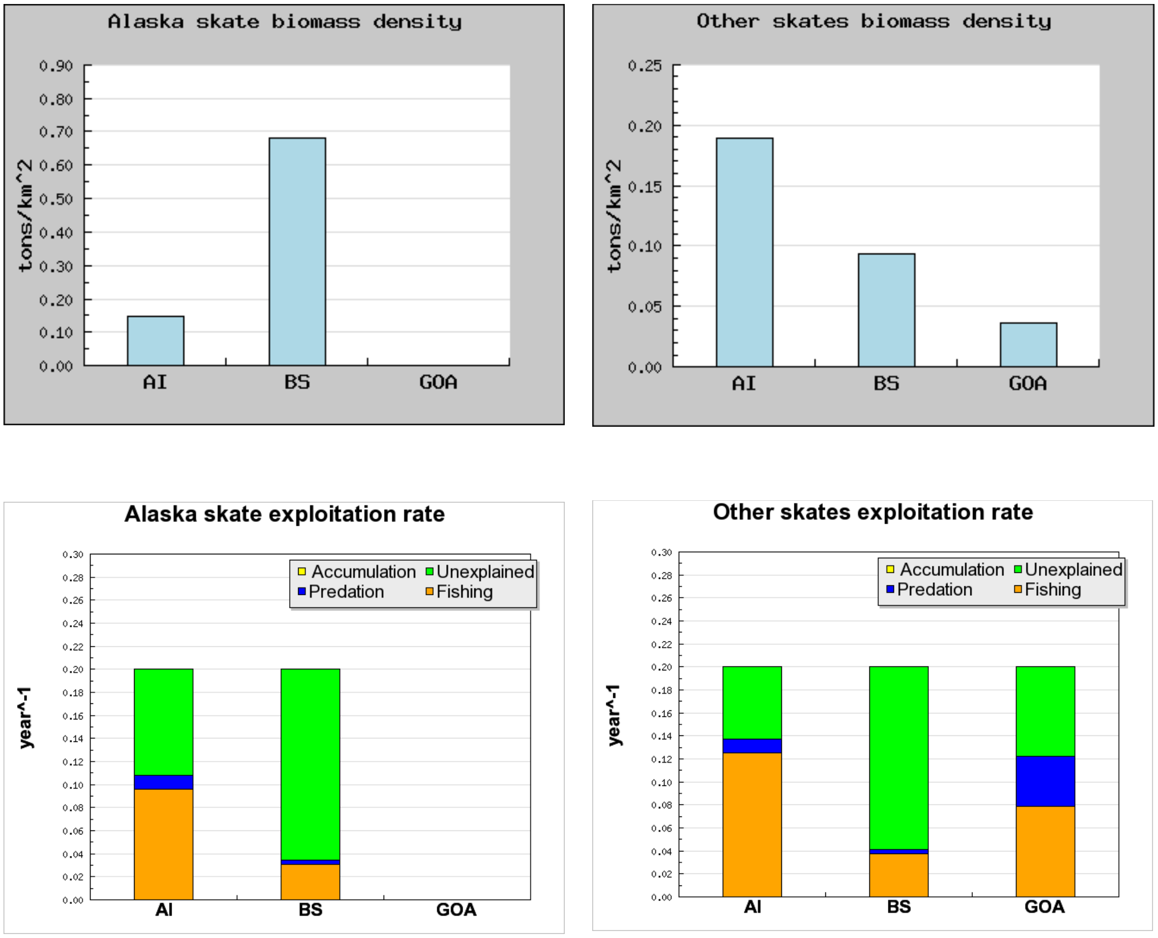


Figure 36. Comparative density (upper panels) and exploitation rate (lower panels) of Alaska (left panels) and all other *Bathyraja* (right panels) skates in the AI, EBS, and GOA (early 1990s, before fishery in GOA). (Alaska skates are a very small component of skate biomass in the GOA, and are therefore 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).

