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.

In response to the 2013 review by the Center of Independent Experts (CIE), and as part of an ongoing process to improve skate assessments, the BSAI Alaska skate model has been completely reworked for 2014. The most fundamental change is a lengthening of the model time period: the preferred model's start year is 1950, all of the EBS shelf survey data from 1982-present are included, and a reconstruction of historical catches extends the catch time series back to 1954. The model was also simplified, especially in relation to the 2012 model revision. This report presents the existing (i.e. 2012) model, the author's preferred new model, and two additional models requested by the Plan Teams and the SSC. Selected results of all four models are included for purposes of comparison; full model results are included only for the author's preferred model.

Also new for 2014, the random effects (RE) model created by the survey averaging working group of the Joint Plan Teams was used to create biomass estimates for "other skates" and to make harvest recommendations for that group.

Summary of Changes in Assessment Inputs

Changes in the input data:

- The entire time series (1982-present) of EBS shelf bottom trawl biomass estimates for skates was included in the model.
- Reconstructed historical catch data beginning in 1954 were included in the model.
- Four length-at-age (LAA) datasets from the EBS shelf survey were included in the model (2003, 2007-2009); a LAA dataset from the longline fishery in 2005 was determined to be inadequate and was not included in the models.
- Weight-at-length data were obtained from a dataset generated during Alaska skate tagging activities on the EBS shelf survey during 2008-2010.

Changes in assessment methodology:

- For all Alaska skate models, growth parameters are estimated within the model.
- The "embryonic stage" (ages 0-3 in previous models) was eliminated from the model, so that in the model age-0 skates are free-swimming individuals in their first year outside of the eggcase.

- The recruitment function was returned to the original formulation, a Beverton-Holt curve with steepness fixed at 1.0; this effectively defines an average level of recruitment at all stock sizes.
- The maximum age was returned to its original value of 25 (from 30 in the 2012 model).
- Age selectivity was not included in the model.
- The random effects model was used to develop harvest recommendations for “other skates”.

Summary of results

1) The exploration of the alternative models suggests a discrepancy between the length composition data (survey and fisheries) and the LAA datasets. The largest sizes of skates observed in the LAA datasets are encountered in only very small numbers in the length composition data.

2) As a result of the phenomenon described in (1), there appear to be essentially two modeling “states”: one approach (“low biomass”) that slightly underestimates LAA at the oldest ages, but provides excellent fits to the length composition data and reasonable estimates of selectivity; and an approach (“high biomass”) that more closely fits the LAA data but provides unreasonable selectivity curves and poor fits to the length compositions. Biomass estimates for the “low biomass” state are approximately ½ that of the “high biomass” state.

3) All of the models suggest a depletion of skate biomass during the period 1950-1980, followed by a large recruitment event in the early 1980s and a return to the higher biomass levels that exist today. The recruitment event is consistent with the limited data available regarding average skate size and abundance during the time period.

4) The preferred model is of the “low biomass” type described in (2) above, as are the two alternative models (but not the existing 2012 model).

5) The author’s preferred model yields an OFL that is approximately 25% higher than the OFL in 2014. The RE model-based OFL for “other skates” is similar to the 2014 OFL.

Alaska skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	*0.13*	*0.13*	**0.13**	0.13
Tier	*3a*	*3a*	**3a**	3a
Projected total (age 0+) biomass (t)	*603,520*	*579,785*	**528,391**	498,957
Female spawning biomass (t)				
Projected	*185,076*	*178,762*	**115,490**	112,195
$B_{100\%}$	*266,810*	*266,810*	**186,923**	186,923
$B_{40\%}$	*106,724*	*106,724*	**74,769**	74,769
$B_{35\%}$	*93,384*	*93,384*	**65,423**	65,423
F_{OFL}	*0.113*	*0.113*	**0.090**	0.090
$maxF_{ABC}$	*0.098*	*0.098*	**0.077**	0.077
F_{ABC}	*0.098*	*0.098*	**0.077**	0.077
OFL (t)	*32,381*	*30,278*	**39,883**	37,343
maxABC (t)	*28,282*	*26,444*	**34,389**	32,199
ABC (t)	*28,282*	*26,444*	**34,389**	32,199
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

other skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	*0.1*	*0.1*	**0.1**	0.1
Tier	*5*	*5*	**5**	5
Biomass (t)	*94,684*	*94,684*	**96,923**	96,923
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)	*9,468*	*9,468*	**9,692**	9,692
maxABC (t)	*7,101*	*7,101*	**7,269**	7,269
ABC (t)	*7,101*	*7,101*	**7,269**	7,269
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

aggregate harvest recommendations for the BSAI complex

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
OFL (t)	**41,849**	39,746	**49,575**	47,035
ABC (t)	**35,383**	33,545	**41,658**	39,468

Responses to SSC and Plan Team Comments on Assessments in General

Plan Team September 2014: "The Teams recommend that stock assessment authors calculate biomass for Tier 5 stocks based on the random effects model and compare these values to status quo."

> *Response*: The random effects model was used to generate biomass estimates and harvest recommendations for "other skates". The results were compared to the 3-survey average using a table and several figures.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC October 2014: "The SSC supports the Plan Team recommendation that the last accepted version of the model (2012) be included in November as a base model for comparison with the author's preferred model from among the new four alternative models. The SSC requested that the author also include two other models in November: (1) Model 3 (the model with logistic selectivity) and (2) a model with a more recent start date but prior to 1989 (e.g. one possibility is starting around the regime shift in 1977)."

> *Response*: The existing (2012) model was run with updated data and included in this report. In addition two alternatives to the new base model were included: 1) selectivity fixed to be asymptotic and 2) 1977 start year instead of 1950.

General Introduction

<u>Contents of this report</u>

Because two different assessment methodologies are used for skates, this report deviates somewhat from the format of other Stock Assessment and Fishery Evaluation (SAFE) documents. The report contains the following sections:

1) General introduction for all Bering Sea and Aleutian Islands (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

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

Skates (family Rajidae) are cartilaginous fishes related to sharks. At least 15 species of skates in four genera, *Raja*, *Beringraja*, *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.

The species within the skate assemblage occupy different habitats and regions within the BSAI Fishery Management Plan (FMP) area (Fig. 1). In this assessment, we distinguish three habitat areas: the eastern Bering Sea (EBS) shelf (< 200 m depth), the EBS slope (> 200 m depth), and the Aleutian Islands (AI) region (Fig. 2). Within the 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. 3; Stevenson et al. 2006). The EBS shelf skate complex is dominated by a single species, the Alaska skate (*Bathyraja parmifera*)

(Table 2 & Fig. 2). The Alaska skate is distributed throughout the EBS shelf habitat area (Fig. 4), 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 (Table 2 & Fig. 5).

While skate biomass is much higher on the EBS shelf than on the slope (Table 2 & Fig. 6), skate diversity is substantially greater on the EBS slope (Fig. 2). The dominant species on the EBS slope is the Aleutian skate *B. aleutica* (Table 2 & Fig. 7). A number of other species are found on the slope in significant numbers, including 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, butterfly skate *Bathyraja mariposa* and leopard skate *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. 2). The whiteblotched skate is found primarily in the eastern and far western Aleutian Islands (Fig. 8). 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.

Management units

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 mainly dependent on the distribution of and limitations placed on target fisheries.

Stock structure

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 (Fig. 9) 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. 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 incidentally-caught large skates occurs, indicative of their market value.

Bycatch and discards

Skates are caught incidentally in substantial numbers in BSAI fisheries (Tables 3-4 & Fig. 12). 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 5). The catch of skates in pollock fisheries has increased in recent years, possibly because the fisheries are targeting pollock closer to the bottom. In this assessment, "bycatch" is interpreted as incidental or unintentional catch regardless of the disposition of catch – it can be either retained or discarded. We do not use the Magnuson Act definition of "bycatch," which always implies discard. When caught as bycatch, skates may be discarded (and may survive depending upon catch handling practices) although skates caught incidentally are sometimes retained and processed. 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 historically experienced the highest incidental skate catch rates in the BSAI, but in recent years the catch in area 509 has increased and 509 has the highest catches in some years (Table 6 & Fig. 12). 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 BSAI Alaska skate population model has been used since 2008 for making harvest recommendations. The model was substantially revised in 2012; the main benefit of the revised model was a closer fit to the length-at-age (LAA) data. However aspects of the model, e.g. fits to some of the length composition data, remained problematic. The model was reviewed by the Center for Independent Experts (CIE) in May 2013 as part of their review of non-target assessments conducted by the Alaska Fisheries Science Center (AFSC). The reviewers concluded that they had insufficient time to properly review the Alaska skate model, but did offer some comments. The reviewers noted some problems such as fits to the length composition data, and were unanimous in stating that the model should include the EBS shelf bottom trawl survey time series. That suggestion formed the basis of the modeling approach described in this report.

The 2014 model revision was guided by a conceptual approach with the following aspects:

1) *Determinate growth*: Several features of the data suggest that Alaska skate growth either slows dramatically or stops altogether at older ages. A strong size mode is observed in many of the Alaska skate length compositions at approximately 100 cm, and the proportion of skates at larger sizes decreases abruptly. Skates larger than 100-104 cm appear to be rare in the population. These data suggest that there is an accumulation of large skates in the population that occurs as skates get older but do not grow appreciably in size. All of the growth parameters were estimated within the model, but starting values were chosen and model development was guided assuming determinate growth.

2) *Large recruitment event*: Earlier versions of the model avoided using the full EBS shelf survey time series because a dramatic increase in skate biomass during the 1980s was difficult to explain and seemed counter to the equilibrium life history strategy assumed for skates. In preparation for the model revision, the available data were explored. Although length data for skates do not exist prior to 1999, it was possible to estimate mean weight of captured skates and mean numerical CPUE for survey hauls using the same net configuration from 1975 to 2013. These data (not included in this document but available) suggest that the increase in skate biomass during the 1980s resulted from both an increase in the number of skates AND the mean size of skates, both

of which increased dramatically. This is consistent with a major recruitment event occurring over a small number of years. The data are still being explored, but this apparent recruitment event occurred at approximately the same time as a major ecological regime shift in the late 1970s and may be related to it. Alaska skates have a long (approximately 3.5 years) embryonic development time during which they are growing inside eggcases deposited on the ocean floor, and the duration of the embryonic stage appears to be highly dependent on temperature (Hoff 2007). It may be that fluctuations in development time during this time of environmental change caused the emergence of multiple year classes from their eggcases at the same time. An alternative or additional explanation is that survival of young skates was enhanced by environmental conditions. The development of the model was guided by the assumption that the model should demonstrate a large recruitment event in the late 1970s and/or early 1980s

3) *Simplification*: The model was also developed with an aim towards simplifying it where appropriate. One aspect of this was to use a simpler approach to the stock-recruit function, which is described below. Another aspect was to eliminate the embryonic development period from the model. All previous versions of the model included the embryonic period, and used knife-edged age selectivity to define those ages (0-3.5) where skates were in eggcases and unavailable to either the survey or fisheries. The embryonic period was included because it seemed important for linking year classes to spawning stocks. However there is essentially no relationship between spawning stock size and recruitment (and in earlier versions of the model, very little contrast in spawning stock size). In addition, the inclusion of knife-edged age selectivity seemed to create problems inside the model. Therefore, all versions of the 2014 modeling process assumed that age-0 skates are those that have recently emerged from eggcases and are free-swimming individuals. Age selectivity was effectively removed from the model by specifying an age-selectivity function where all ages were fully selected, and selectivity was only a function of length.

Data

Summary of data used in the Alaska skate model

source	data	years
AKRO Catch Accounting System	catch	2003-2014
KRO historical catch record	catch	1954-2002
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	biomass index	1982- 2014
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	length composition	2000-2014
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	2009-2013

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 (Table 7 & Fig. 13). These fisheries have different selectivities and the majority of catches occur in the longline fisheries. Retention of skates is high and discard mortality is assumed to be 100%; therefore all captured skates are assumed to be dead.

Four models were included in this report and are described below. Three of the models (1-3) included in this report used catch data from 1954-2014; one model (model 4) used catch data from 1977-2014. All data regarding Alaska skate catches rely to some degree on assumptions regarding the proportion of

Alaska skates in the total skate catch. The earlier data also rely on assumptions regarding removals by gear type:

- *1954-1996*: Reconstruction of skate catches relied heavily on two assumptions: 1) that the proportion of trawl vs. longline effort was represented by the proportion of yellowfin sole catch vs. Pacific cod catch, and 2) that the total catch of Alaska skates could be estimated by subdividing the catch of an "Other Species" group (skates, sculpins, sharks, and octopus) based on the proportion of skates in Other Species catches in the modern era (2003-2013) and the proportion of Alaska skates in recent trawl surveys (1999-2013).
- *1997-2013*: Skate-specific catches are available during the modern era from two sources: the Blend database (1992-2002) and the Catch Accounting System (CAS) maintained by the Alaska Regional Office (AKRO). Specific catch data for Alaska skate either do not exist or are unreliable, due to the difficulty of identifying *Bathyraja* species skates in longline fisheries. Therefore, the catches were partitioned based on survey species composition during 1999-2013 and the distribution of effort among the EBS shelf and slope and the Aleutian Islands (AI). The methodology is described in complete detail in Ormseth and Matta (2007).

Catch data for 2014 were available only through October 8, so the 2014 data are incomplete. To estimate the full 2014 catch, the average increase in reported catch from early October to the end of the year for the last five years was used to create a correction factor for the 2014 data.

<u>Fishery length compositions</u>
Fishery length compositions from 2009-2013 were included for both gear types. Length data for the Alaska skate were collected during 2007 & 2008 as a special project by fishery observers, but the datasets are incomplete. 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, and this change was fully implemented for 2009. Therefore, 2009 is considered the first year of reliable fishery length composition data for Alaska skate. Length data were aggregated into 4-cm bins and converted to proportions as for the survey data (Table 8). Sample size is discussed below.

<u>Survey biomass</u>
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, biomass estimates from only the EBS shelf survey are used in this model. Survey efforts on the EBS shelf began in the 1970s, but survey methodology was only standardized in 1982; as a result, the survey time series is considered to begin in 1982. Biomass estimates from 1982-2013 were included in the model (Table 9). Reliable skate species identification in the survey is only available starting in 1999. For each survey prior to 1999, total skate biomass estimates were partitioned into Alaska skate and "other" skates based on the average proportion (0.95) of Alaska skate in the 1999-2013 surveys. The modeling software employs the coefficient of variation (CV) as the standard deviation (s) associated with each estimate. For the estimates prior to 1999, the value of s for the entire skate complex was used.

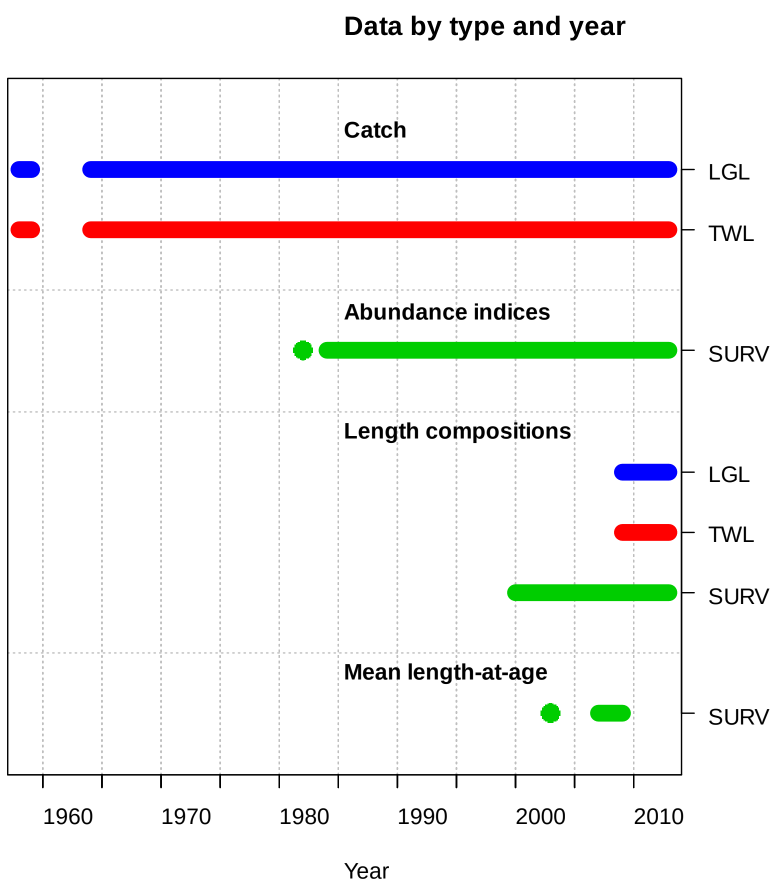
<u>Survey length compositions</u>
Length composition data from the EBS shelf survey were available from 2000-2013 (Table 10). The survey takes length measurements for every skate in each haul. The haul-specific data are then weighted by the number of skates in each haul to produce an estimate of numbers at length for the entire EBS population. The length data were aggregated into 4-cm bins and converted to proportions for inclusion in the model. Sample size is discussed below.

<u>Length at age</u>

Four LAA datasets from the years 2003 (N=182), 2007 (N=237), 2008 (N=165), and 2009 (N=330) were included in the model. Age was determined through examination of annual growth rings in vertebral thin sections following hatching from the eggcase. All four datasets used vertebrae collected during the EBS shelf survey. The 2003 dataset was generated during a graduate student project (Matta 2006); the remaining datasets resulted from production ageing at the AFSC. A dataset generated from vertebrae collected during the 2005 longline fishery and included in earlier model versions was considered to be flawed (due to a poor sampling design) and was eliminated from the model.

Sample size

Appropriate sample size (N) for the length compositions and LAA data can be difficult to determine. Previous versions of the model used N=100 for all length compositions. After exploring the literature, including other SAFE reports conducted by the AFSC, and through discussions with other assessment authors, the following approach was taken regarding sample size. In general, hauls are considered to be the sampling unit rather than individual length measurements. The total number of hauls each year varies little for the survey, so N=200 was used for all survey length compositions. In the fisheries, a large number of hauls is sampled, so the square root of the number of hauls was used for input N to avoid overemphasis on fishery length compositions. For the LAA data, the actual number of individuals was used as input N. Some exploration of the effect of changing input Ns was performed: for example, fishery length composition N was set equal to the survey N. Unless very large changes were made, these changes had only minor influence on the model.



Summary of data sources included in all 4 model alternatives.

Analytic Approach

Model structure

The 2014 model revisions were conducted using Stock Synthesis 3 (SS3) assessment software[1] (Methot 2005, 2007). Stock Synthesis allows the flexibility to incorporate both age- and size-structured information in an age-structured model. In the models 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. In SS3 it is possible to differentially weight the likelihood components by specifying weighting factors (lambdas) in the control file. With one exception, the model alternatives presented here weight all components equally.

Numerous alternative models were explored during the 2014 revision process. Four models were presented to the Plan Team in September 2014; based on the resulting discussion and requests from the Plan Team and SSC the following models are included in this report:

- Model 1: Existing model with updated data (i.e. model used in the 2012 assessment).
- Model 2: Base version of new model, with features described below. **Author's preferred model.**
- Model 3: Base model with selectivity parameter 6 fixed for both fisheries and the survey, creating asymptotic selectivity curves. This model offered a contrast to the dome-shaped selectivity curves generated in the base model.
- Model 4: Base model (Model 2) starting in 1977 rather than 1950.

All of the models continued a number of assumptions used since the model was first created. The entire BSAI was treated as one homogenous area. Because growth and maturity patterns are similar for males and females, only one sex was specified. Spawning was assumed to occur at the midpoint of the year. No informative priors were used. It was assumed that parameters did not vary with season or year and were not influenced by environmental conditions. All parameters are listed in Table 11 and described in more detail below.

Parameters estimated outside the assessment model

Natural mortality (M)

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

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. Maturity was estimated directly from paired

[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]

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 previous models. Survey catchability was fixed at 1. 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.

Age selectivity

In contrast to earlier versions of the model, selectivity at age was not included in the model, i.e. all ages were fully selected and selectivity was solely a function of length.

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 through analysis data obtained during an Alaska skate tagging project conducted aboard EBS shelf surveys 2008-2010 (O. Ormseth, unpublished data). Parameters were not significantly different between sexes, so data were combined. For sexes combined, *a* was estimated as 9.0×10^{-6} and *b* was estimated as 2.9617 (Figure 14; $r^2 = 0.93$, N = 1,515).

Spawner-recruit parameters

The 2012 version of the model (Model 1) used a survivorship function developed for low-fecundity species rather than a traditional stock-recruit function. Upon further review, it was decided that insufficient data were available to parameterize the more complex survivorship function. All of the 2014 models returned to the approach used in the original model, where a Beverton-Holt function is specified and steepness fixed at 1.0 to create a mean level of recruitment. All models used a fixed σ_R value of 0.4.

Parameters estimated inside the assessment model

Growth parameters

An analysis by Matta (2006) suggested that a Gompertz growth model best fit the length-at-age data for Alaska skate. As in the 2012 model, the Gompertz growth function was approximated in SS3 by choosing the Schnute 4-parameter growth model option (Schnute 1981). 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 τ_1 and τ_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. All growth parameters were estimated within the model, as were the two uncertainty parameters (CV of LAA at ages τ_1 and τ_2).

Length selectivity

For models 1, 2, & 4 all length selectivity parameters were estimated within the model. All models used a double-normal selectivity function recommended in the documentation for SS3 (Methot 2012). 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. In model 3, p6 was fixed so that the selectivity function was asymptotic. Selectivity parameters are summarized in Table 11. All bounds were the default values specified in the SS3 documentation.

Spawner-recruit parameters
The natural log of unfished recruitment (R_0) was estimated within the model. In addition, recruitment deviations were estimated for 1950-2013; in SS3 each deviation is considered a separate parameter.