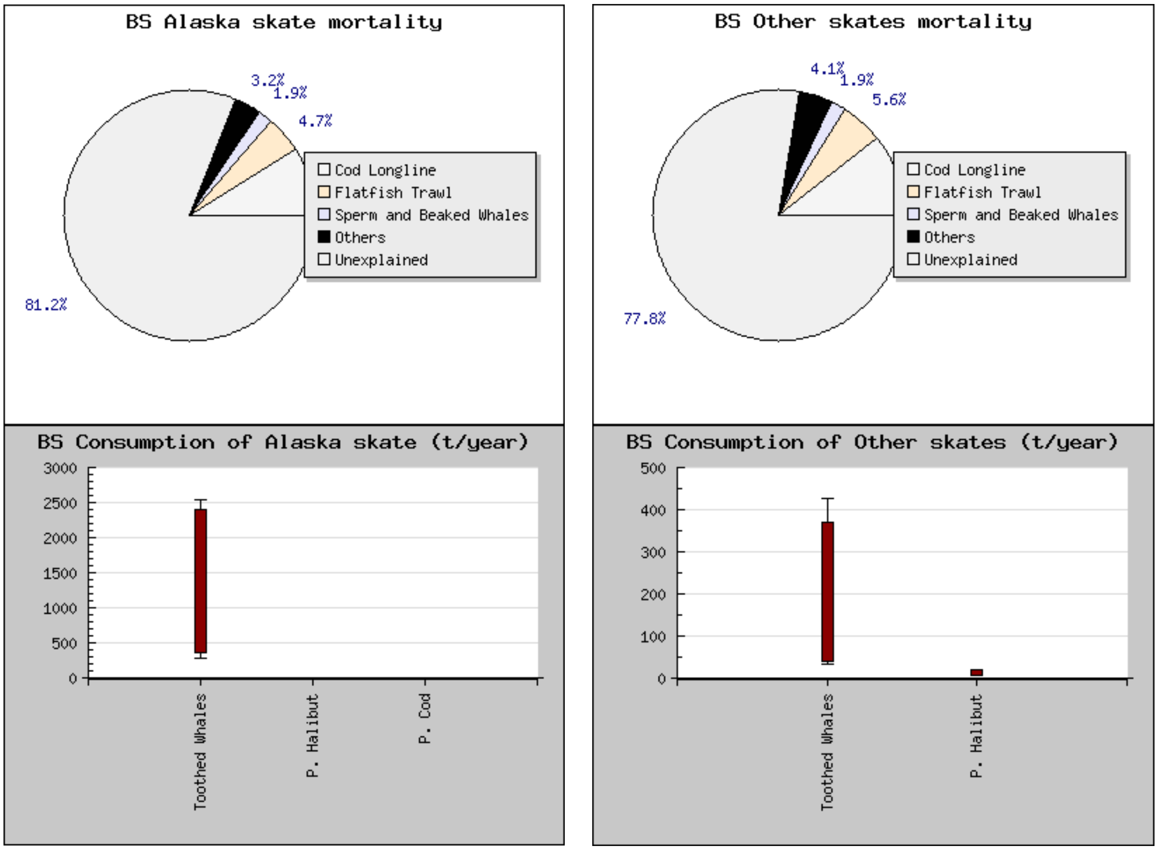


Figure 37. Mortality sources and consumption of skates in the EBS—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for EBS Alaska skates (left panels) and all other EBS skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