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

Results

Model Evaluation

Model evaluation criteria

A summary of model fit comparisons is located in Table 12. The models were evaluated using the following criteria:

1) The standard deviation of the parameter estimates was converted to CV; a lower CV indicated a better fit.
2) Model fit to the survey data was conducted by comparing root mean squared error (RMSE), the average standardized residual, the correlation between observed and predicted values and the proportion of survey biomass estimates where the model estimate was within the 95% confidence interval (CI) of the observed value. For RMSE and the average residual, lower values indicated a better fit. For the correlation and the proportion of model estimates within the CIs, higher values indicated a better fit.
3) Comparison of effective sample sizes (N_{eff}) for length compositions, with higher N_{eff} indicating better fit to the data.
4) Comparison of effective sample sizes (N_{eff}) for LAA datasets, with higher N_{eff} indicating better fit to the data.
5) Visual inspection of model fits to length compositions and LAA data.
6) Reasonable estimates of fishery length selectivity parameters.
7) Reasonable estimates of unfished recruitment and recruitment variability as well as consistency with the conceptual approach described in the overview.

Evaluation of model criteria

1) The CV of parameter estimates varied among the models. Models 1-3 all had an equivalent number of lowest CVs; model 4 had none (Table 12).
2) All of the models showed good fits to the survey data. Model 1 had the lowest RMSE; of the 3 “new” models, Model 2 had the lowest RMSE. Model 2 also had the lowest average standardized residual. Model 2 had the highest proportion of model fits within the CI, while Model 4 had the highest correlation between observations and predictions.
3) Effective Ns for the length compositions were much greater than one for all the models. The highest effective Ns were observed in Models 2 & 4. Effective Ns for Model 1 were generally low relative to the 3 new models.
4) For the LAA data, Model 2 had the highest effective N.

5) Visually, Model 2 had the best fits to the length composition data (Figure 15), although the fit for models 2-4 were very similar. Model 1 had noticeably worse fits to the length composition data; Model 1 did not fit the mode at large sizes in the longline and survey length compositions. All of the models fit the LAA data well (Figures 16 & 17), although all 4 slightly underestimated LAA at larger.
6) There was a substantial difference in the selectivity curves produced by the models (Figure 18). Models 2 & 4 produced moderately descending limbs for both fisheries and the survey. The decrease in selectivity at larger sizes varied by fleet, with final selectivity ranging from 0.5 to 0.8. In contrast, Model 1 produced an unrealistic degree of dome-shaped selectivity, with selectivity rapidly descending to zero above 100 cm. Model 3 was parameterized so that selectivity was asymptotic.
7) Models 2-4 provided different estimates of recruitment (Figure 19), but all of the estimates were consistent with a large recruitment event in the early 1980s. In contrast, the older model configuration (Model 1) included no such event. The recruitment event in Models 2 & 3 occurred over several years, while in Model 4 there was a single year of very high recruitment.

Discussion of model evaluation and designation of preferred model

The new base model (Model 2) provided the best overall fits when the data are considered as a whole (Table 12 & Figs. 15-26), produced results that are consistent with the conceptual approach, and is the author's preferred model. There are two potential issues with Model 2. First, as is the case for the other "low biomass" models, LAA was slightly underestimated which may lead to an underestimate of spawning biomass. However, particularly for the 2008 and 2009 datasets, the underestimate was small. In addition, as described earlier, closer fits are only possible if the selectivity function is allowed to drop to zero. Essentially, the model can only fit the larger sizes in the LAA dataset by reducing the selectivity to an unrealistic level.

An additional issue is the estimation of descending limbs for the selectivity functions. Examination of the distribution of Alaska skate by size in the BSAI (Figure 27) suggests that the fisheries and survey may indeed have limited access to larger skates. Alaska skates display a marked ontogenetic movement from nursery areas on the slope in towards the inner domain of the EBS shelf. They reach the innermost shelf at approximately the age of maturity, at which time they appear to either disperse or return to the slope for spawning. Thus, the largest skates are generally encountered either along the slope or in the innermost domain. The variation in the descending limbs is consistent with this pattern. The trawl fishery, which is conducted mainly in the middle domain where few large skates are found, has the biggest decrease. The longline fishery, which occurs mainly in the outer domain and along the slope, has only a small decrease in selectivity at large sizes. The survey is intermediate to the two fisheries.

Time series results

Results presented below are for the preferred model, Model 2.

Definitions

Biomass is shown as total (age 0+) biomass (metric tons; t) of all Alaska skates in the population, and as spawning biomass (for both sexes; t). Recruitment is reported as the number (in thousands) of Alaska skates at age 0. The CV is included for spawning biomass and age-0 recruits.

<u>Biomass time series</u>
Time series of total biomass and spawning biomass estimates from 1950-2013 are reported in Table 13. Spawning biomass is also shown in Figure 28. The model suggests that the skate population declined beginning in the 1950s, with the steepest decline during the 1970s. The population then rebounded dramatically during the 1980s and has been relatively stable since 1990. Table 14 shows a comparison between the existing model (Model 1) and the new preferred model (Model 2). Unfished biomass was higher in the existing model, but 2014 biomass was fairly similar.

<u>Recruitment</u>
Time series of age-0 recruitment are reported in Table 13 and Fig. 29. The model suggests that a period of increased recruitment occurred between the years 1980-1984, with the highest level of recruitment in 1982. The model also estimates the recruitment was low during the 2000s but has rebounded since 2010. In the comparison between Model 1 & Model 2 (Table 14), unfished and 2014 recruitment was similar but the high recruitments during the early 1980s were not present in the Model 1 model.

<u>Exploitation rate</u>
A time series of exploitation (catch/total biomass) is given in Table 15. These rates suggest that skates experienced the greatest fishing pressure in the 1970s and that most of these removals occurred in the trawl fishery. Exploitation rates have been fairly stable (~0.4-0.5) since the 1990s.

Harvest recommendations

Alaska skate harvest recommendations

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	*0.13*	*0.13*	**0.13**	0.13
Tier	*3a*	*3a*	**3a**	3a
Projected total (age 0+) biomass (t)	*603,520*	*579,785*	**528,391**	498,957
Female spawning biomass (t)				
Projected	*185,076*	*178,762*	**115,490**	112,195
$B_{100\%}$	*266,810*	*266,810*	**186,923**	186,923
$B_{40\%}$	*106,724*	*106,724*	**74,769**	74,769
$B_{35\%}$	*93,384*	*93,384*	**65,423**	65,423
F_{OFL}	*0.113*	*0.113*	**0.090**	0.090
$maxF_{ABC}$	*0.098*	*0.098*	**0.077**	0.077
F_{ABC}	*0.098*	*0.098*	**0.077**	0.077
OFL (t)	*32,381*	*30,278*	**39,883**	37,343
maxABC (t)	*28,282*	*26,444*	**34,389**	32,199
ABC (t)	*28,282*	*26,444*	**34,389**	32,199
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

OTHER SKATES – Tier 5 assessment

Data

Survey biomass

The biomass of the skate assemblage as a whole has increased since the early 1980s (Tables 16-20 & Figs. 30-33). 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. 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

Results of the random effects (RE) model for other skates varied by region (Table 21 & Fig. 34). For the EBS slope and AI surveys, the RE estimates showed less annual variability than the survey estimates but greater variability than the 3-survey running average that has historically been used for harvest specifications. For the EBS shelf survey, the RE model was only able to fit an average biomass value that did not vary across the entire 1999-2014 time series. This may have been due to the lack of a trend in the relatively short timeseries, and/or the high interannual variability and CVs in the early part of the time series. The RE model for the EBS shelf was run using a number of different configurations (e.g. truncating the dataset to remove the early values, changing the initial survey estimates, and modifying the CVs). All configurations had the same result. The RE model estimate was very close to the mean of all the survey biomass estimates. The RE model results were determined to be reasonable and were aggregated to produce a BSAI-wide estimate for other skates for use in harvest recommendations.

Analytic Approach

Parameter Estimates

Natural Mortality (*M*)

There is a great deal of uncertainty regarding reliable estimates of *M* for the skate complex. This assessment used the value of *M*=0.1 that has been used consistently in the BSAI and GOA for skates.

Results

Harvest recommendations

other skate harvest recommendations				
	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	*0.1*	*0.1*	**0.1**	0.1
Tier	*5*	*5*	**5**	5
Biomass (t)	*94,684*	*94,684*	**96,923**	96,923
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)	*9,468*	*9,468*	**9,692**	9,692
maxABC (t)	*7,101*	*7,101*	**7,269**	7,269
ABC (t)	*7,101*	*7,101*	**7,269**	7,269
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a

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 that what was previous thought to be Alaska skate in the AI was likely the leopard skate. 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.

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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Tables

Table 1. Life history and depth distribution information available for BSAI 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, the last year in which all BSAI areas were surveyed within the same year.

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, 2011-2014*. All values are in metric tons except for retention rate.. 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. Source: Alaska Regional Office.

year	**skate complex OFL**	**skate complex ABC**	**skate complex TAC**	**skate complex catch**	**skate retention rate**
2011	37,800	31,500	16,500	23,748	24%
2012	39,100	32,600	24,700	24,968	29%
2013	45,800	38,800	24,000	27,260	29%
*2014**	41,849	35,383	26,000	*22,446*	*29%*

*2014 data are incomplete; retrieved October 8, 2014

Table 4. Estimated catch (t) of all skate species combined by BSAI area, 1997 - 2014*. Source: Alaska Regional Office.

	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	18,738	674	19,412
2004	21,993	905	22,897
2005	22,714	709	23,423
2006	19,568	1,033	20,601
2007	17,753	1,040	18,793
2008	20,469	1,422	21,891
2009	19,442	1,227	20,669
2010	16,515	1,403	17,918
2011	23,005	743	23,748
2012	23,873	1,095	24,968
2013	26,165	1,095	27,260
*2014**	*21,319*	*1,126*	*22,446*

. *2014 data are incomplete; retrieved October 8, 2014.

Table 5. Estimated catch (t) of all skate species combined by target fishery, 2003 – 2014*.. Source: Alaska Regional Office..

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	***2014****
Pacific cod	15,153	18,643	19,754	15,443	13,618	14,507	12,756	11,594	17,269	18,613	20,715	*17,290*
yellowfin sole	1,517	600	942	1,133	1,406	1,301	1,799	1,907	2,129	2,219	2,687	*1,619*
walleye Pollock	480	844	733	1,310	1,291	2,761	3,861	1,891	2,358	2,021	1,764	*813*
rock sole	549	530	437	932	1,005	569	955	1,221	713	654	530	*687*
Atka mackerel	92	149	140	144	155	179	185	247	269	511	345	*446*
IFQ halibut	267	283	130	83	20	1,370	0	25	10	48	339	*803*
Rockfish	73	24	31	37	75	65	92	53	108	101	236	*164*
flathead sole	631	1,199	848	855	770	664	362	301	112	75	205	*274*
arrowtooth flounder	104	65	127	281	81	298	193	185	122	207	184	*160*
Sablefish	64	13	27	124	63	42	131	117	138	46	112	*75*
Greenland turbot	222	137	170	121	176	69	209	369	370	360	51	*36*
Kamchatka flounder	0	0	0	0	0	0	0	0	93	101	49	*57*
Alaska plaice	0	0	0	1	0	1	1	5	36	8	42	*0*
other flatfish	30	80	44	7	64	2	14	2	3	3	0	*0*
BSAI total	**19,412**	**22,897**	**23,423**	**20,601**	**18,793**	**21,891**	**20,669**	**17,918**	**23,748**	**24,968**	**27,260**	***22,446***

*2014 data incomplete; retrieved October 8, 2014.

Table 6. Estimated catch (t) of all skate species combined by reporting area, 2003 – 2014*. Source: Alaska Regional Office.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	*2014 **
EBS												
508	0	0	0	0	0	0	0	0	6	0	0	*0*
509	2,046	2,261	3,349	3,571	3,655	4,096	5,027	2,832	6,272	6,174	8,283	*2,920*
512	25	205	15	0	0	33	16	13	7	161	50	*20*
513	2,765	2,831	4,013	2,668	2,324	2,052	2,503	1,862	3,085	1,812	3,414	*3,401*
514	279	67	196	221	445	83	134	78	150	1,585	229	*767*
516	133	409	242	253	399	489	576	664	256	780	971	*369*
517	2,901	3,015	3,703	2,442	2,186	2,502	3,207	2,849	2,760	3,304	4,753	*3,060*
518	25	6	16	12	5	459	57	49	26	21	54	*72*
519	262	501	295	262	154	317	76	147	334	200	196	*255*
521	8,977	10,341	8,490	8,365	7,128	7,770	6,187	6,622	8,696	8,033	7,178	*9,375*
523	309	329	243	283	333	242	264	396	267	1,076	883	*555*
524	1,016	2,027	2,153	1,493	1,123	2,427	1,396	1,003	1,147	728	154	*525*
530	0	0	0	0	0	0	1	0	0	0	0	*0*
EBS total	**18,738**	**21,993**	**22,714**	**19,568**	**17,753**	**20,469**	**19,442**	**16,515**	**23,005**	**23,873**	**26,165**	***21,319***
AI												
541	312	478	499	593	363	507	459	486	507	783	627	*899*
542	243	285	126	371	398	572	347	474	205	274	378	*178*
543	119	142	83	69	280	344	421	443	30	37	91	*50*
AI total	**674**	**905**	**709**	**1,033**	**1,040**	**1,422**	**1,227**	**1,403**	**743**	**1,095**	**1,095**	***1,126***
BSAI total	**19,412**	**22,897**	**23,423**	**20,601**	**18,793**	**21,891**	**20,669**	**17,918**	**23,748**	**24,968**	**27,260**	***22,446***

*2014 data incomplete; retrieved October 8, 2014.

Table 7. Reconstructed catch data used in the Alaska skate model, by year.

year	longline	trawl	year	Longline	trawl
1955	0	0	1985	1,443	4,045
1956	0	0	1986	1,301	3,675
1957	0	0	1987	1,062	3,006
1958	8	61	1988	1,443	4,287
1959	21	156	1989	588	1,752
1960	0	0	1990	688	2,009
1961	0	0	1991	6,246	1,372
1962	0	0	1992	12,484	2,803
1963	0	0	1993	8,998	2,020
1964	43	304	1994	10,468	2,350
1965	150	928	1995	10,961	2,461
1966	130	924	1996	9,305	2,089
1967	537	1,967	1997	13,059	2,932
1968	1,539	9,252	1998	14,100	3,178
1969	690	4,365	1999	10,288	2,318
1970	1,220	6,502	2000	13,362	3,055
1971	856	5,613	2001	14,244	3,291
1972	1,377	4,916	2002	15,943	3,571
1973	3,264	23,062	2003	14,270	3,386
1974	3,700	24,994	2004	16,724	3,991
1975	3,348	22,736	2005	17,918	3,455
1976	1,702	10,897	2006	15,136	3,401
1977	2,559	15,090	2007	13,751	3,096
1978	3,864	25,571	2008	15,893	3,591
1979	2,609	16,207	2009	15,074	3,399
1980	4,578	12,310	2010	12,868	2,922
1981	4,503	12,553	2011	17,712	3,952
1982	2,349	6,437	2012	18,438	4,133
1983	1,971	5,456	2013	20,189	4,520
1984	1,072	2,995	2014	21,279	4,781

Table 8. Alaska skate length compositions from the BSAI longline and trawl fisheries, 2009-2013. Bin number is the lower limit of each 4 cm length interval. N = sample size used in the model (square root of number of sampled hauls).

bin	longline					trawl				
	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
4	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0.001	0	0	0
16	0	0	0	0	0	0.001	0.002	0	0	0
20	0	0	0	0	0	0.003	0.004	0.002	0.002	0.001
24	0	0	0	0.001	0	0.011	0.011	0.012	0.003	0.006
28	0	0	0	0.003	0	0.024	0.018	0.02	0.01	0.009
32	0.001	0.001	0	0.007	0	0.034	0.031	0.026	0.011	0.01
36	0.001	0.001	0.001	0.01	0.001	0.051	0.037	0.034	0.017	0.02
40	0.003	0.002	0.003	0.013	0.002	0.063	0.053	0.049	0.034	0.039
44	0.006	0.006	0.007	0.018	0.003	0.064	0.055	0.059	0.042	0.047
48	0.011	0.014	0.014	0.021	0.008	0.056	0.05	0.052	0.052	0.05
52	0.02	0.024	0.02	0.025	0.013	0.051	0.042	0.047	0.049	0.051
56	0.025	0.032	0.027	0.03	0.022	0.044	0.041	0.04	0.043	0.045
60	0.034	0.046	0.041	0.041	0.031	0.043	0.043	0.038	0.044	0.042
64	0.044	0.056	0.05	0.053	0.038	0.048	0.048	0.039	0.046	0.043
68	0.058	0.069	0.064	0.068	0.056	0.049	0.056	0.053	0.054	0.05
72	0.063	0.07	0.077	0.072	0.069	0.048	0.053	0.06	0.069	0.055
76	0.068	0.062	0.074	0.072	0.079	0.041	0.049	0.059	0.07	0.058
80	0.068	0.071	0.077	0.08	0.093	0.052	0.054	0.059	0.08	0.068
84	0.067	0.067	0.076	0.077	0.097	0.044	0.054	0.053	0.071	0.069
88	0.081	0.071	0.082	0.087	0.105	0.059	0.056	0.06	0.077	0.08
92	0.094	0.09	0.095	0.094	0.115	0.059	0.069	0.069	0.073	0.081
96	0.124	0.103	0.112	0.098	0.117	0.056	0.068	0.068	0.069	0.077
100	0.119	0.104	0.106	0.078	0.089	0.049	0.055	0.058	0.051	0.058
104	0.067	0.057	0.049	0.034	0.04	0.029	0.029	0.025	0.022	0.029
108	0.03	0.028	0.018	0.013	0.013	0.01	0.013	0.01	0.008	0.007
112	0.009	0.013	0.004	0.003	0.003	0.006	0.004	0.002	0.002	0.002
116	0.005	0.006	0.001	0.001	0.002	0.002	0.003	0.002	0	0.001
120	0.001	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001
124	0.001	0.001	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0	0	0	0	0
132	0	0	0	0	0	0	0	0	0.001	0
N	67	65	72	77	85	56	61	56	50	61

Table 9. Estimates of Alaska skate biomass (t) from the EBS shelf bottom trawl survey, 1982-2013. Estimates and CVs in bold (1999-2013) 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 1999-2013.

year	biomass	CV
1982	166,457	0.10
1983	-	-
1984	188,482	0.08
1985	163,239	0.13
1986	253,342	0.14
1987	337,865	0.09
1988	349,786	0.12
1989	392,634	0.08
1990	457,619	0.11
1991	429,660	0.09
1992	378,474	0.09
1993	368,769	0.07
1994	383,556	0.08
1995	342,536	0.08
1996	400,012	0.06
1997	396,800	0.07
1998	350,056	0.05
1999	**323,240**	**0.17**
2000	**311,977**	**0.06**
2001	**414,539**	**0.06**
2002	**364,004**	**0.07**
2003	**372,379**	**0.05**
2004	**424,808**	**0.05**
2005	**487,742**	**0.05**
2006	**437,737**	**0.05**
2007	**478,872**	**0.07**
2008	**361,298**	**0.06**
2009	**350,233**	**0.06**
2010	**366,186**	**0.06**
2011	**410,340**	**0.05**
2012	**369,881**	**0.06**
2013	**386,816**	**0.06**
2014	**404,380**	**0.05**

Table 10. Alaska skate EBS shelf survey length compositions, 2000-2013. Bin number is the lower limit of each 4 cm length bin; data are proportions of each bin. N = sample size used in the model.

bin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
20	0.005	0.010	0.007	0.005	0.003	0.005	0.004	0.007	0.004	0.009	0.003	0.004	0.004	0.003	0.003
24	0.034	0.032	0.025	0.027	0.015	0.019	0.025	0.030	0.016	0.021	0.016	0.015	0.009	0.012	0.007
28	0.044	0.047	0.037	0.024	0.027	0.024	0.026	0.020	0.019	0.020	0.017	0.021	0.017	0.012	0.017
32	0.038	0.048	0.048	0.042	0.029	0.030	0.031	0.027	0.026	0.032	0.017	0.025	0.017	0.020	0.015
36	0.049	0.043	0.049	0.041	0.032	0.039	0.033	0.037	0.036	0.042	0.027	0.027	0.020	0.028	0.026
40	0.051	0.047	0.054	0.044	0.049	0.045	0.043	0.052	0.048	0.052	0.036	0.039	0.028	0.031	0.027
44	0.047	0.052	0.057	0.048	0.052	0.059	0.048	0.050	0.058	0.055	0.048	0.054	0.042	0.042	0.035
48	0.055	0.046	0.054	0.080	0.060	0.055	0.055	0.062	0.059	0.055	0.041	0.064	0.049	0.049	0.045
52	0.063	0.052	0.065	0.049	0.067	0.054	0.051	0.052	0.066	0.064	0.049	0.063	0.056	0.066	0.042
56	0.059	0.047	0.053	0.041	0.053	0.058	0.055	0.054	0.064	0.067	0.054	0.061	0.059	0.061	0.056
60	0.061	0.055	0.047	0.044	0.052	0.061	0.056	0.048	0.060	0.067	0.053	0.065	0.059	0.055	0.063
64	0.045	0.046	0.039	0.040	0.044	0.051	0.055	0.059	0.062	0.057	0.060	0.065	0.061	0.056	0.059
68	0.036	0.047	0.048	0.052	0.052	0.044	0.050	0.056	0.047	0.050	0.066	0.061	0.059	0.052	0.066
72	0.035	0.046	0.042	0.042	0.047	0.046	0.048	0.051	0.051	0.053	0.057	0.061	0.068	0.061	0.064
76	0.027	0.038	0.042	0.045	0.050	0.040	0.049	0.044	0.050	0.043	0.055	0.051	0.069	0.064	0.055
80	0.039	0.032	0.029	0.047	0.040	0.040	0.038	0.045	0.046	0.047	0.056	0.047	0.063	0.064	0.052
84	0.030	0.027	0.026	0.039	0.042	0.040	0.045	0.036	0.042	0.041	0.061	0.047	0.047	0.054	0.058
88	0.036	0.036	0.045	0.045	0.045	0.051	0.039	0.042	0.045	0.045	0.057	0.046	0.067	0.061	0.077
92	0.052	0.065	0.054	0.054	0.060	0.051	0.061	0.063	0.055	0.049	0.070	0.053	0.064	0.067	0.088
96	0.074	0.072	0.070	0.079	0.073	0.063	0.069	0.060	0.057	0.056	0.072	0.058	0.065	0.070	0.070
100	0.066	0.069	0.060	0.061	0.068	0.070	0.065	0.059	0.054	0.047	0.048	0.047	0.050	0.043	0.046
104	0.040	0.029	0.030	0.037	0.030	0.041	0.039	0.031	0.026	0.021	0.026	0.018	0.020	0.022	0.022
108	0.012	0.012	0.012	0.011	0.008	0.012	0.012	0.010	0.009	0.006	0.008	0.006	0.005	0.005	0.005
112	0.002	0.002	0.005	0.003	0.003	0.002	0.002	0.004	0.001	0.000	0.001	0.001	0.001	0.001	0.002
116	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
132	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
N	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Table 11. Input parameter values for the base model (Model 2). Where parameters were estimated freely within the model, minimum and maximum bounds are shown. Superscripts indicate how parameters were changed in the alternative models.

parameter		value	min	max	fix?
growth and natural mortality	natural mortality (*M*)	0.13			X
	length at A1 (L1)	20	-10	30	
	length at A2 (L2)	110	70	150	
	von Bertalanffy coefficient (κ)	0.15	0.05	0.15	
	Richards coefficient (γ)	0.1	-1	2	
	CV of LAA @ L1	0.1	0.05	0.35	
	CV of LAA @ L2	0.1	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
stock-recruit function	ln virgin recruitment level (R_0)	10.00	5	15	
	steepness	1			X
	σ_R	0.4			X
EBS shelf survey catchability	ln catchability (q)	0			X
longline length selectivity[a]	peak (p1)	111	7.6	126	
	top (p2)	-0.1	-6	4	
	ascending width (p3)	4.9	-1	9	
	descending width (p4)	4.7	-1	9	
	selectivity at first size bin (p5)	-2.2	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
trawl length selectivity[a]	peak (p1)	49	7.6	126	
	top (p2)	-5	-6	4	
	ascending width (p3)	4.8	-1	9	
	descending width (p4)	4.4	-1	9	
	selectivity at first size bin (p5)	-0.7	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
survey length selectivity[a]	peak (p1)	49	7.6	126	
	top (p2)	-5	-6	4	
	ascending width (p3)	4.8	-1	9	
	descending width (p4)	4.4	-1	9	
	selectivity at first size bin (p5)	-0.7	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
initial fishing mortality	longline fishery F	0.030	0	1	
	trawl fishery F	0.005	0	1	

a In model 3, p6 was fixed at the starting value for all fleets.