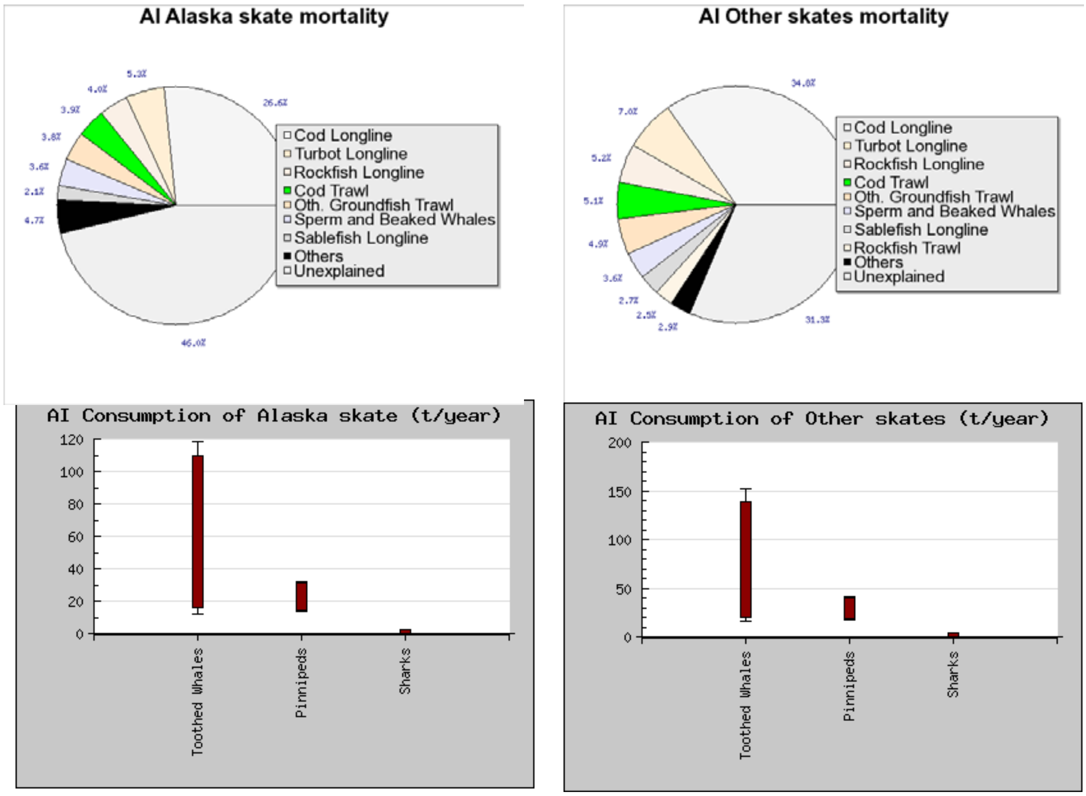


Figure 38. Mortality sources and consumption of skates in the AI—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for AI (former) Alaska skate (left panels) and AI Other Skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

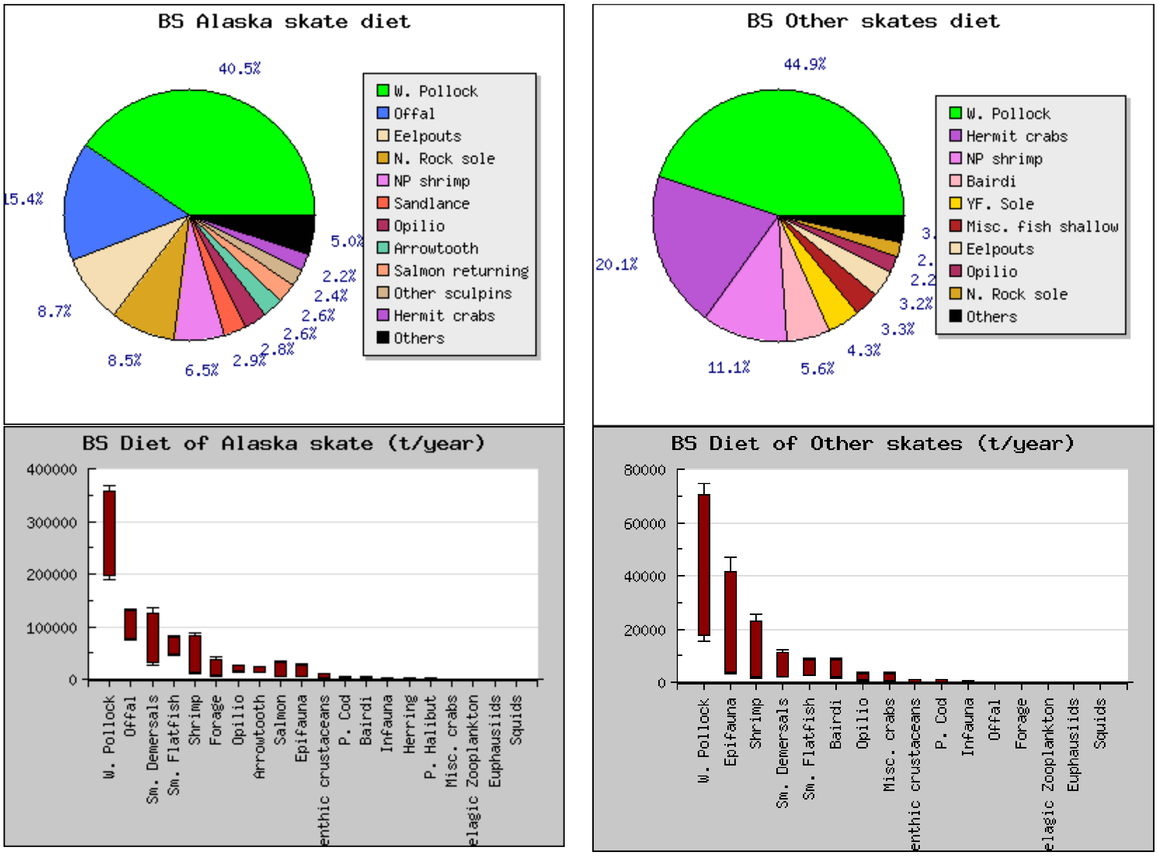


Figure 39. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for EBS Alaska skates (left panels) and Other Skates (right panels). Results were generated from stomach content collections occurring during RACE trawl surveys.