Table 12. Results from models 1-4 for use in model comparison and evaluation.

model number		1	2	3	4
Description		existing (2012) model	new base model (preferred)	new base model w/ asymptotic selectivity	new base model starting in 1977
likelihood components					
	survey	-28.3094	-37.4977	-33.6539	-33.7349
	length comps	91.8971	82.0901	86.0581	84.8489
	LAA	51.7705	130.047	133.826	129.01
	recruitment	-26.4296	-41.0622	-42.1409	-5.3949
	total	96.1761	133.599	144.109	174.822
parameters estimated		68	89	86	64
L_amin		23.8	14.0	15.9	14.2
	CV	*0.0356*	*0.0367*	*0.0431*	*0.0377*
L_amax		110.0	101.9	102.6	102.0
	CV	*0.0132*	*0.0037*	*0.0040*	*0.0039*
K		0.20	0.38	0.35	0.37
	CV	*0.0000*	*0.0222*	*0.0226*	*0.0230*
CV young		0.21	0.35	0.30	0.35
	CV	*0.1159*	*0.0002*	*0.0918*	*0.0005*
CV old		0.05	0.05	0.05	0.05
	CV	*0.0445*	*0.0575*	*0.0582*	*0.0594*
ln (Rzero)		10.2	10.2	10.0	10.2
	CV	*0.0033*	*0.0046*	*0.0024*	*0.0043*
spawnbio_unfished		460,075	354,080	295,425	346,340
	CV	*0.068*	*0.052*	*0.027*	*0.050*
recruit_unfished		27,472	26,619	22,565	25,991
	CV	*0.034*	*0.046*	*0.024*	*0.044*
RMSE_survey		0.106	0.125	0.131	0.132
% within survey CI		74%	81%	78%	75%
correlation obs-pred		0.299	0.834	0.816	0.846
average standardized residual		0.815	0.813	0.819	0.835
mean longline input N		94.6	73.2	73.2	73.2
mean longline eff N		322.5	924.3	884.3	1038.3
mean longline effN/N		3.41	12.63	12.08	14.18
mean trawl input N		87.3	56.8	56.8	56.8
mean trawl eff N		371.2	1160.5	747.3	921.2
mean trawl effN/N		4.25	20.43	13.16	16.22
mean survey input N		113.3	200.0	200.0	200.0
mean survey eff N		451.1	836.5	751.2	782.4
mean survey effN/N		3.98	4.18	3.76	3.91
mean LAA N		337.0	223.8	223.8	223.8
mean LAA eff N		532.7	2976.2	2627.0	2970.0
mean LAA eff N/N		1.58	13.30	11.74	13.27

Table 13. Time series of total (age 0+) biomass, spawning biomass and the number of age 0 recruits predicted by Model 2.

	spawning biomass		age-0 recruits			spawning biomass		age-0 recruits	
	Estimate	CV	estimate	CV		estimate	CV	estimate	CV
unfished	354,080	0.05	26,619	0.05	1982	135,083	0.13	64,018	0.69
1950	354,080	0.05	23,074	0.39	1983	130,718	0.13	50,212	0.70
1951	354,080	0.05	22,908	0.39	1984	128,180	0.13	35,448	0.49
1952	354,080	0.05	22,723	0.39	1985	128,534	0.12	28,555	0.42
1953	354,080	0.05	22,519	0.39	1986	129,777	0.11	25,203	0.39
1954	354,080	0.05	22,295	0.39	1987	133,130	0.10	23,927	0.38
1955	354,080	0.05	22,049	0.38	1988	139,339	0.10	23,952	0.38
1956	354,080	0.05	21,783	0.38	1989	148,662	0.09	25,117	0.38
1957	354,080	0.05	21,497	0.38	1990	165,158	0.09	27,520	0.39
1958	354,080	0.05	21,193	0.38	1991	195,168	0.09	28,345	0.38
1959	352,630	0.05	20,875	0.37	1992	226,054	0.08	24,308	0.37
1960	350,213	0.06	20,546	0.37	1993	250,008	0.08	24,455	0.36
1961	347,064	0.06	20,211	0.37	1994	269,757	0.08	30,257	0.36
1962	343,299	0.07	19,872	0.37	1995	281,032	0.08	34,630	0.34
1963	339,178	0.07	19,534	0.36	1996	285,147	0.08	29,120	0.35
1964	334,899	0.08	19,201	0.36	1997	285,578	0.08	32,430	0.34
1965	330,373	0.08	18,876	0.36	1998	280,649	0.08	35,271	0.34
1966	325,424	0.09	18,571	0.35	1999	274,456	0.08	36,077	0.32
1967	320,522	0.09	18,297	0.35	2000	271,391	0.08	40,151	0.28
1968	314,761	0.09	18,057	0.35	2001	265,412	0.08	32,360	0.28
1969	304,019	0.10	17,842	0.35	2002	258,879	0.08	29,687	0.29
1970	296,729	0.10	17,625	0.34	2003	253,372	0.08	33,816	0.30
1971	287,823	0.10	17,402	0.34	2004	251,757	0.08	41,450	0.29
1972	279,714	0.10	17,201	0.34	2005	248,737	0.08	37,412	0.31
1973	271,752	0.10	17,057	0.34	2006	247,111	0.08	34,872	0.30
1974	251,945	0.11	17,012	0.34	2007	248,826	0.08	30,565	0.33
1975	230,901	0.11	17,098	0.34	2008	252,801	0.08	32,041	0.29
1976	211,712	0.12	17,419	0.34	2009	257,724	0.08	23,666	0.30
1977	200,905	0.12	18,176	0.34	2010	261,787	0.08	19,245	0.30
1978	187,626	0.12	19,722	0.35	2011	265,739	0.07	17,211	0.30
1979	168,237	0.13	22,649	0.38	2012	266,615	0.07	18,290	0.32
1980	155,678	0.13	27,976	0.42	2013	269,042	0.07	20,678	0.35
1981	144,910	0.13	37,857	0.52	2014	269,884	0.07	26,619	0.05

Table 14. Comparison of spawning biomass and age-0 recruits between Model 1 and Model 2.

	spawning biomass		age-0 recruits	
	Model 2	Model 1	Model 2	Model 1
unfished	354,080	460,075	26,619	27,472
1980	155,678	330,065	27,976	22,616
1981	144,910	330,065	37,857	22,574
1982	135,083	330,065	64,018	22,666
1983	130,718	330,065	50,212	22,948
1984	128,180	330,065	35,448	23,515
1985	128,534	330,064	28,555	24,390
1986	129,777	330,059	25,203	25,362
1987	133,130	330,044	23,927	26,013
1988	139,339	330,007	23,952	26,043
1989	148,662	329,928	25,117	25,949
1990	165,158	329,781	27,520	28,659
1991	195,168	329,542	28,345	32,150
1992	226,054	327,895	24,308	37,926
1993	250,008	323,063	24,455	34,723
1994	269,757	319,671	30,257	30,967
1995	281,032	314,480	34,630	28,976
1996	285,147	308,740	29,120	25,775
1997	285,578	304,606	32,430	34,771
1998	280,649	298,672	35,271	30,467
1999	274,456	293,026	36,077	26,163
2000	271,391	291,014	40,151	31,864
2001	265,412	287,864	32,360	25,920
2002	258,879	285,524	29,687	30,146
2003	253,372	284,065	33,816	27,962
2004	251,757	286,605	41,450	26,483
2005	248,737	289,137	37,412	23,505
2006	247,111	291,476	34,872	19,875
2007	248,826	294,640	30,565	17,314
2008	252,801	296,889	32,041	12,620
2009	257,724	298,136	23,666	11,032
2010	261,787	299,002	19,245	12,422
2011	265,739	300,132	17,211	28,228
2012	266,615	298,371	18,290	28,466
2013	269,042	294,489	20,678	28,686
2014	269,884	289,241	26,619	28,886

Table 15. Time series of exploitation rates (catch/total biomass) as estimated by the preferred new model (Model 2).

year	longline	trawl	total F	year	longline	trawl	total F
1950	0.000	0.000	0.000	1983	0.009	0.026	0.035
1951	0.000	0.000	0.000	1984	0.005	0.013	0.018
1952	0.000	0.000	0.000	1985	0.006	0.016	0.022
1953	0.000	0.000	0.000	1986	0.005	0.013	0.018
1954	0.000	0.000	0.000	1987	0.003	0.009	0.013
1955	0.000	0.000	0.000	1988	0.004	0.012	0.016
1956	0.000	0.000	0.000	1989	0.001	0.004	0.006
1957	0.000	0.000	0.000	1990	0.002	0.005	0.006
1958	0.000	0.000	0.000	1991	0.013	0.003	0.017
1959	0.000	0.000	0.000	1992	0.026	0.006	0.032
1960	0.000	0.000	0.000	1993	0.019	0.005	0.023
1961	0.000	0.000	0.000	1994	0.022	0.005	0.027
1962	0.000	0.000	0.000	1995	0.023	0.006	0.029
1963	0.000	0.000	0.000	1996	0.020	0.005	0.025
1964	0.000	0.001	0.001	1997	0.028	0.007	0.035
1965	0.000	0.002	0.003	1998	0.031	0.008	0.039
1966	0.000	0.002	0.003	1999	0.023	0.006	0.028
1967	0.001	0.005	0.006	2000	0.030	0.008	0.037
1968	0.003	0.024	0.027	2001	0.032	0.008	0.040
1969	0.002	0.011	0.013	2002	0.035	0.009	0.044
1970	0.003	0.018	0.020	2003	0.032	0.008	0.040
1971	0.002	0.016	0.018	2004	0.037	0.010	0.046
1972	0.003	0.014	0.017	2005	0.039	0.008	0.047
1973	0.008	0.069	0.078	2006	0.033	0.008	0.041
1974	0.010	0.081	0.091	2007	0.029	0.007	0.036
1975	0.010	0.080	0.090	2008	0.033	0.008	0.042
1976	0.005	0.041	0.046	2009	0.031	0.008	0.039
1977	0.009	0.059	0.068	2010	0.026	0.007	0.033
1978	0.014	0.108	0.122	2011	0.036	0.009	0.045
1979	0.010	0.074	0.084	2012	0.037	0.009	0.047
1980	0.019	0.058	0.078	2013	0.041	0.010	0.052
1981	0.020	0.062	0.081	2014	0.045	0.011	0.056
1982	0.011	0.032	0.042				

Table 16. 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 17. 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
	2014	3,515	0.40	39,468	0.12	42,983	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
	2013	386,816	0.06	26,961	0.41	413,776	0.06
	2014	404,380	0.05	24,465	0.21	428,845	0.05

Table 18. 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
	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
EBS slope	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
	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
AI	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			8,721	0.21	56	0.45	24,151	0.20
	2012	1	0.87	6,072	0.18	109	0.17	15,360	0.20
	2014	80	0.35	7,563	0.24	137	0.36	22,400	0.18
	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		
EBS shelf	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			8,223	0.56	8,585	0.17		
	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
	2013			11,483	0.35	12,099	0.30	0	n/a
	2014			8,149	0.41	12,570	0.15	0	n/a

Table 19. 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
	2014			1,831	0.25					8	0.73
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						
	2013	3,378	1.00								
	2014	3,596	0.60	149	1.00						

Table 20. Survey biomass estimates for longnose, Okhotsk, deepsea, leopard, and butterfly skates, by area and year.

		longnose		Okhotsk		deepsea		leopard		butterfly	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			47	0.59						
	2004			8	1.00	164	0.73				
	2008	12	1.00			165	0.62				
	2010					345	0.64				
	2012										
AI	1980										
	1983										
	1986										
	1991	97	0.99								
	1994	28	1.00								
	1997	368	1.00								
	2000										
	2002										
	2004										
	2006										
	2010							12,958	0.21	123	0.49
	2012							10,421	0.24	307	0.32
	2014							7,040	0.23	409	0.37
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								
	2013										
	2014										

Table 21. Comparison of “other skate” biomass estimates (t) from 3 sources: single survey estimates, 3-survey averages, and a random effects (RE) model, 1999-2014, for each subarea of the BSAI region.

	EBS slope				**AI**				**EBS shelf**			
yrs	survey estimate	3-survey average	RE estimate	RE CV	survey estimate	3-survey average	RE estimate	RE CV	survey estimate	3-survey average	RE estimate	RE CV
1999									31,148		19,595	0.063
2000					19,551		20,483	0.112	24,743		19,595	0.063
2001							22,549	0.148	17,405	24,432	19,595	0.063
2002	33,344		31,347	0.090	23,732		24,823	0.111	18,648	20,265	19,595	0.063
2003			30,903	0.084			29,361	0.156	32,381	22,811	19,595	0.063
2004	28,909		30,465	0.073	40,319	27,868	34,730	0.148	14,656	21,895	19,595	0.063
2005			31,161	0.084			37,109	0.163	20,828	22,622	19,595	0.063
2006			31,873	0.086	40,643	34,898	39,650	0.123	18,515	17,999	19,595	0.063
2007			32,601	0.080			40,918	0.178	17,236	18,859	19,595	0.063
2008	33,033	31,762	33,346	0.063			42,226	0.192	19,617	18,456	19,595	0.063
2009			34,336	0.073			43,576	0.174	20,162	19,005	19,595	0.063
2010	33,882	31,941	35,355	0.070	48,260	43,074	44,970	0.111	18,902	19,560	19,595	0.063
2011			36,893	0.078			40,495	0.144	17,771	18,945	19,595	0.063
2012	40,901	35,939	38,498	0.080	33,902	40,935	36,466	0.107	16,664	17,779	19,595	0.063
2013							37,630	0.145	26,961	20,465	19,595	0.063
2014		35,939			39,468	40,543	38,830	0.110	24,465	22,696	19,595	0.063

Figures

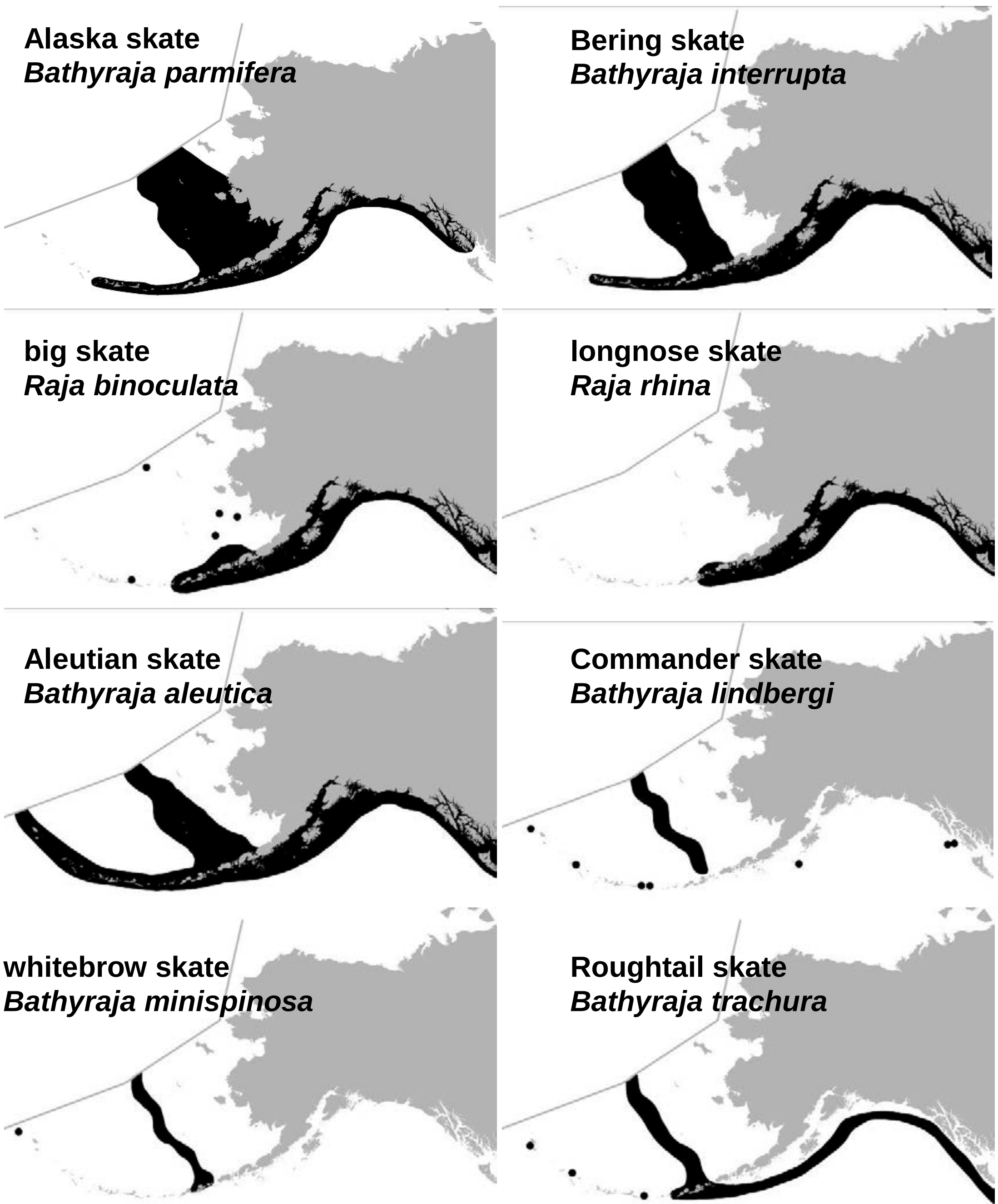

Figure 1. Distribution of skate species in Alaskan waters. These maps were created primarily using survey data, although observer records were included whenever positive species identification was possible (through voucher specimens or photographs). (Source: Stevenson et al. 2007)

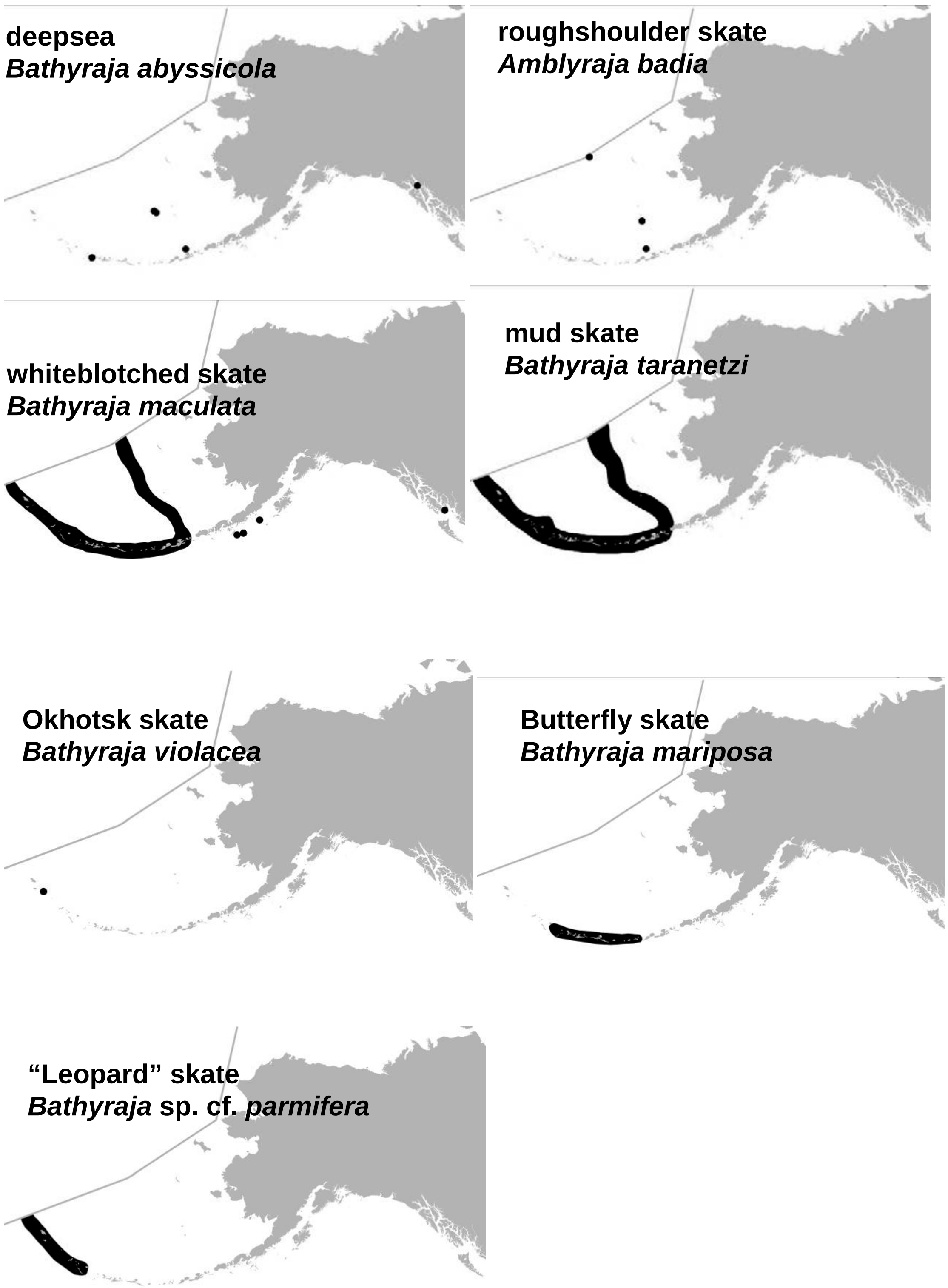

Figure 1 continued. Distribution of skate species in Alaskan waters. (Source: Stevenson et al. 2007)

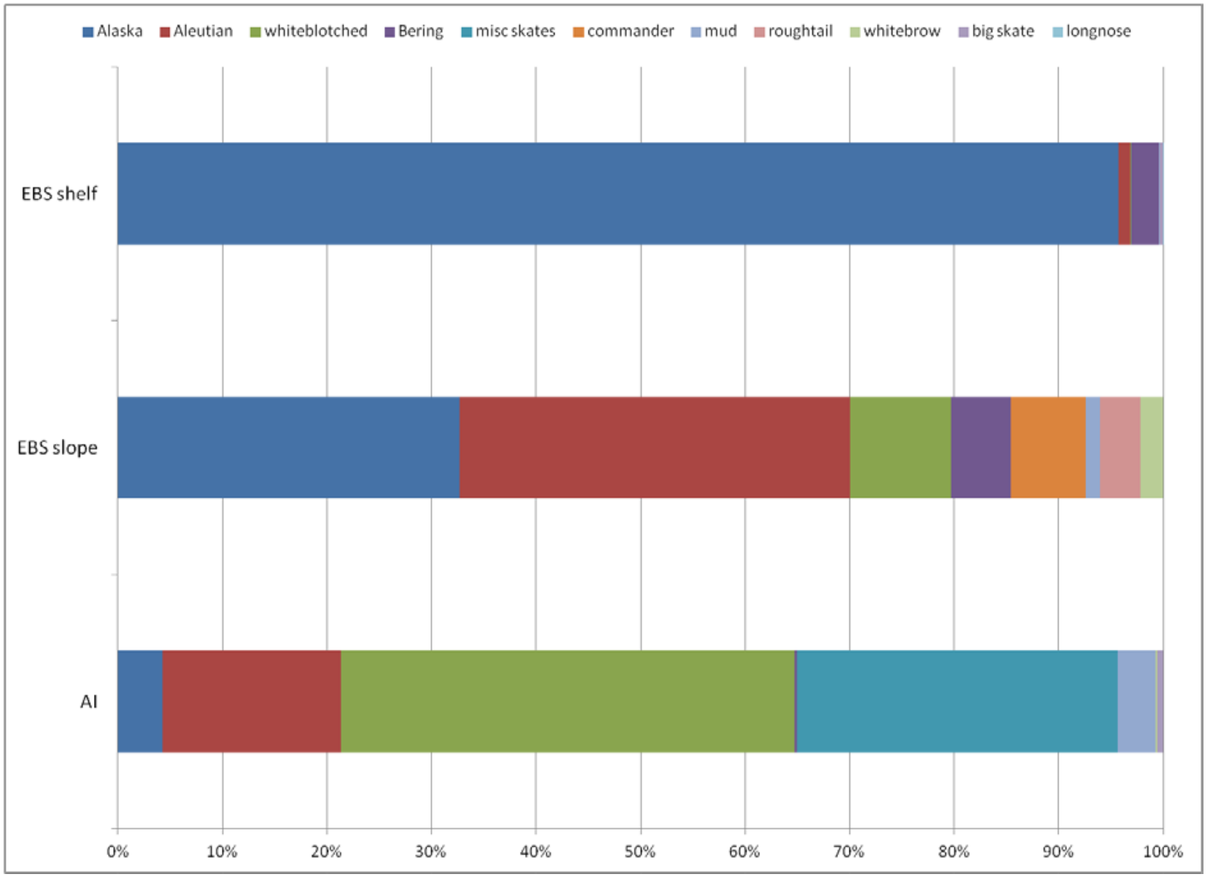

Figure 2. Skate species composition (by weight) by BSAI subregion, from surveys conducted in each region in 2012. In the AI, “misc skates” includes leopard skates.

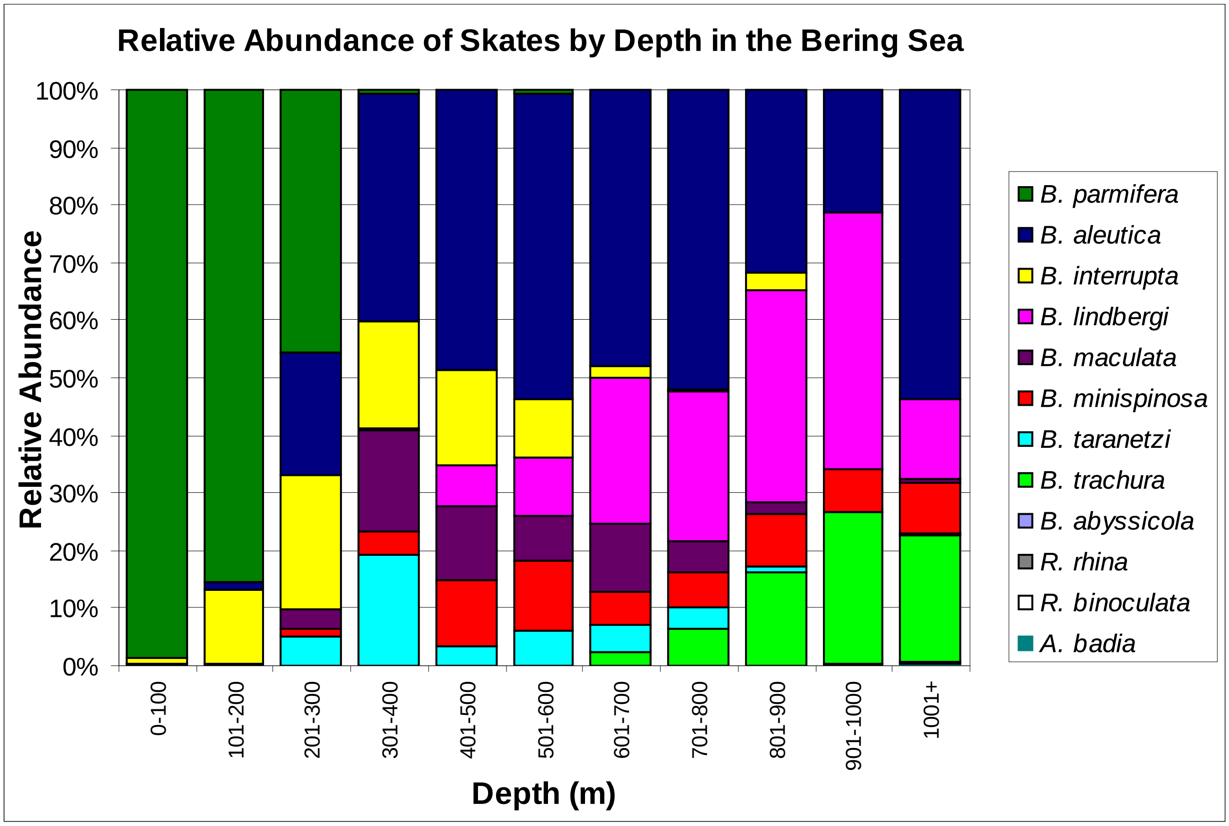

Figure 3. Relative abundance of skate species in the EBS by depth. (Source: Stevenson et al. 2006.)

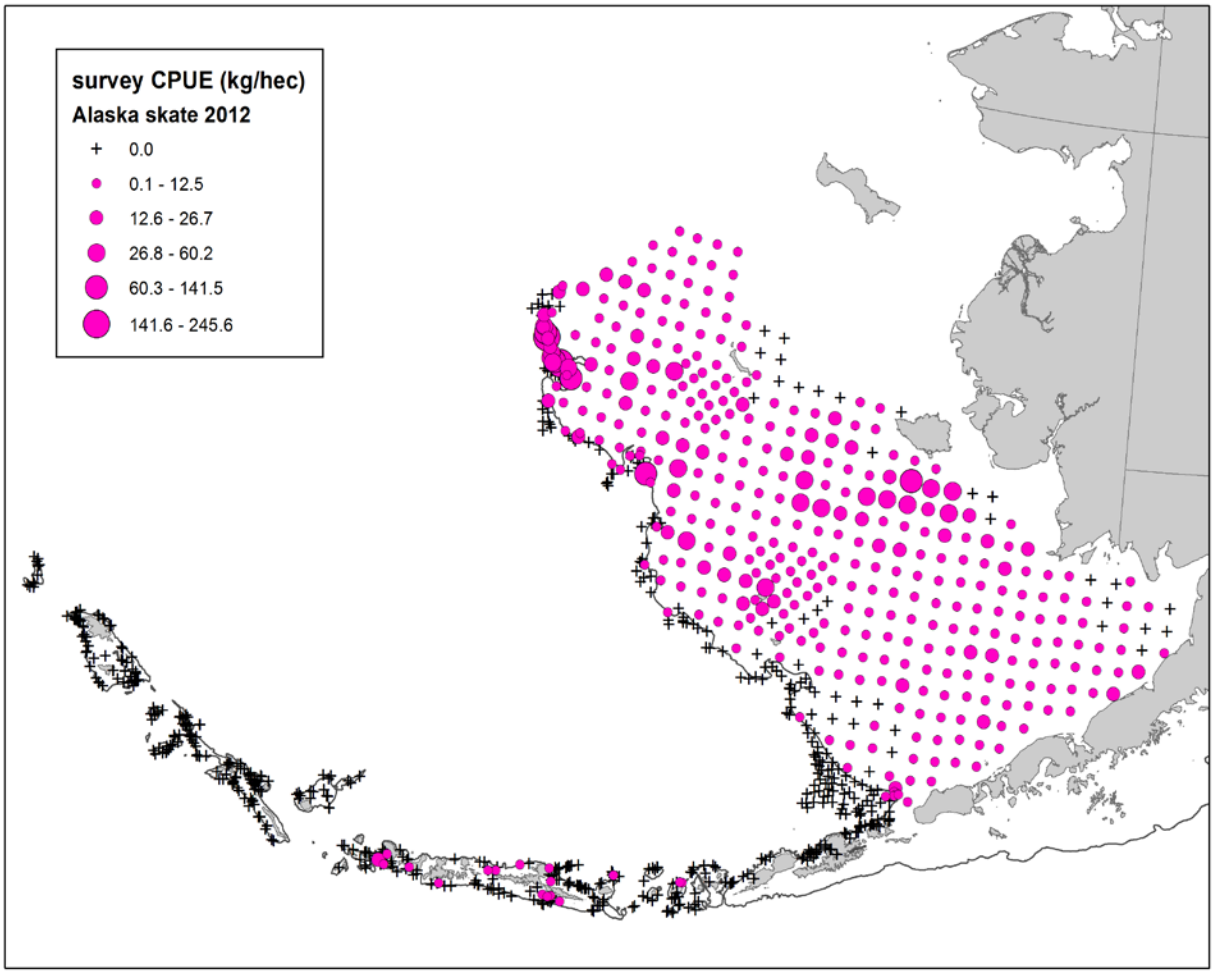

Figure 4. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Alaska skate in 2012, the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

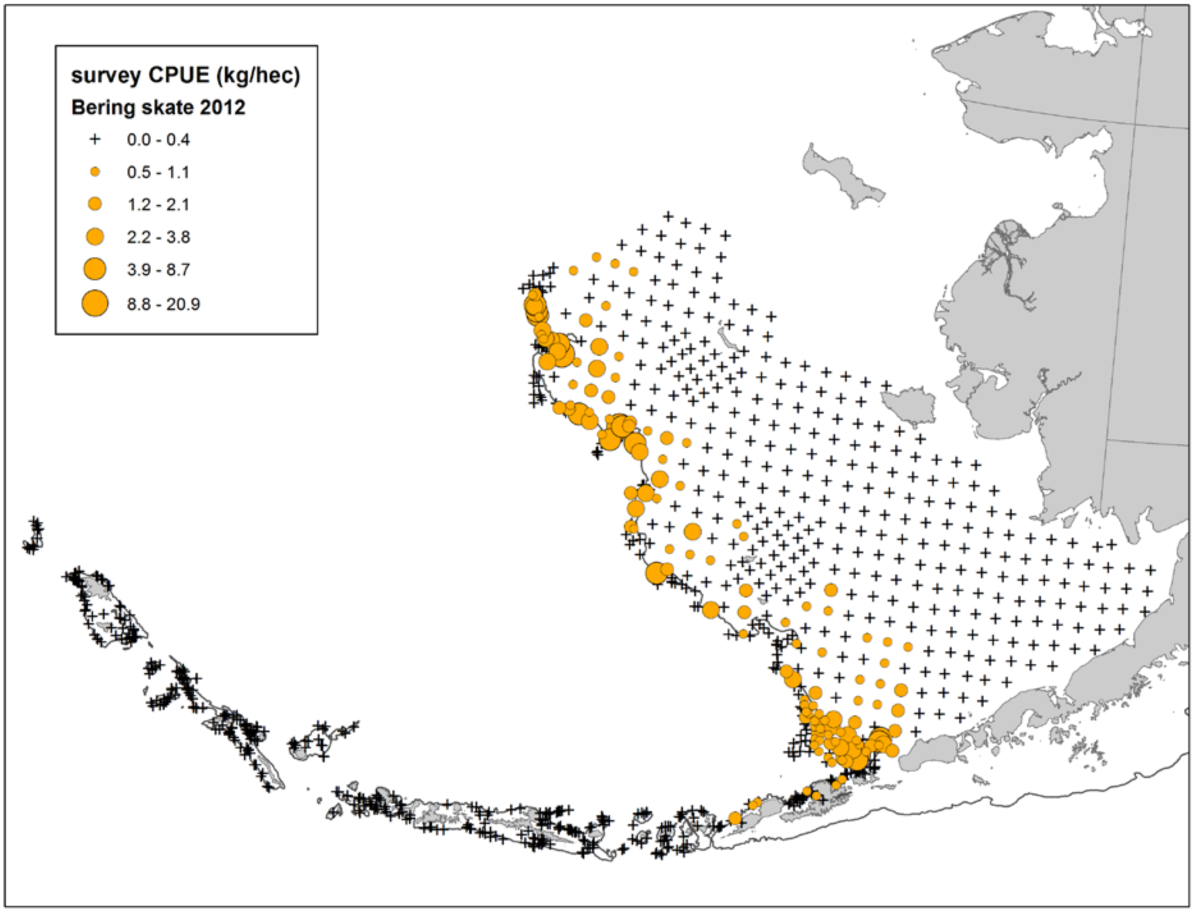

Figure 5. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Bering skate in 2012, the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station.and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

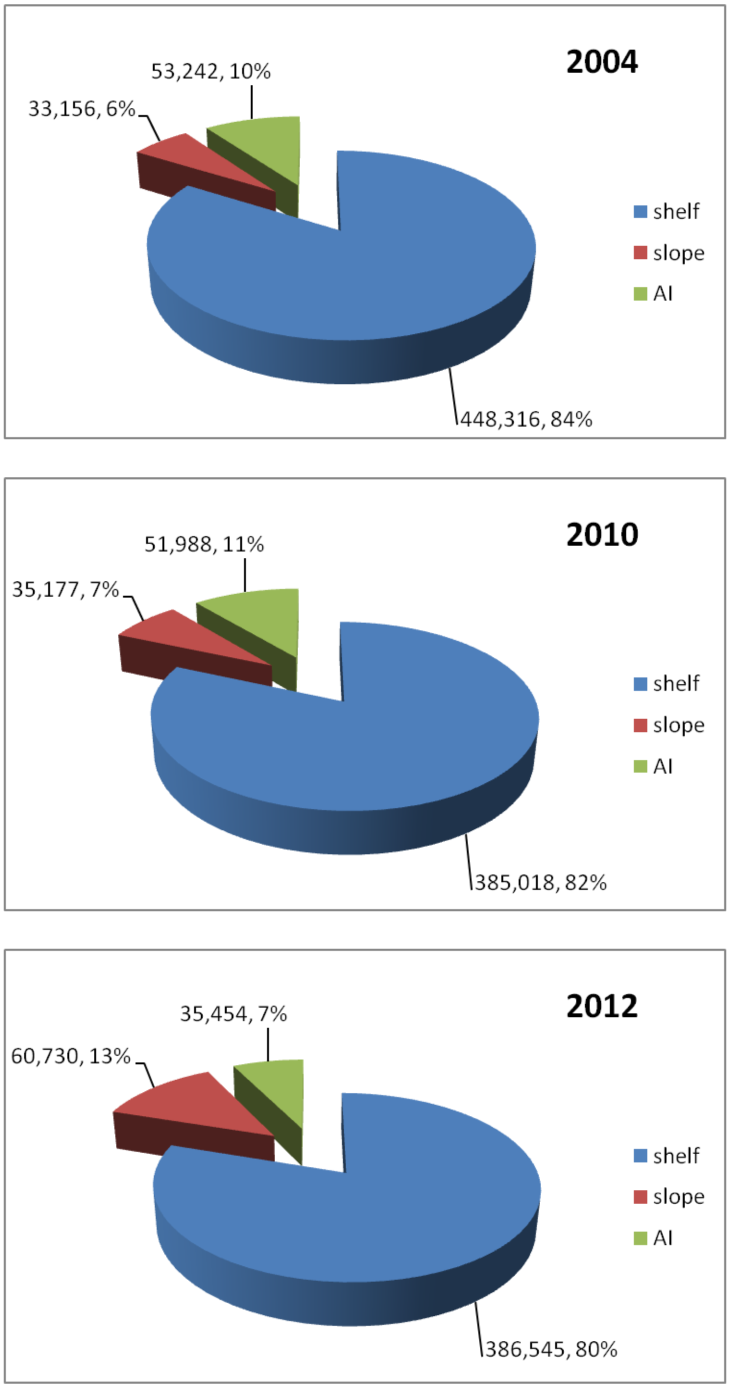

Figure 6. Distribution of skate biomass in the 3 subregions of the BSAI in 2004, 2010, and 2012. These are the 3 most recent years when all 3 surveys in the BSAI were conducted in the same year. Data are biomass estimates (t) and relative proportions from AFSC groundfish surveys.