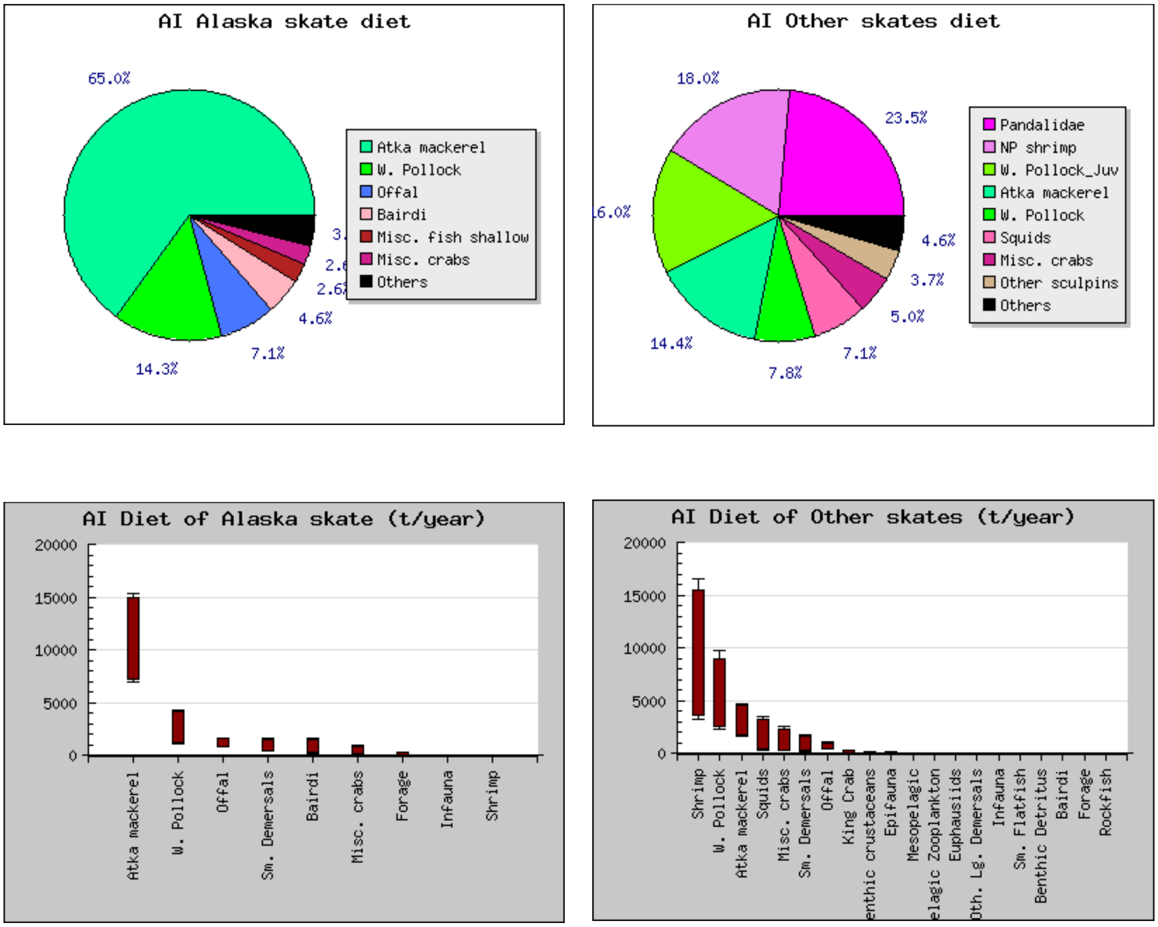
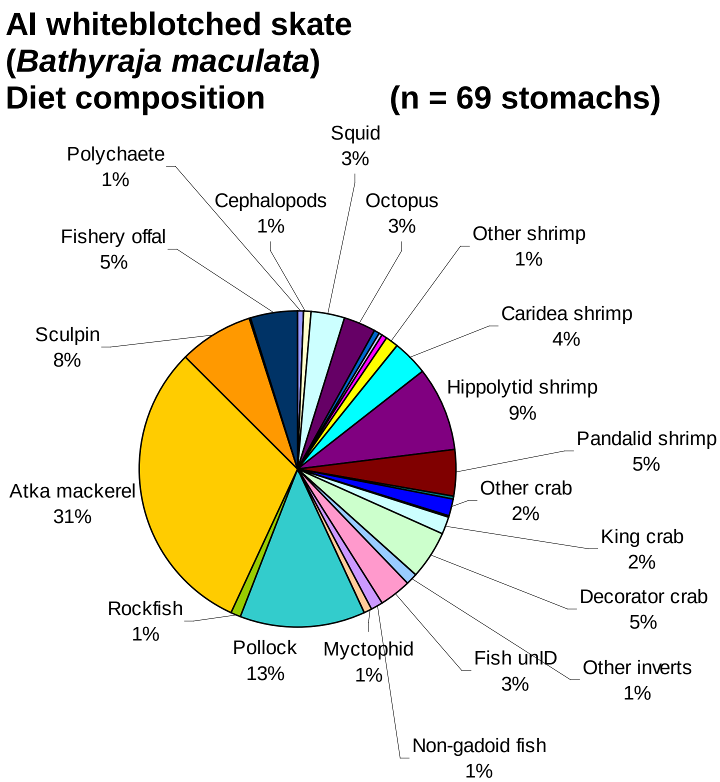