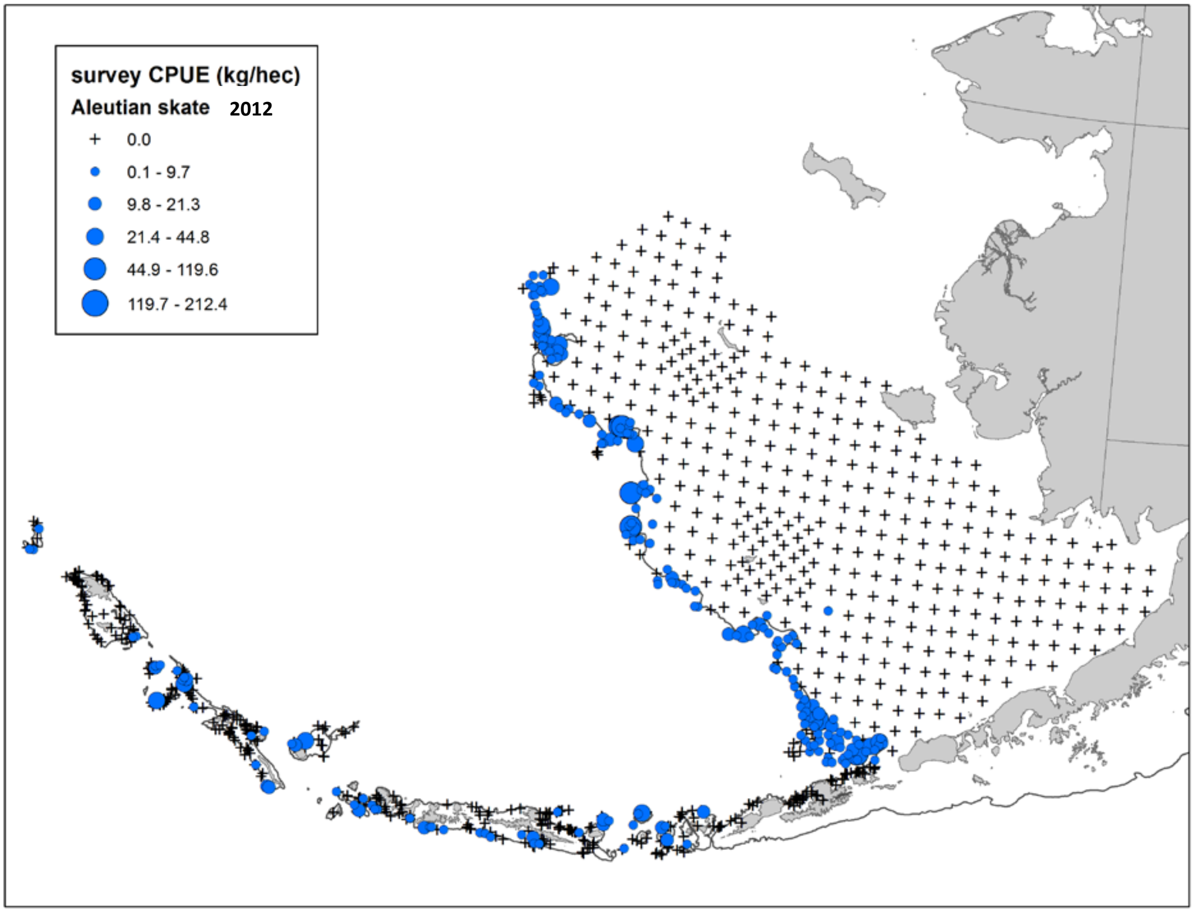

Figure 7. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Aleutian skate in 2012 , the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station.and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

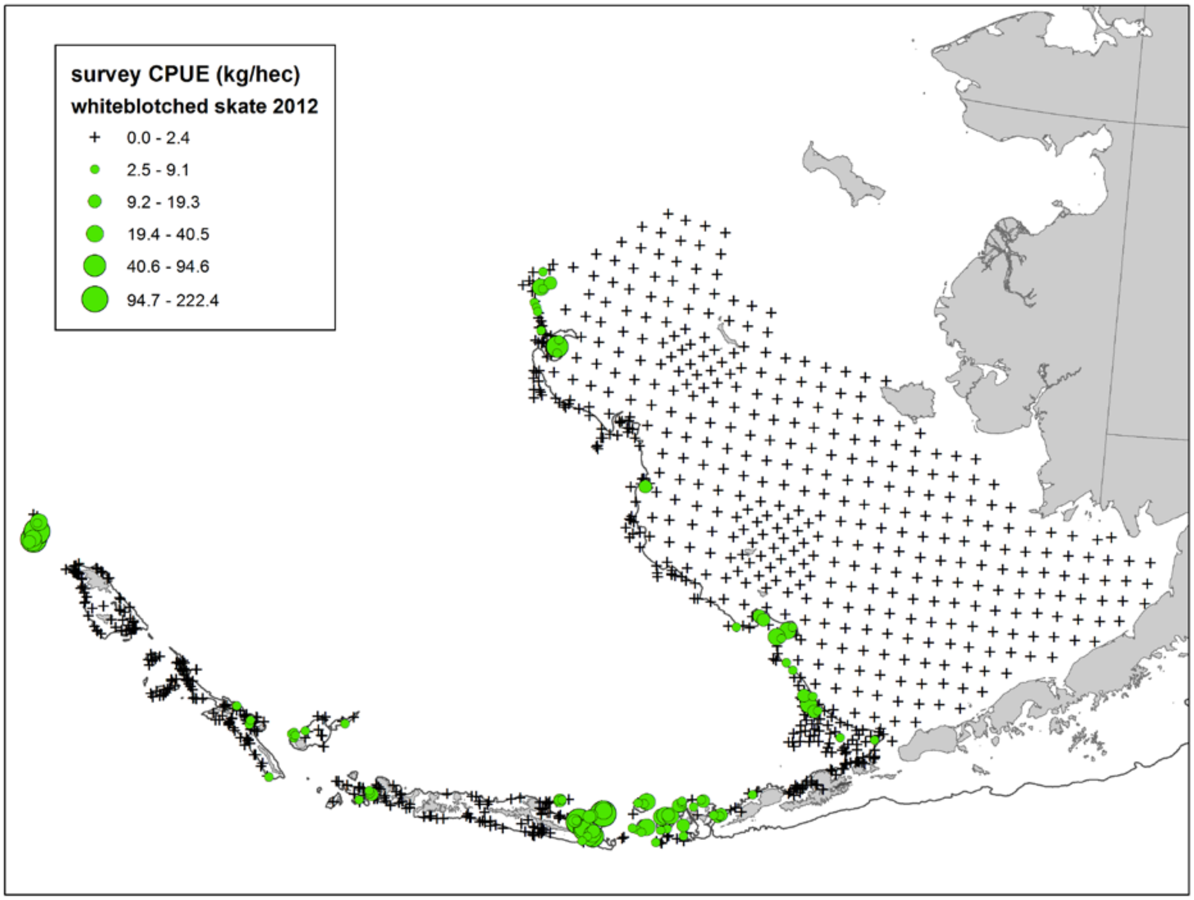

Figure 8. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of whiteblotched skate in 2012 , the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station.and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

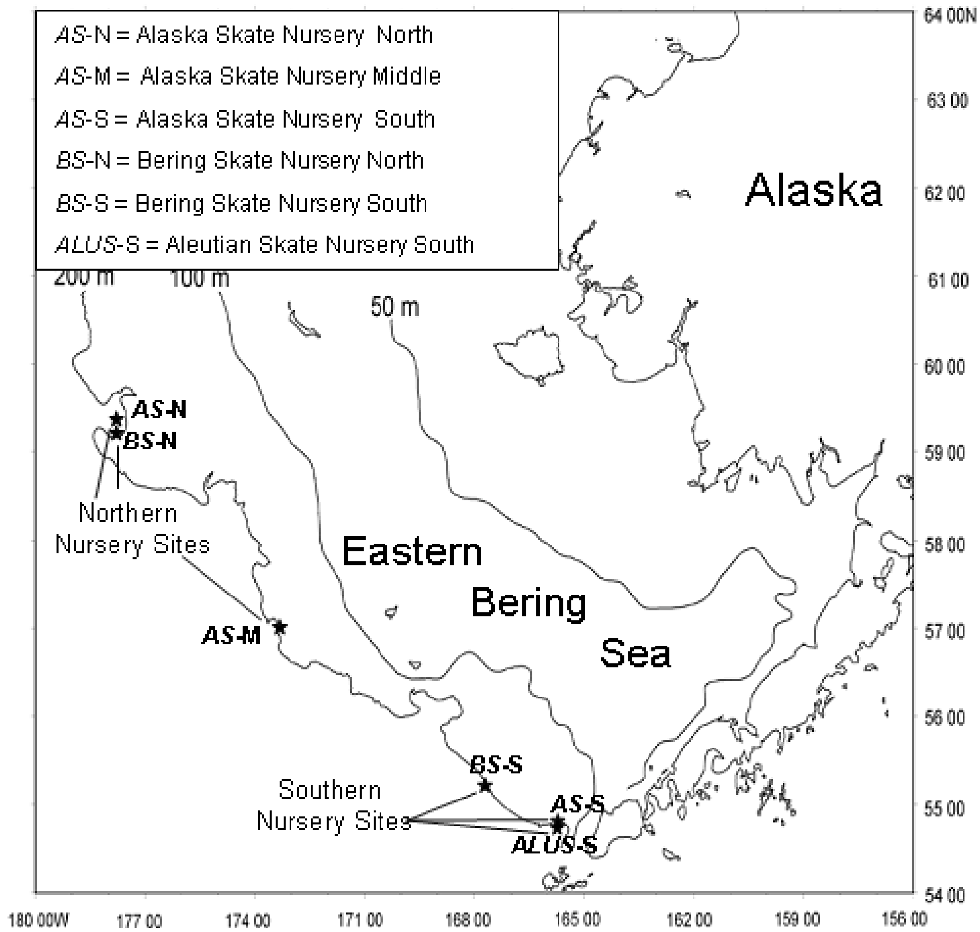

Figure 9. Map of the eastern Bering Sea with the six known skate nursery site locations and designations as a northern or southern nursery site. (See the legend for nursery site designation.) Source: Gerald Hoff, AFSC, unpublished data.

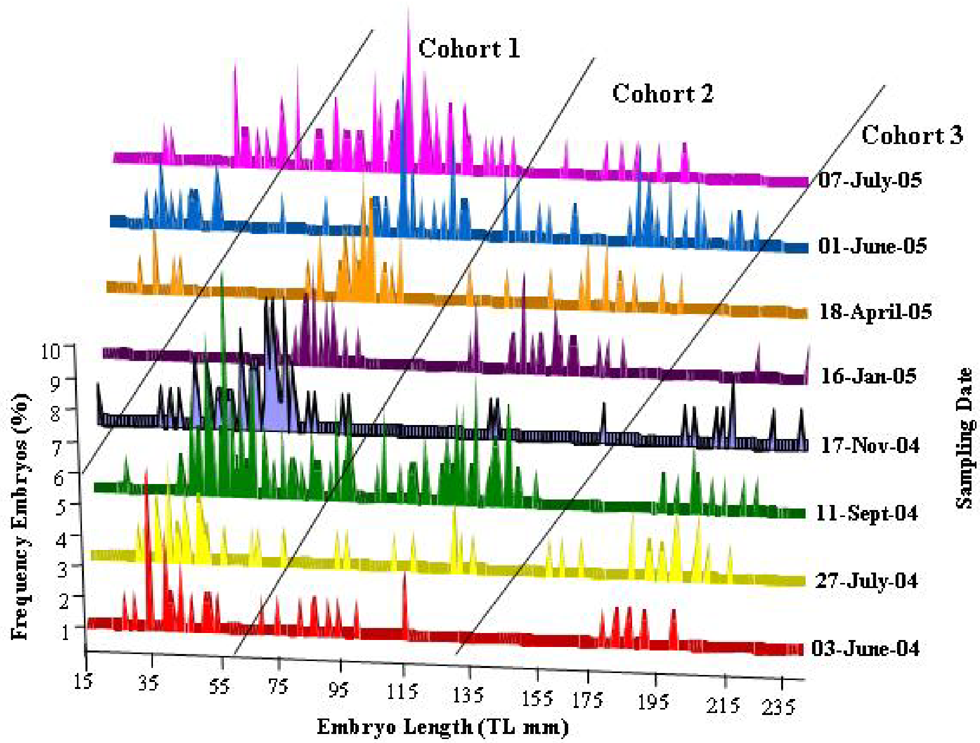

Figure 10. Embryo length composition data used in a cohort analysis of embryo development time. Figure is from G. Hoff (AFSC, pers. comm.).

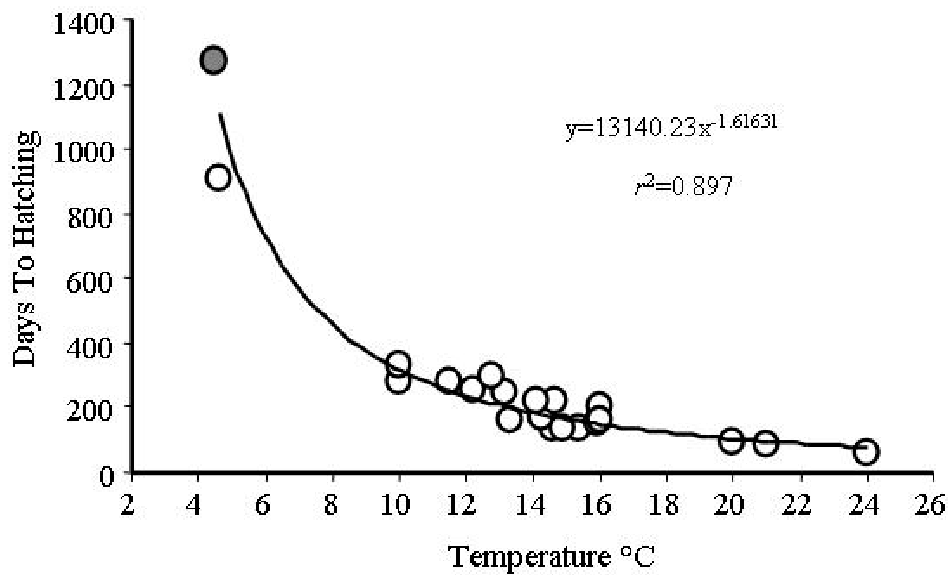

Figure 11. Ocean temperature versus embryo development time for 21 skate species. Dark grey circle is the Alaska skate. Equation and R^2 are the values of the fitted relationship. Figure is from G. Hoff (AFSC, pers. comm.)

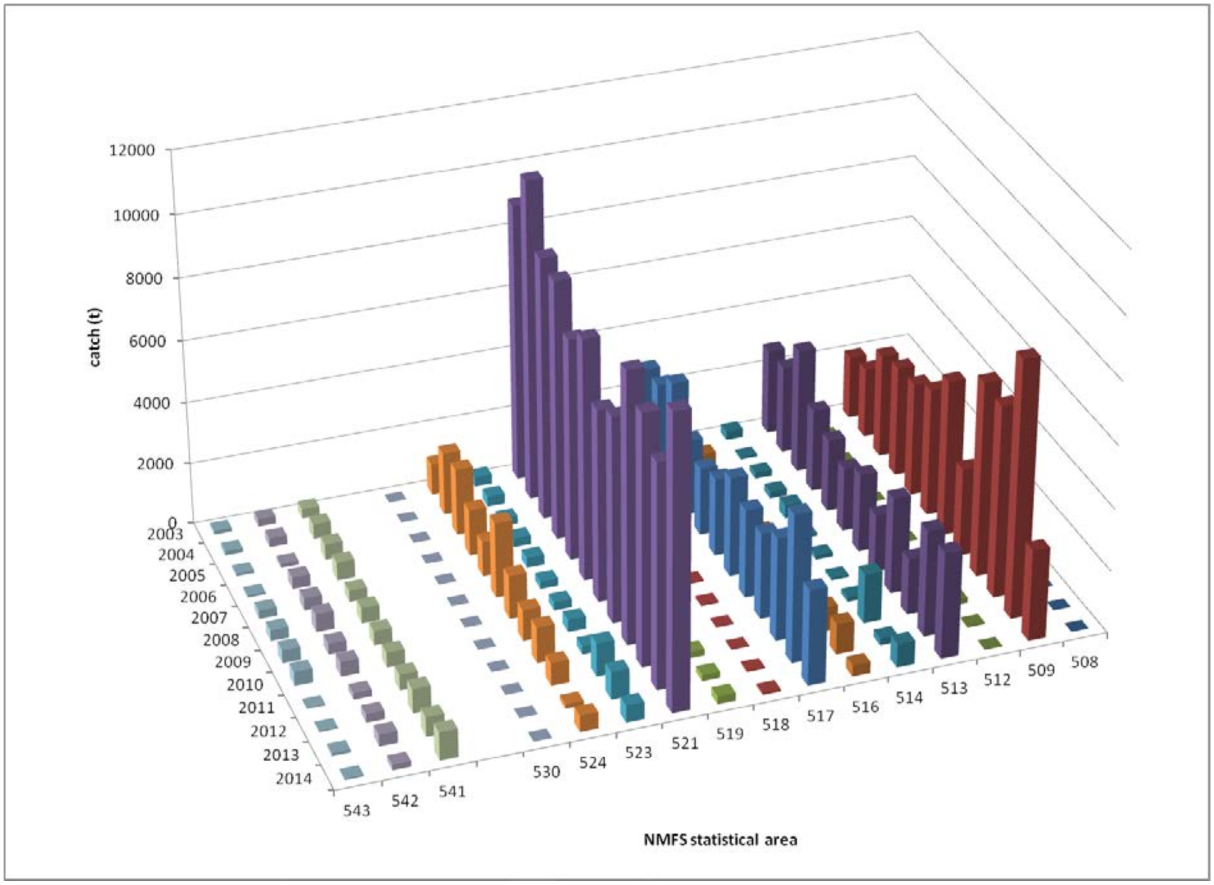

Figure 12. Total skate catch (all species combined) by FMP reporting area for both the EBS and the AI, 2003 - 2014. Source: AKRO CAS. 2014 data incomplete; retrieved October 8, 2014.

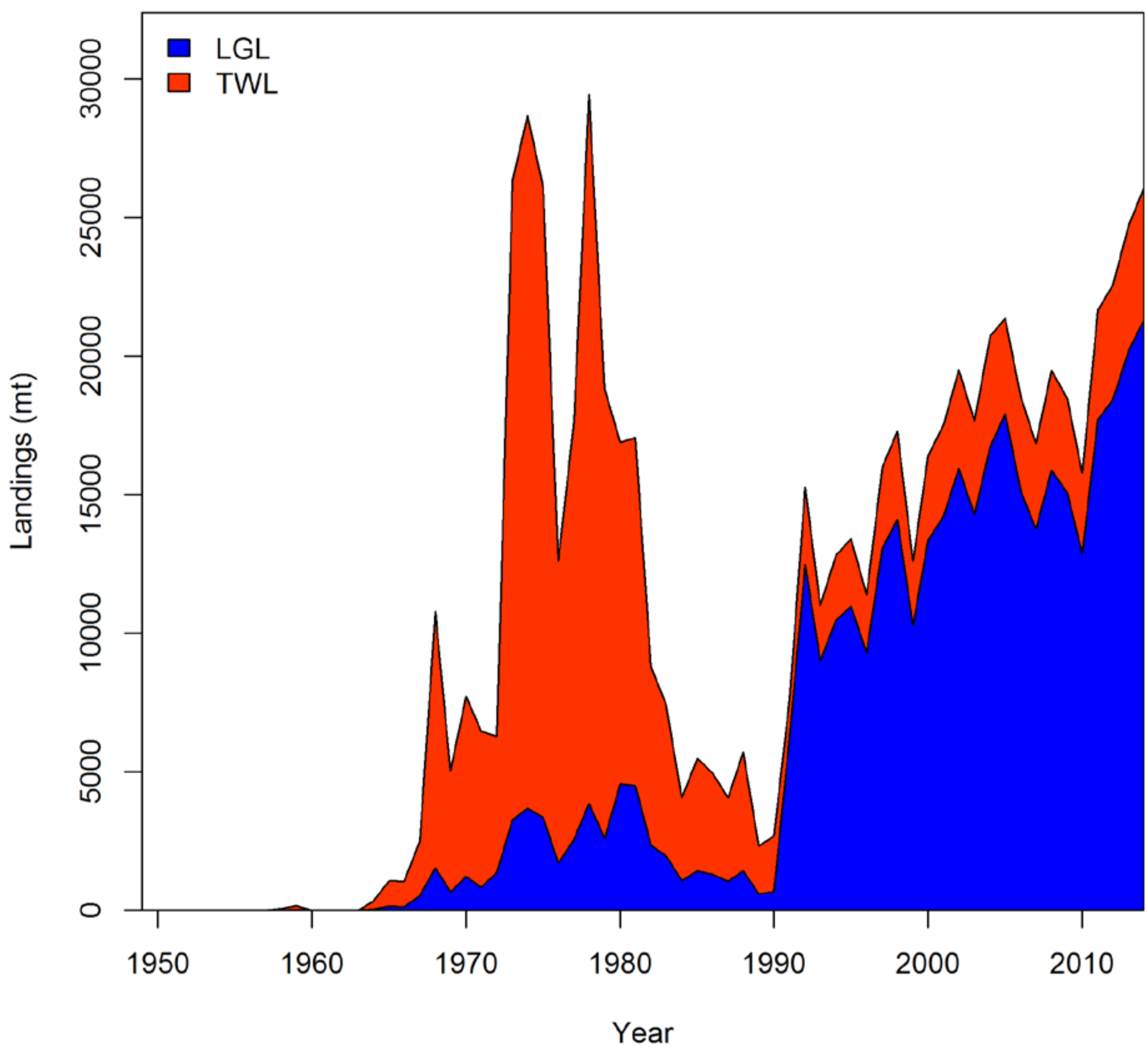

Figure 13. Estimated catch of Alaska skates (t) in the BSAI 1954-2014. LGL = longline fishery, TWL = trawl fishery. Source:……

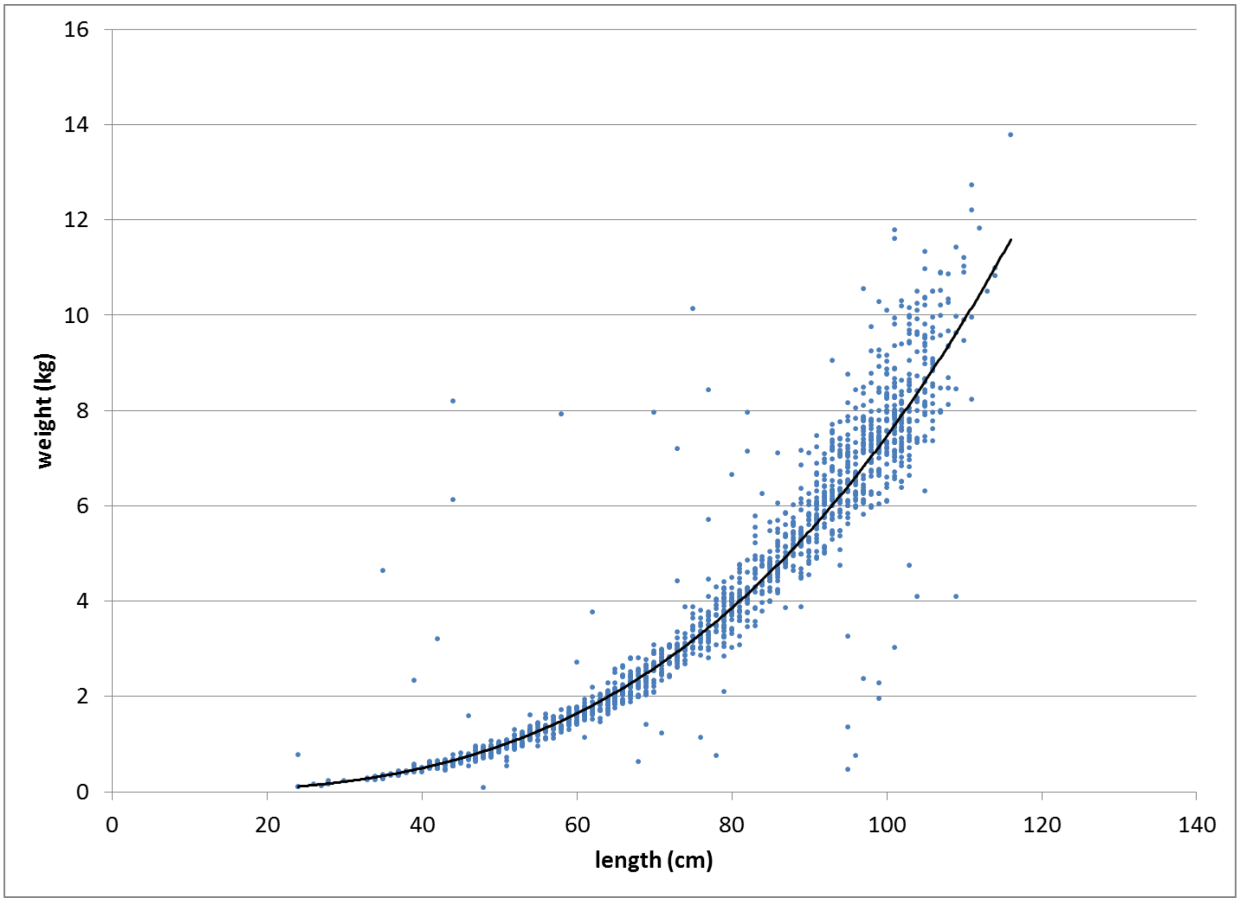

Figure 14. Length-weight relationship for Alaska skates captured in the EBS shelf trawl survey, 2008-2010. Black line indicates line of best fit to the data, r^2 = 0.93, N = 1,515.

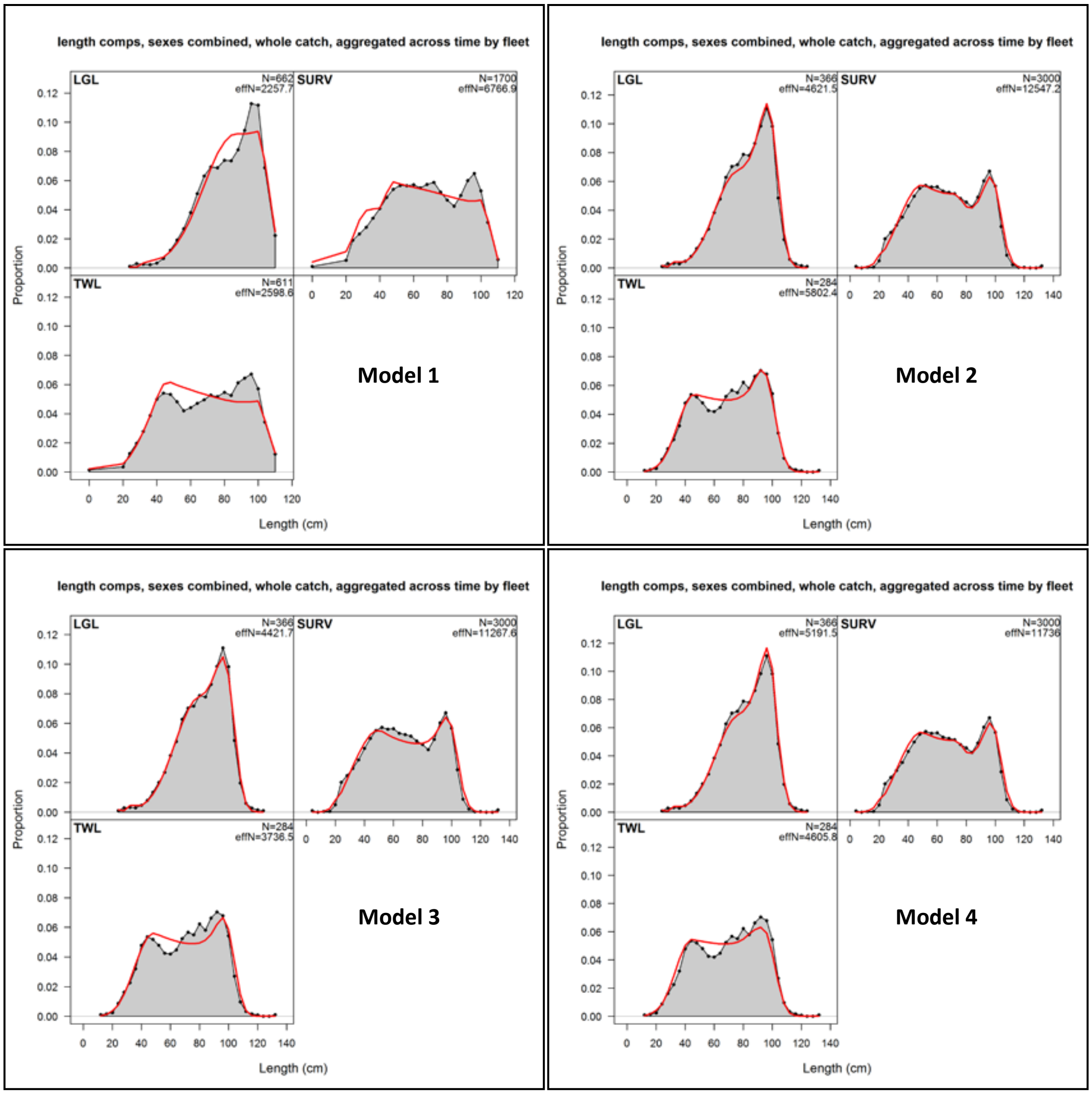

Figure 15. Fits to length composition data for the 4 alternative models. For each fleet, observed data (grey) and model fit (red line) are aggregated across years. LGL = longline fishery, TWL = trawl fishery, SURV = trawl survey.

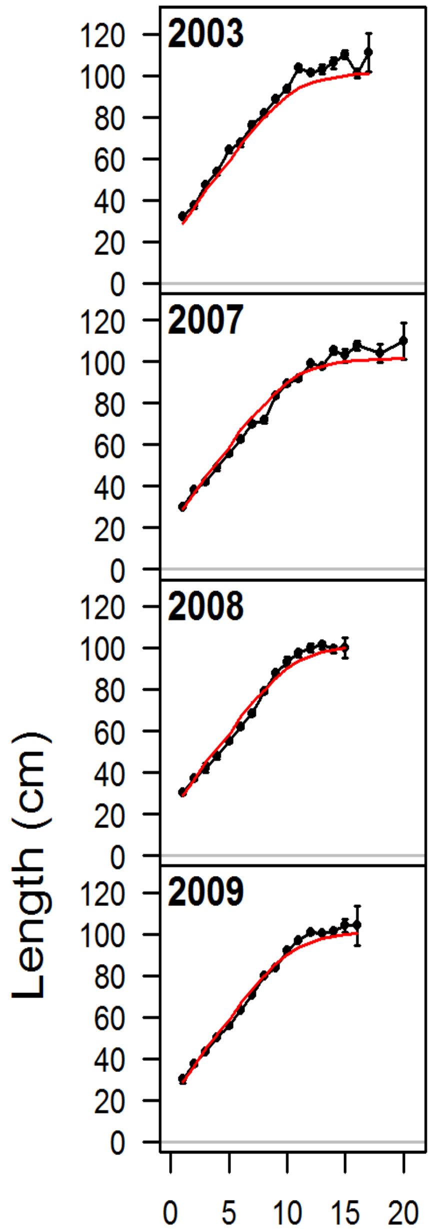

Figure 16. Observed (black circles) and model-predicted (red line) length-at-age for Model 2, the author's preferred model.

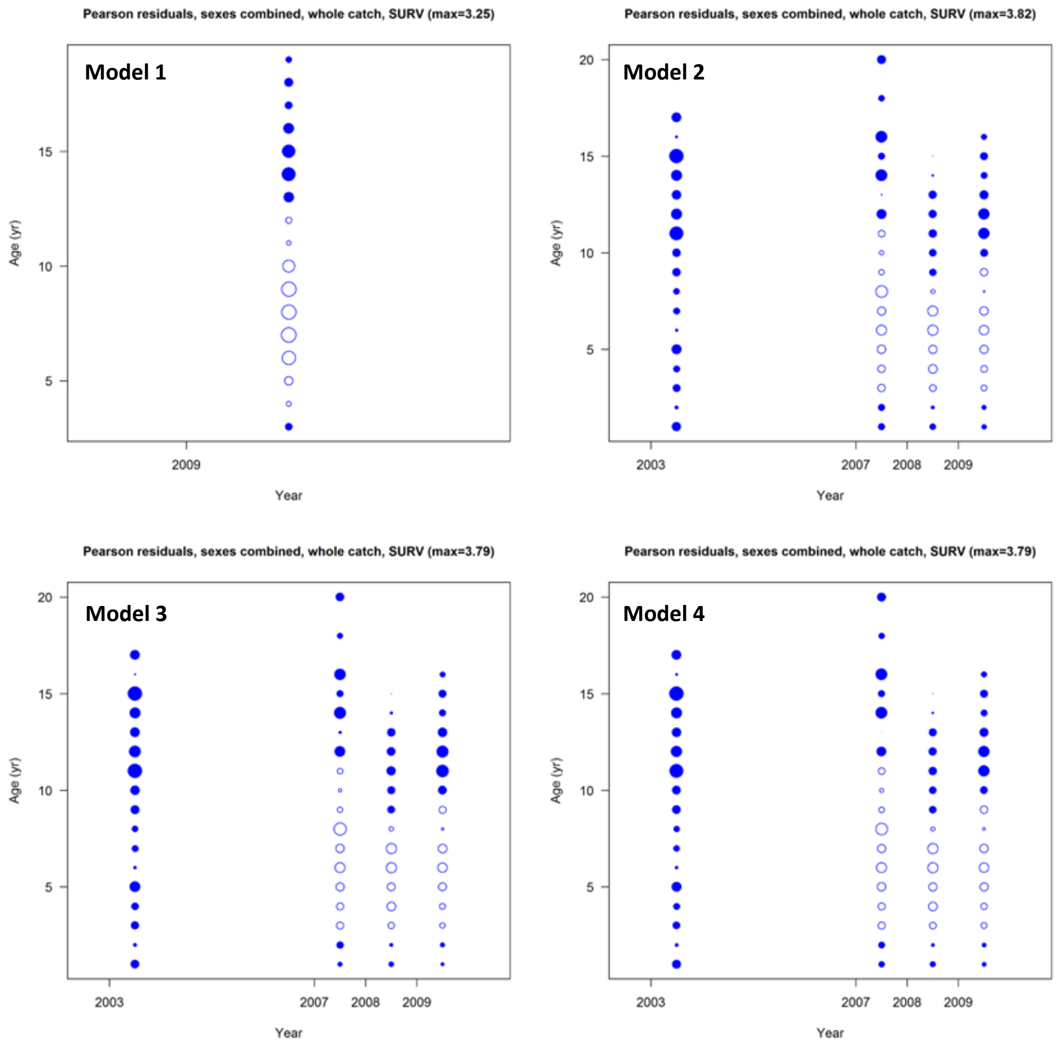

Figure 17. Pearson residuals for the length-at-age-datasets for the four models included in this report.

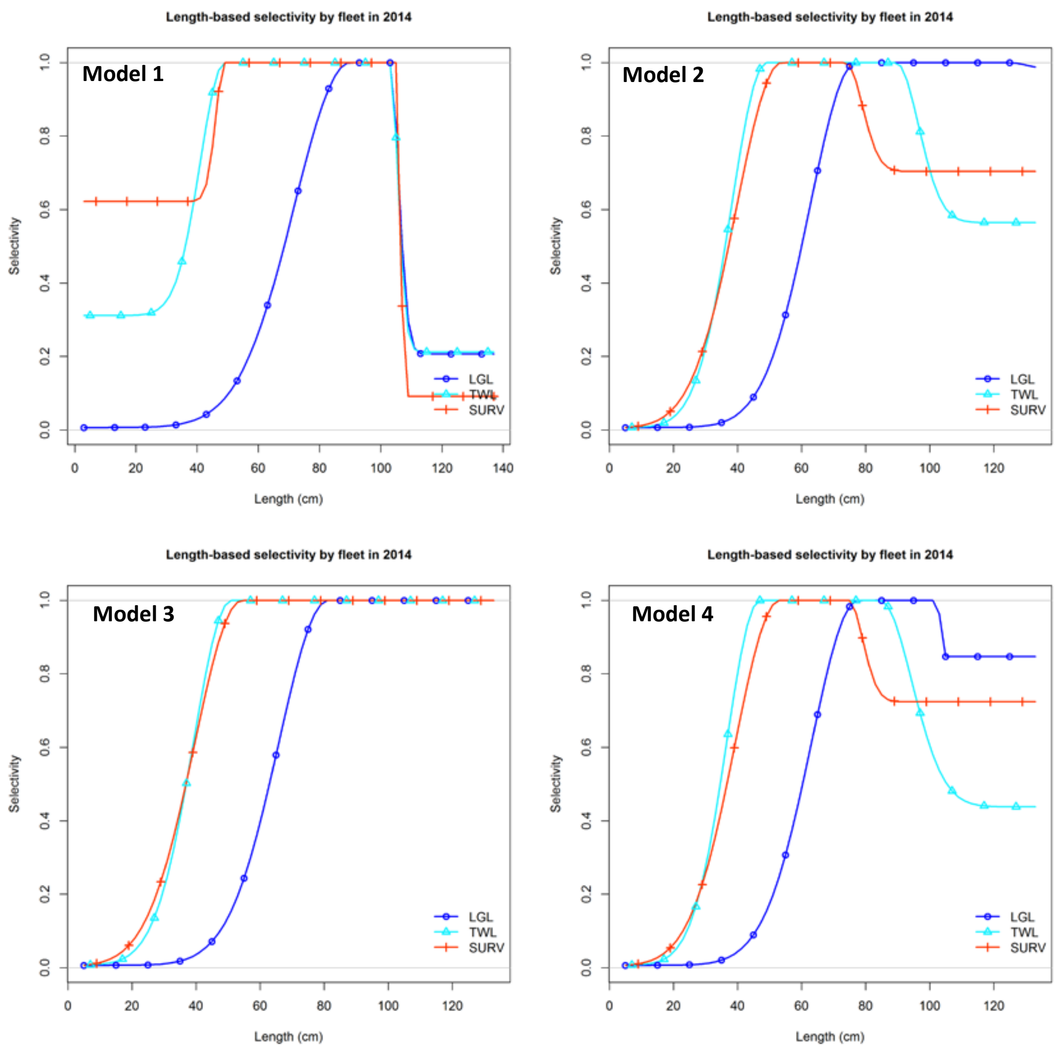

Figure 18. Selectivity functions for the four model alternatives. LGL = longline fishery, TWL = trawl fishery, SURV = trawl survey.

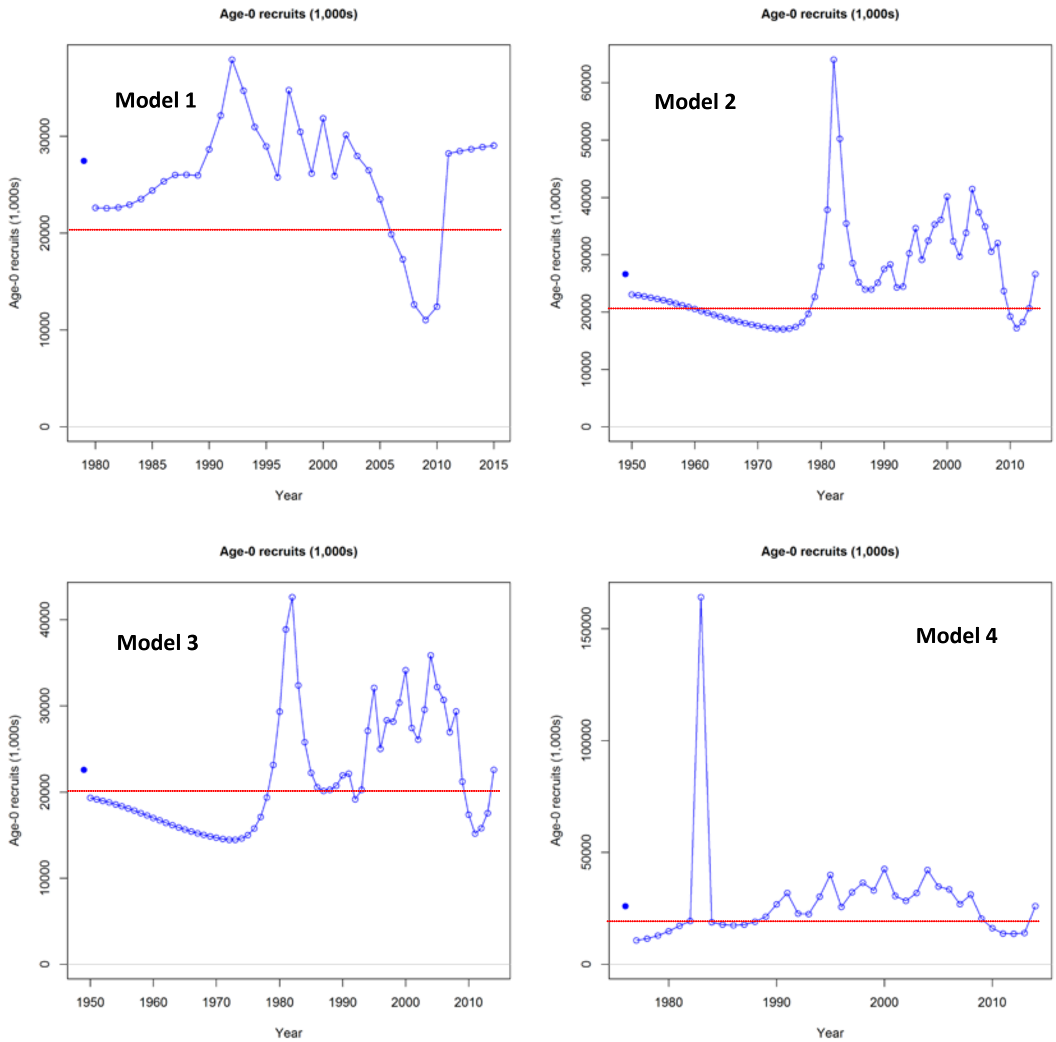

Figure 19. Time series of recruitment for the 4 alternative models. Filled blue circle indicates unfished recruitment. Vertical axis scales differ among plots; dashed red horizontal line indicates identical values among plots.

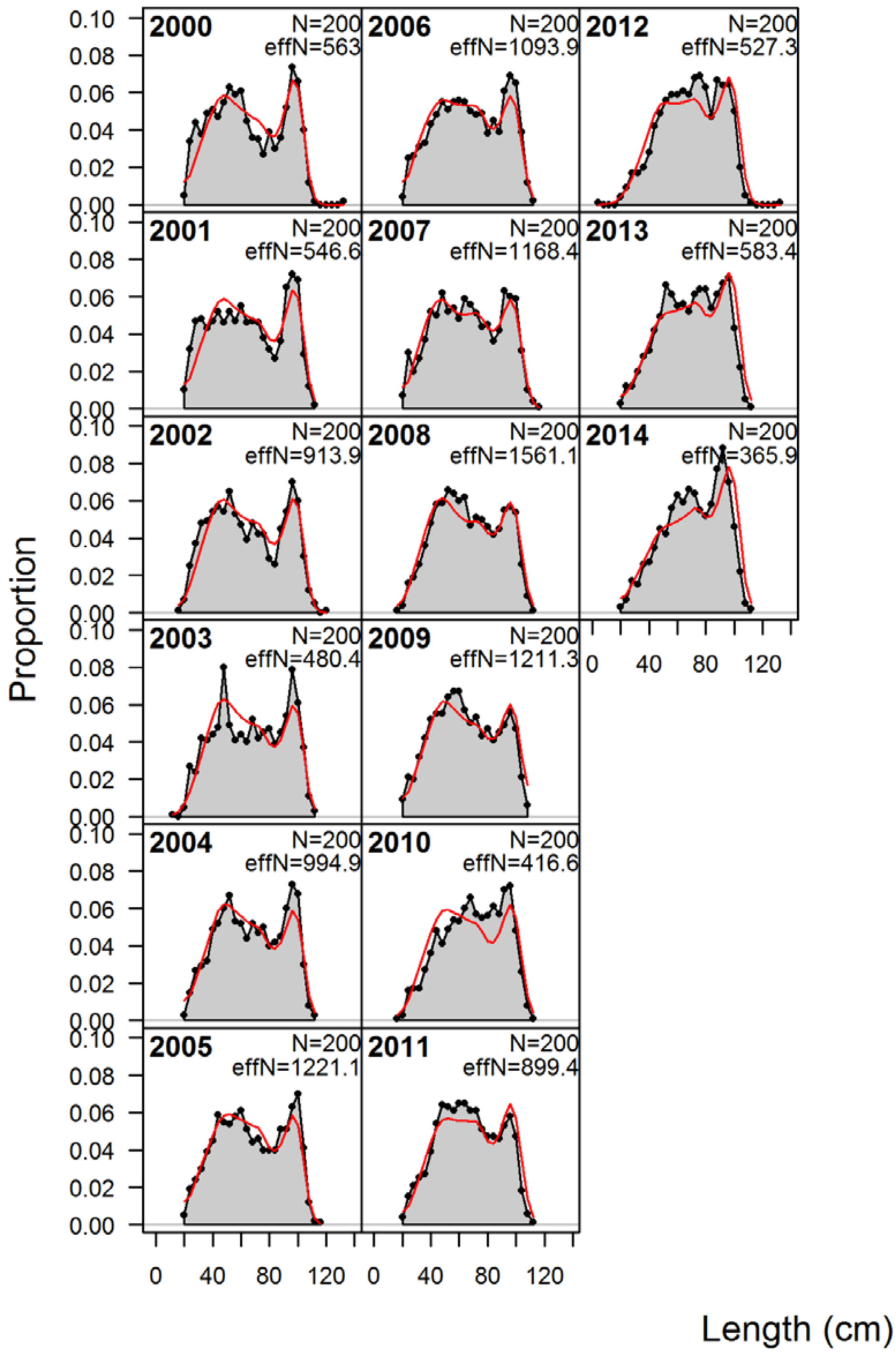

Figure 20. EBS shelf survey length compositions from 2000-2014. Grey shading = observed proportions; red line = model predictions. X-axis values are lengths in cm.