Figure 40. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for AI Alaska skates (left panels) and Other Skates (right panels). Consumption rates were estimated using published diet data from the Kuril Islands (Orlov 1998, 1999) and estimated prey densities.



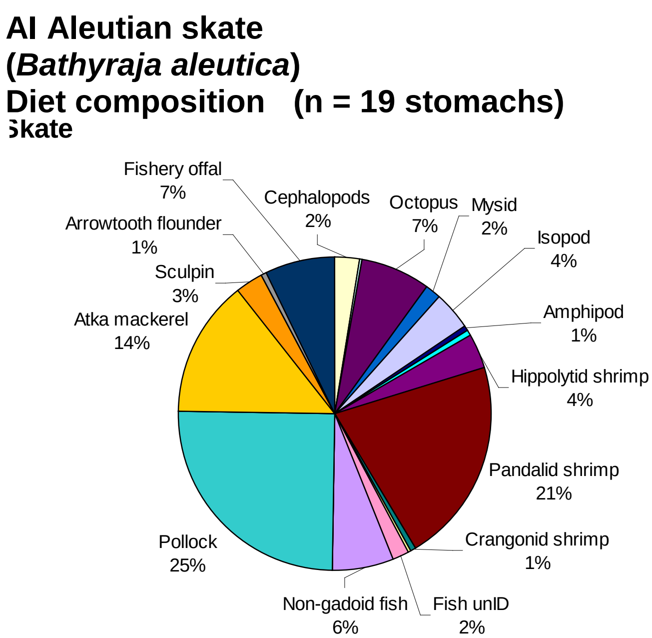


Figure 41. Diet composition (by weight) for the other two biomass-dominant skate species in the Aleutian Islands (which are included in the "Other Skates" group in the previous figure): whiteblotched skate (top) and Aleutian skate (bottom). Results were generated from stomach content collections occurring during trawl surveys, and are described in more detail in Yang (2007).

Appendix: Supplementary catch information

This section is provided to comply with the National Standard guidelines requirement for complete catch accounting. The appendix contains data concerning non-commercial catches of skates (in kilograms) and was obtained from the Alaska regional office.

agency	activity	2006	2007	2008	2009	2010	2011
ADF&G	BLUE KING CRAB POT					568	
	LARGE-MESH TRAWL					232	215
	PRIBILOF ISLANDS SURVEY - KING CRAB POT						2
IPHC	IPHC ANNUAL SURVEY					41,976	25,617
NMFS	2010 ALEUTIAN ISLAND BOTTOM TRAWL SURVEY					7,675	
	2010 BERING SEA BOTTOM TRAWL SURVEY					31,118	
	2010 BERING SEA SLOPE SURVEY					9,567	
	2010 NORTHERN BERING SEA BOTTOM TRAWL SURVEY					4,929	
	ALEUTIAN ISLANDS COOPERATIVE ACOUSTIC SURVEY			3			
	EASTERN BERING SEA BOTTOM TRAWL SURVEY						34,540
	GULF OF ALASKA BOTTOM TRAWL SURVEY						25
	LONGLINE	10,570	22,576	11,326	7,455	6,093	5,393