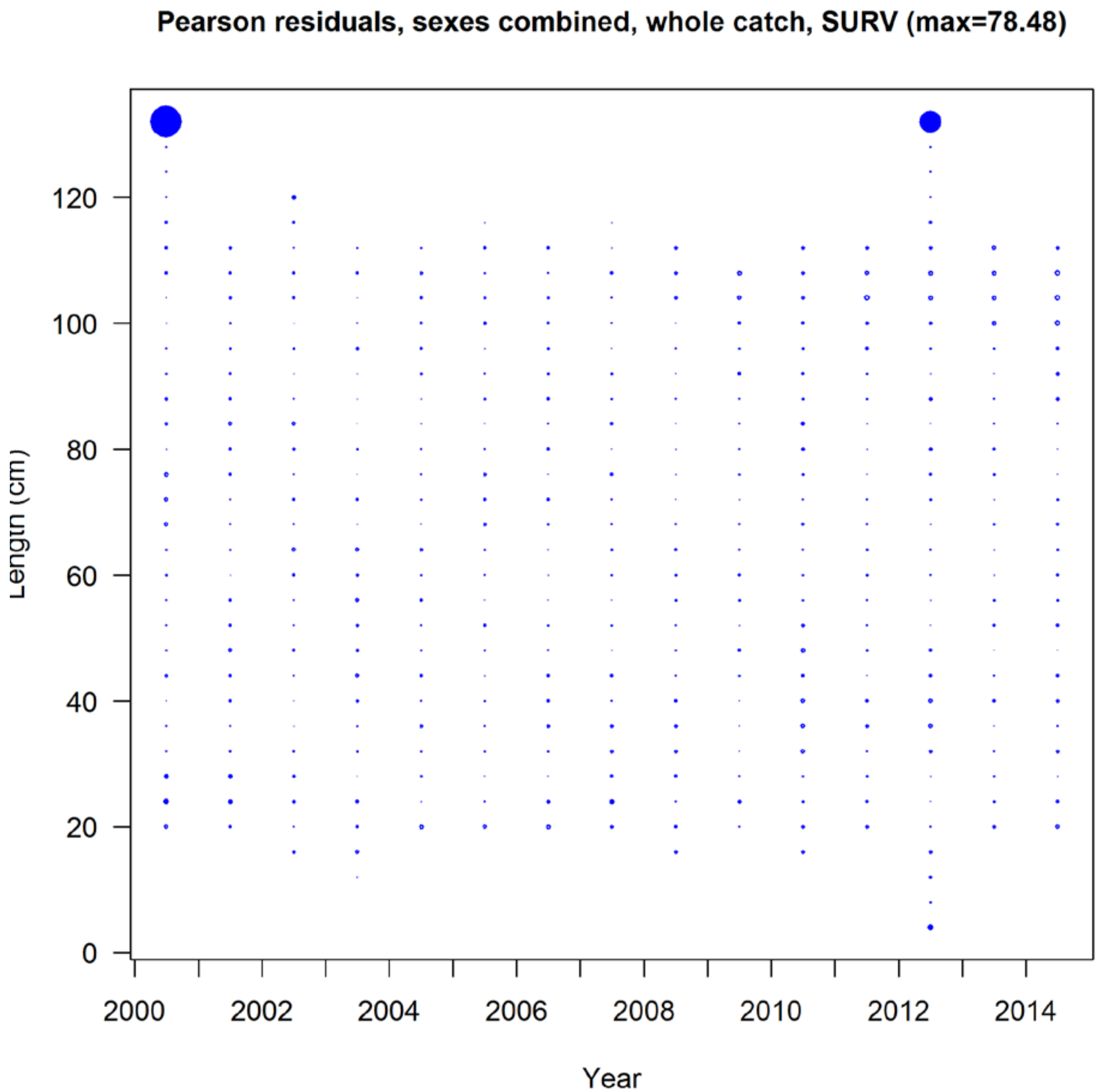

Figure 21. Pearson residuals for model fit to survey length composition data. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 78.48. Solid circles indicate positive residuals, open circles indicate negative residuals.

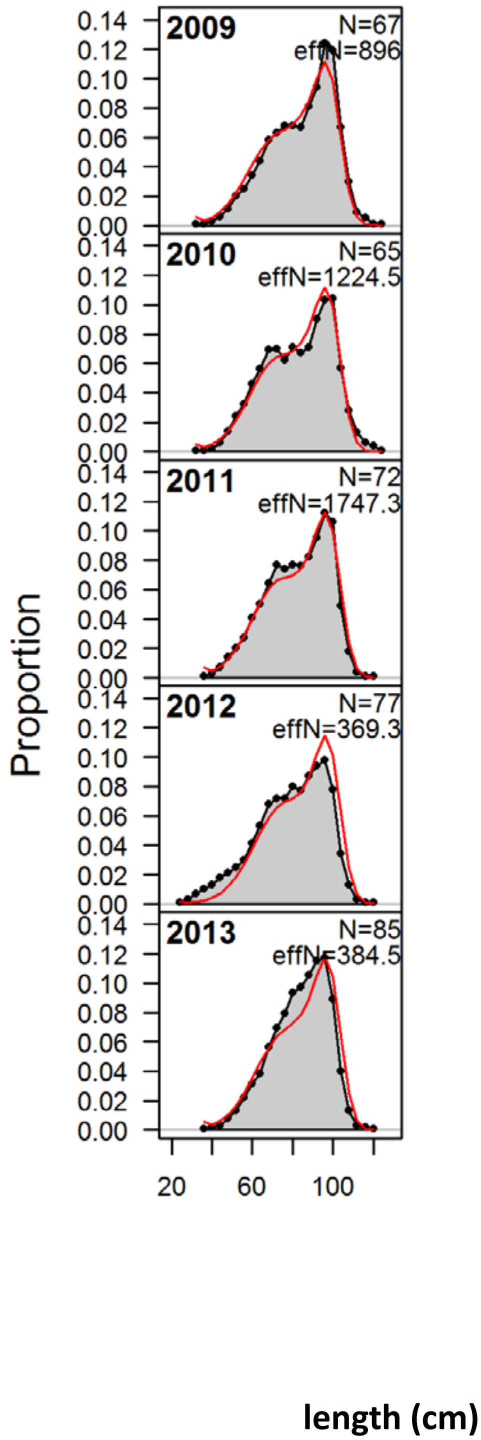

Figure 22. Observed and model-predicted length compositions from the 2009-2013 longline fisheries, with model predictions. Grey shading = observed proportions; red line = model predictions.

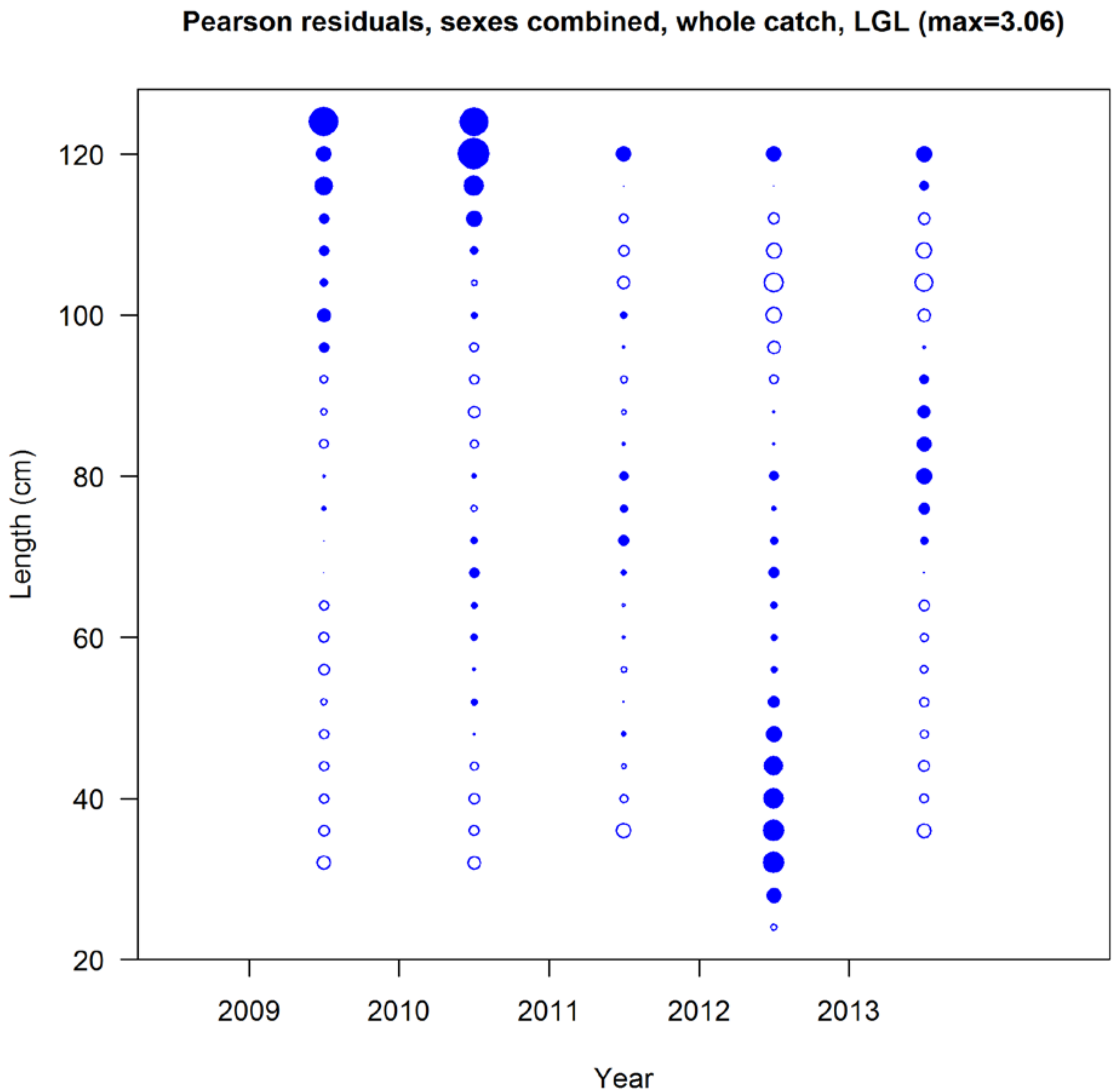

Figure 23. Pearson residuals for model fit to longline fishery length composition data, 2009-2013. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 3.06. Solid circles indicate positive residuals, open circles indicate negative residuals.

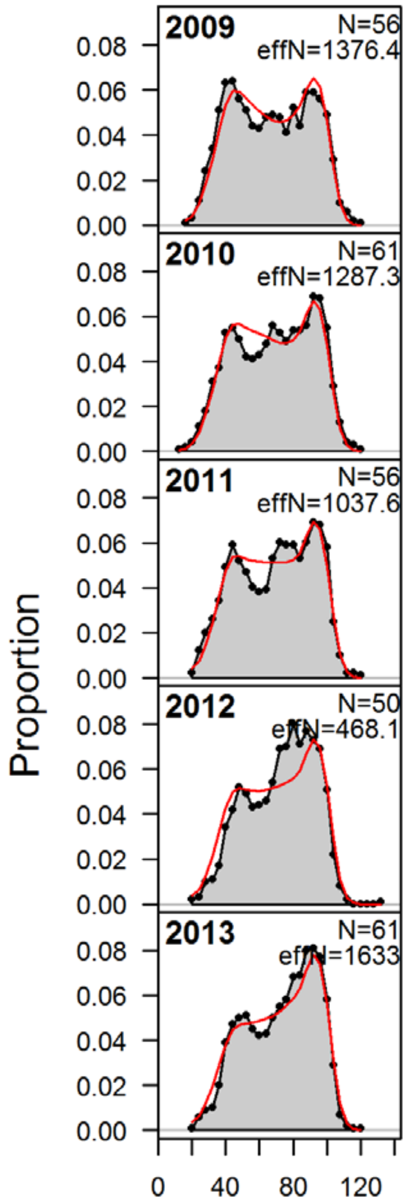

Figure 24. Observed and model-predicted length compositions from the 2009-2013 trawl fisheries, with model predictions. Grey shading = observed proportions; red line = model predictions.

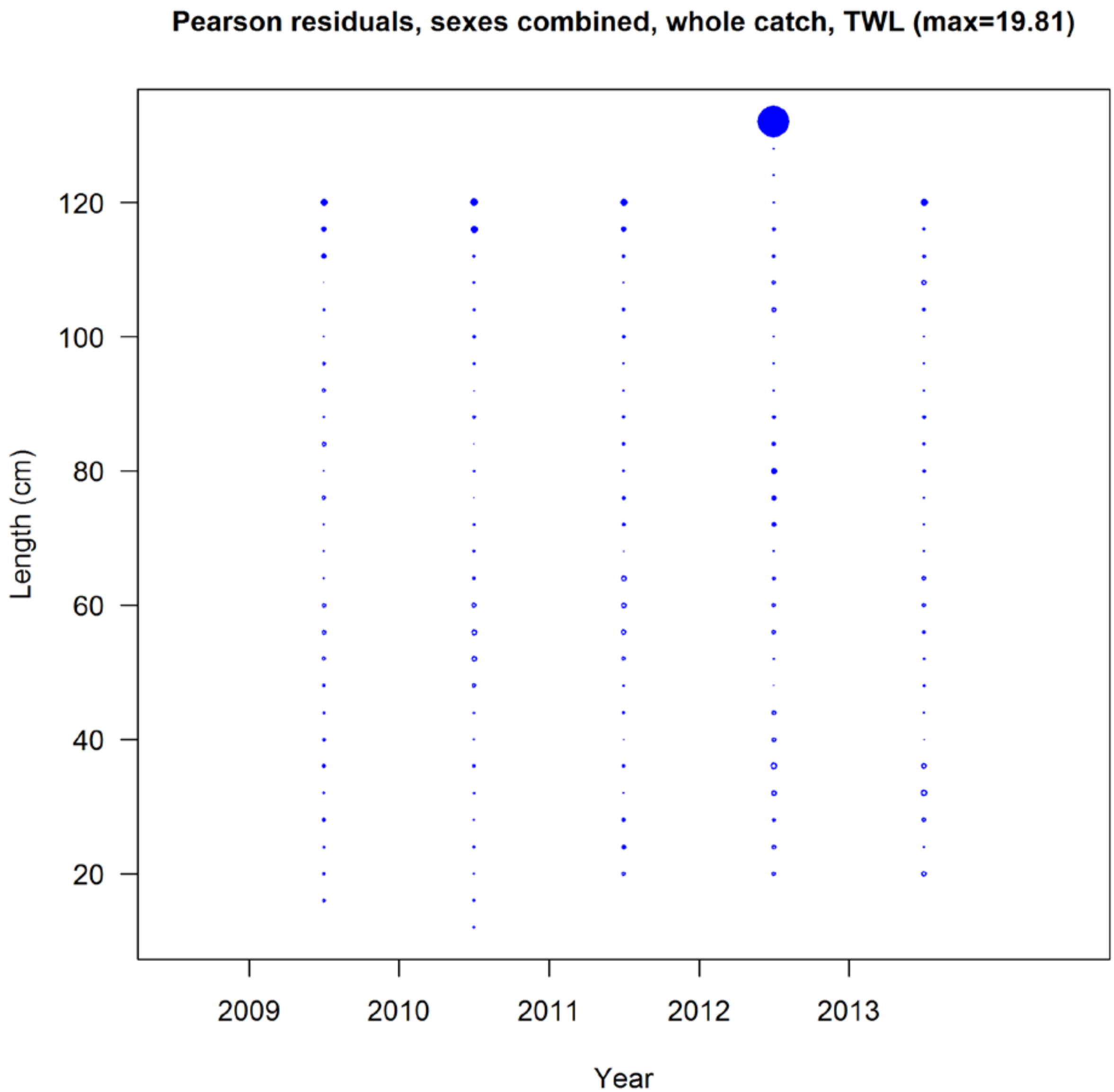

Figure 25. Pearson residuals for model fit to trawl fishery length composition data, 2009-2013. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 19.81. Solid circles indicate positive residuals, open circles indicate negative residuals.

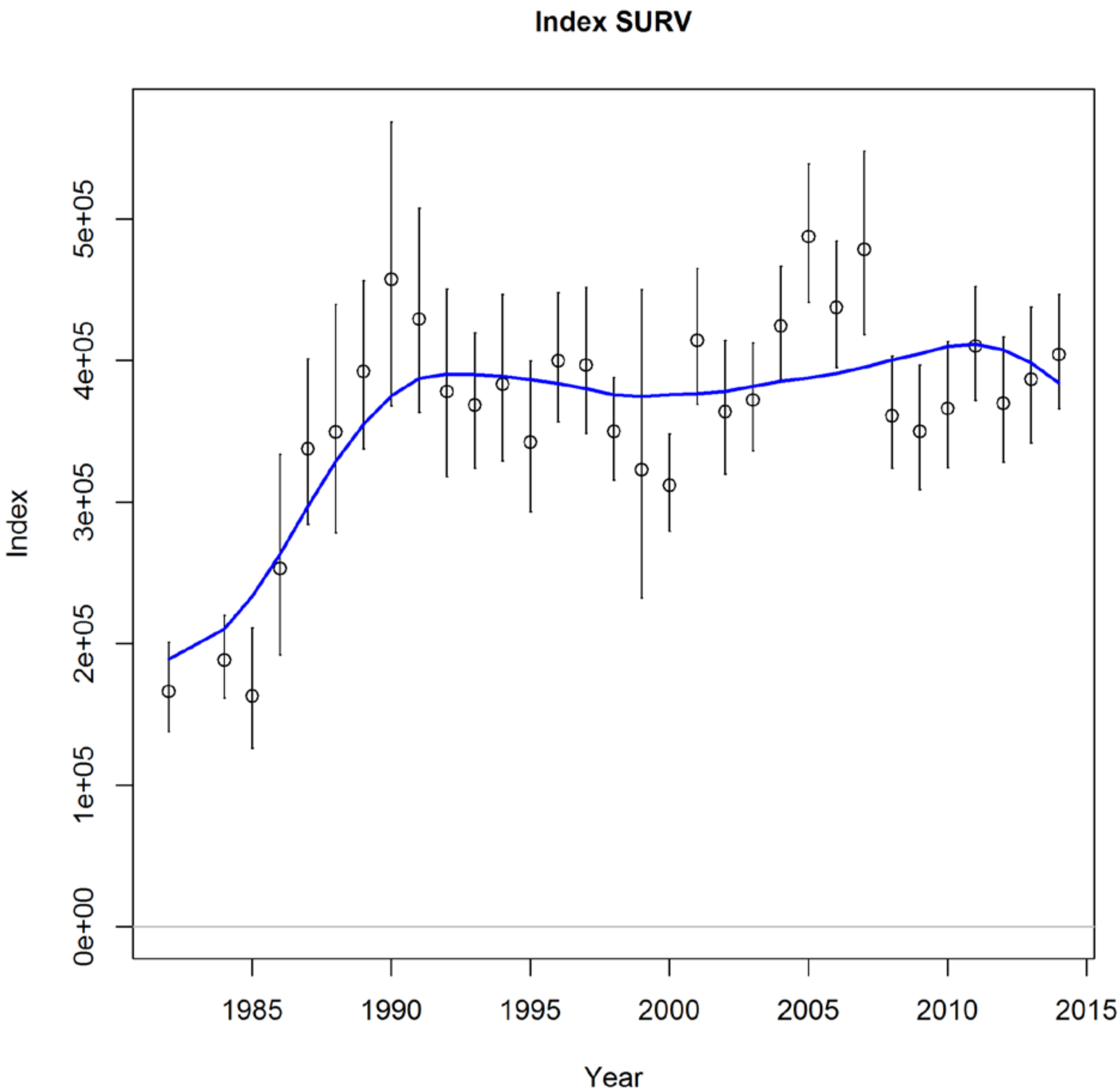

Figure 26. Observed biomass (circles) from EBS shelf surveys 1982-2014, with confidence intervals (± 2 SE), and predicted survey biomass from the model (blue line).

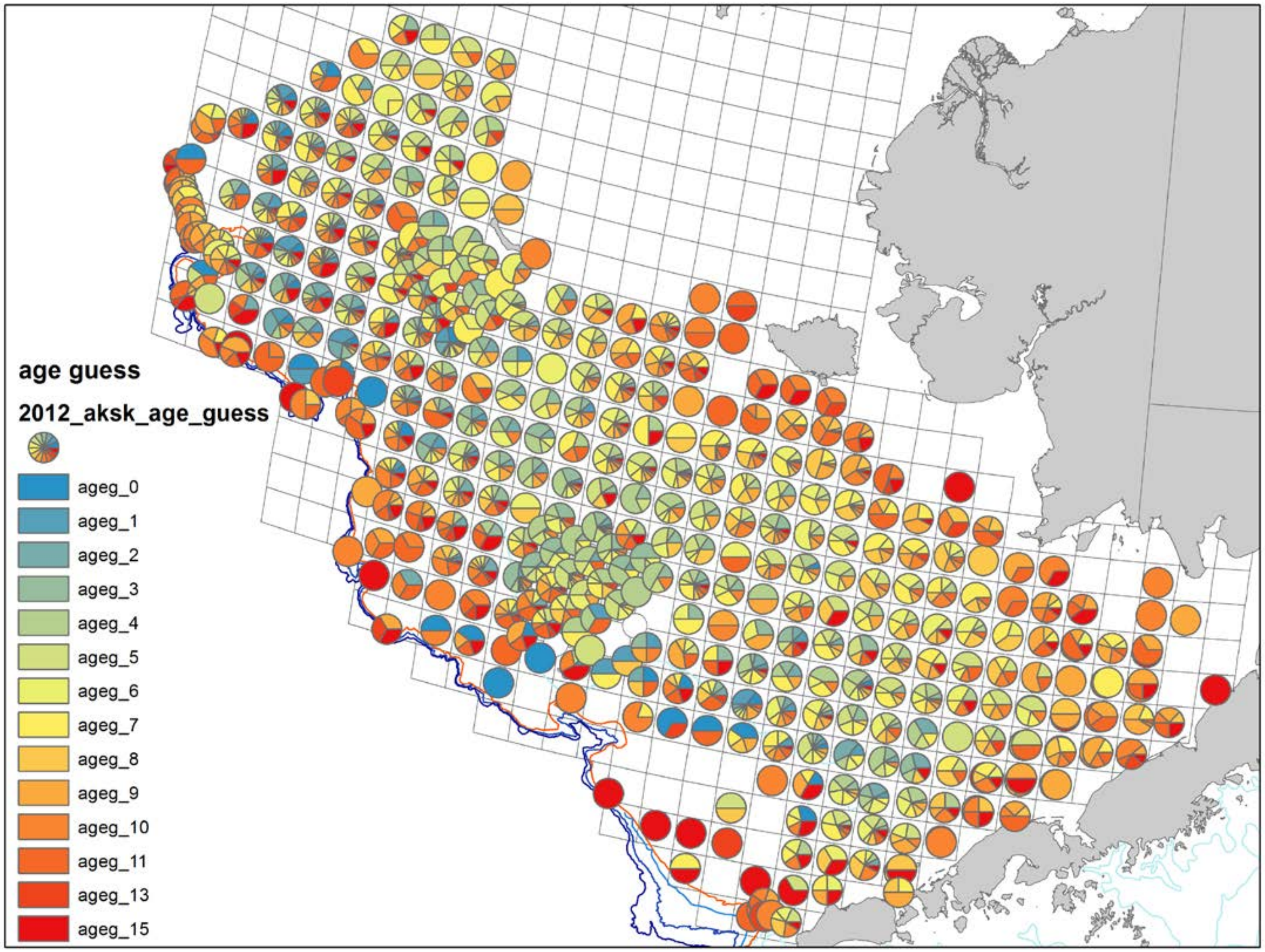

Figure 27. Proportional distribution of Alaska skates in the BSAI by estimated age ("age guess"). Data include the EBS shelf and slope surveys, and each circle indicates a survey haul. Length data were converted to estimated age by interpolating mean length-at-age data from the 2009 survey.

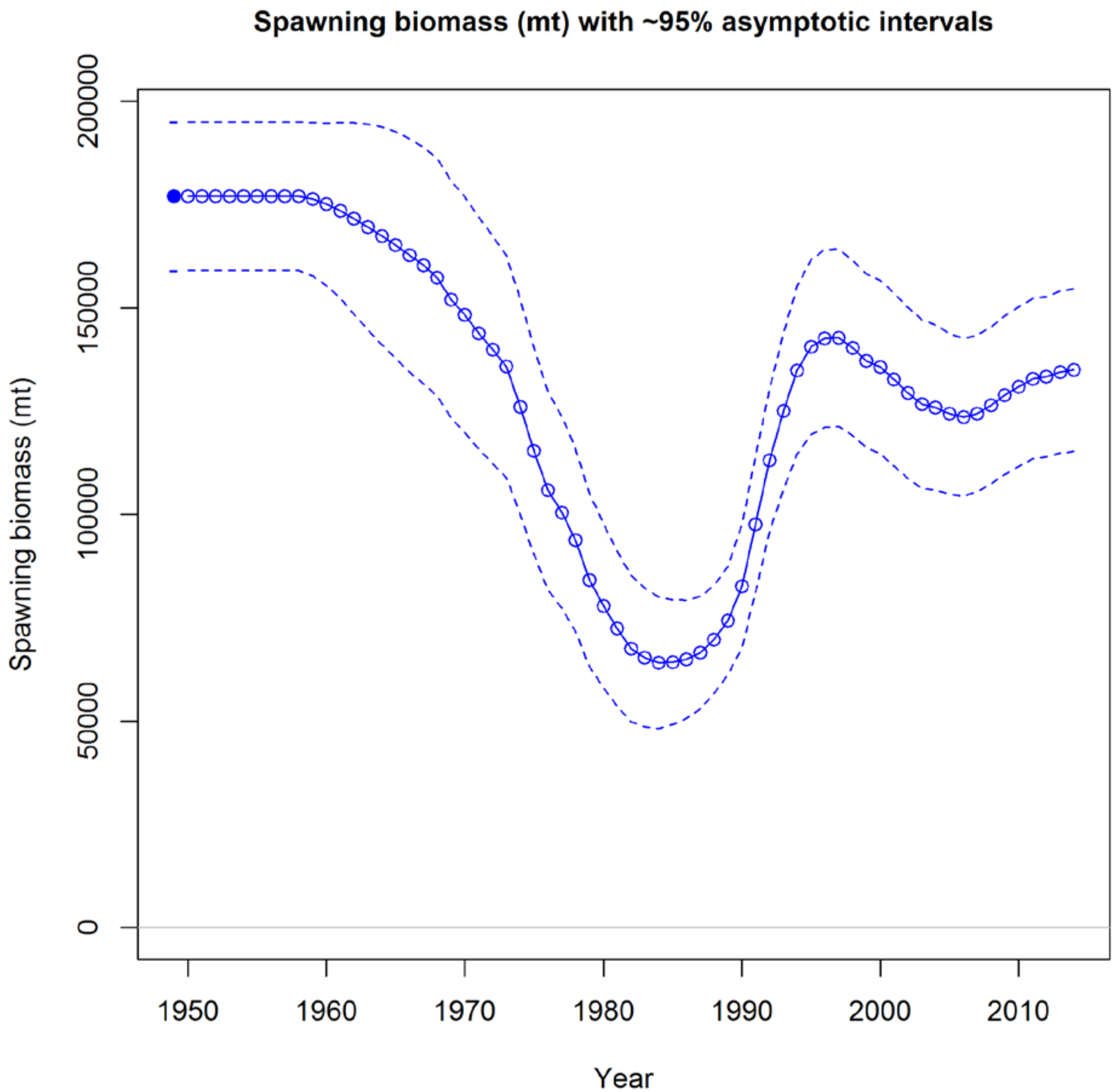

Figure 28. Model estimate of Alaska skate female spawning biomass. Dashed lines indicate 95% confidence interval.

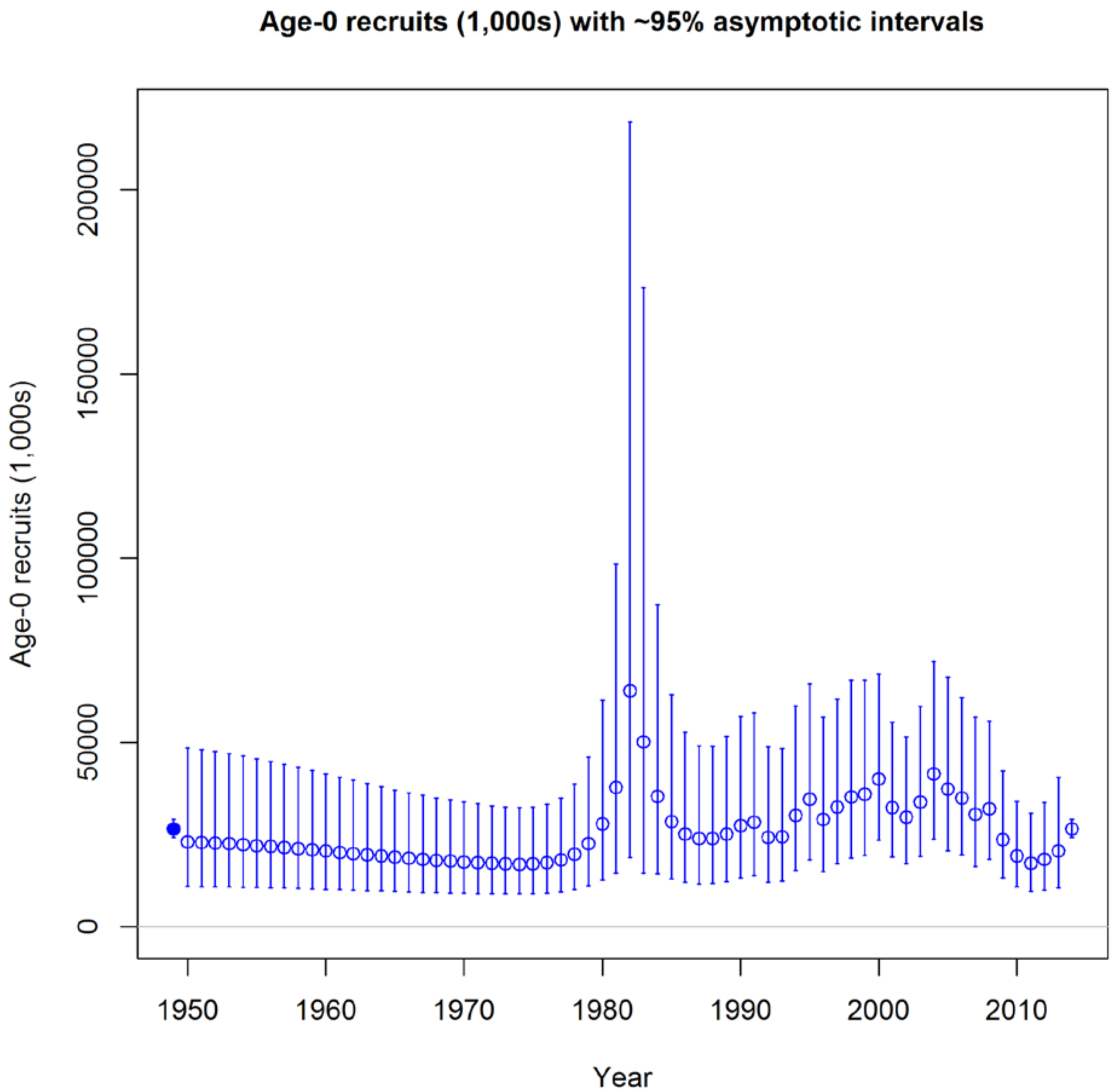

Figure 29. Model estimate of age-o recruitment of Alaska skates, with 95% confidence interval.

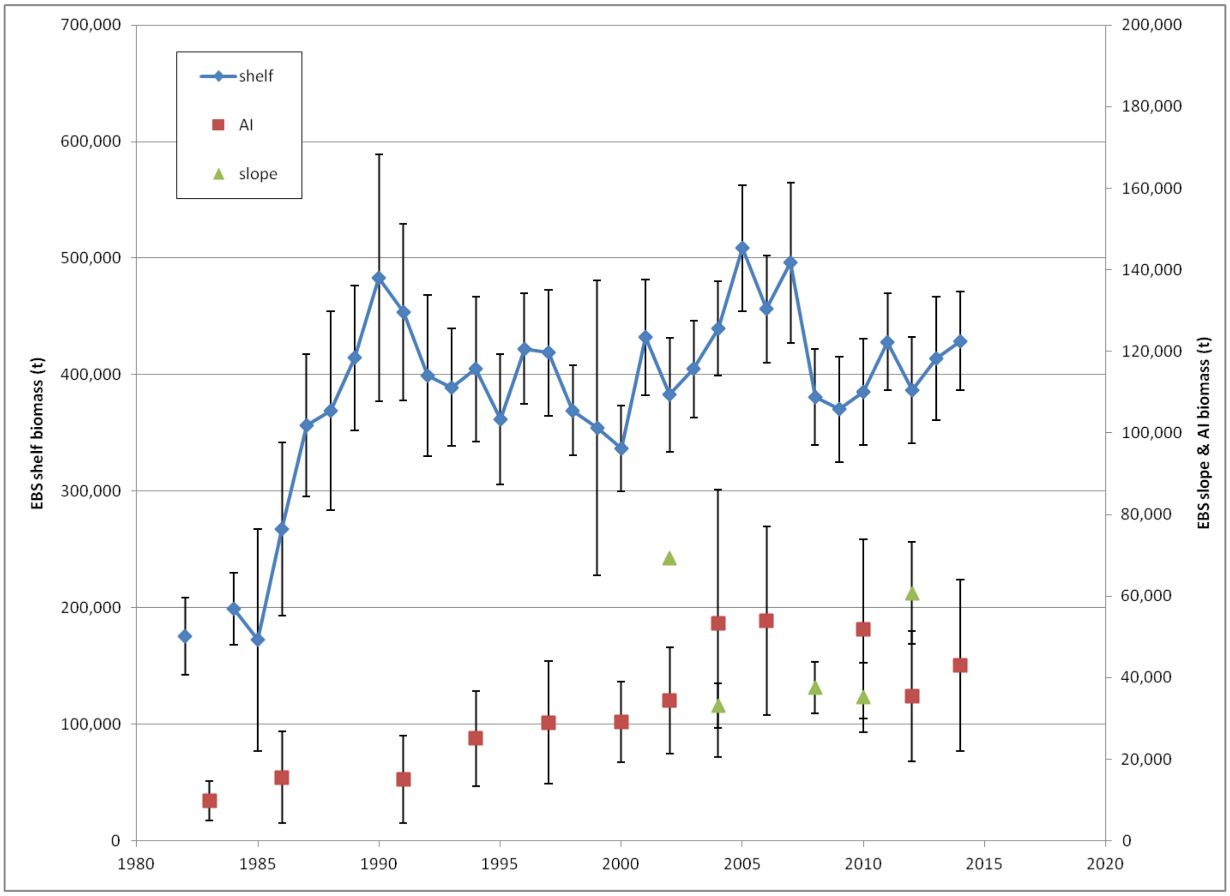

Figure 30. Aggregated skate biomass (t) and 95% confidence intervals estimated from RACE bottom trawl surveys in each of the three major habitat areas (1982 – 2014). Note that slope and AI estimates are much smaller and pertain to the secondary y-axis.

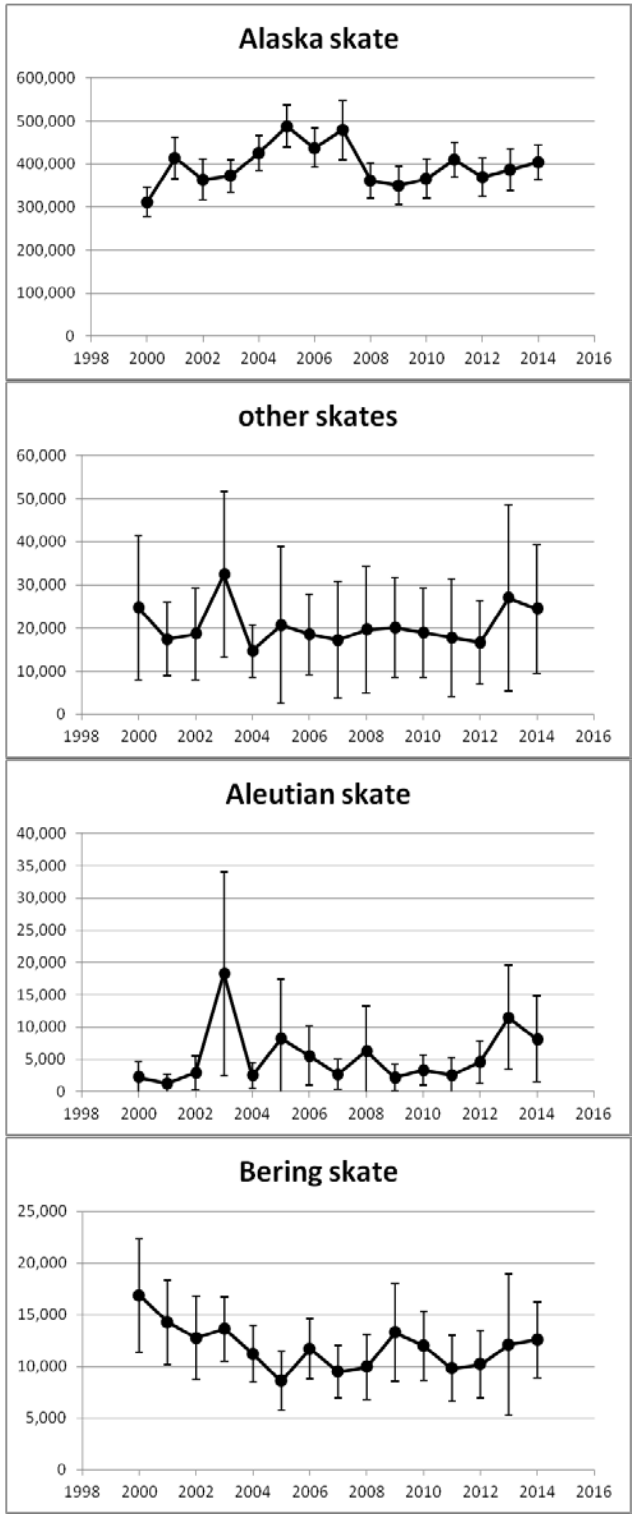

Figure 31. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS shelf. “Other skates” includes Aleutian and Bering skates and is included here to complement the skate management units. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, with greatest biomass at the top.

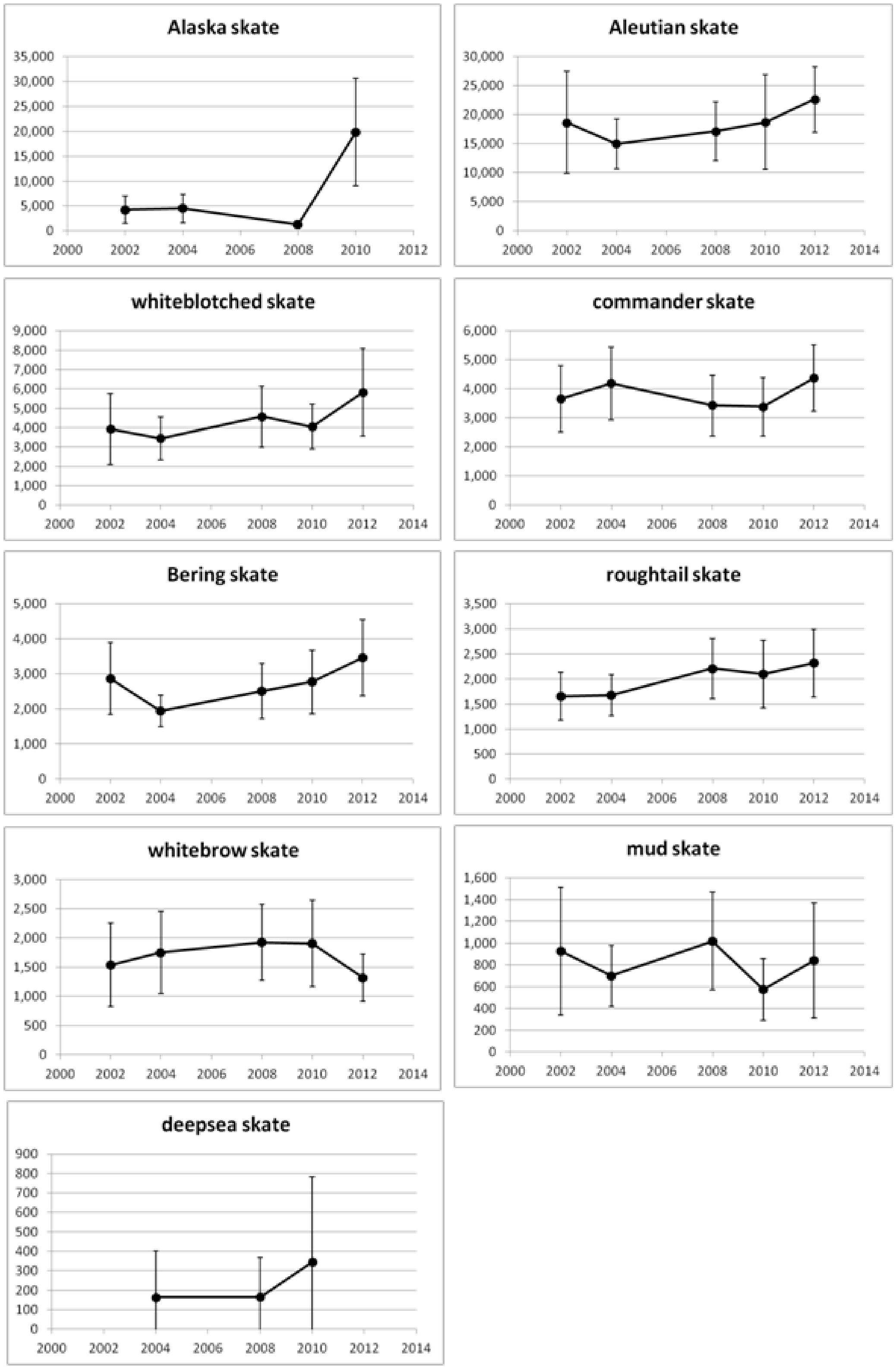

Figure 32. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS slope. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, from top left.

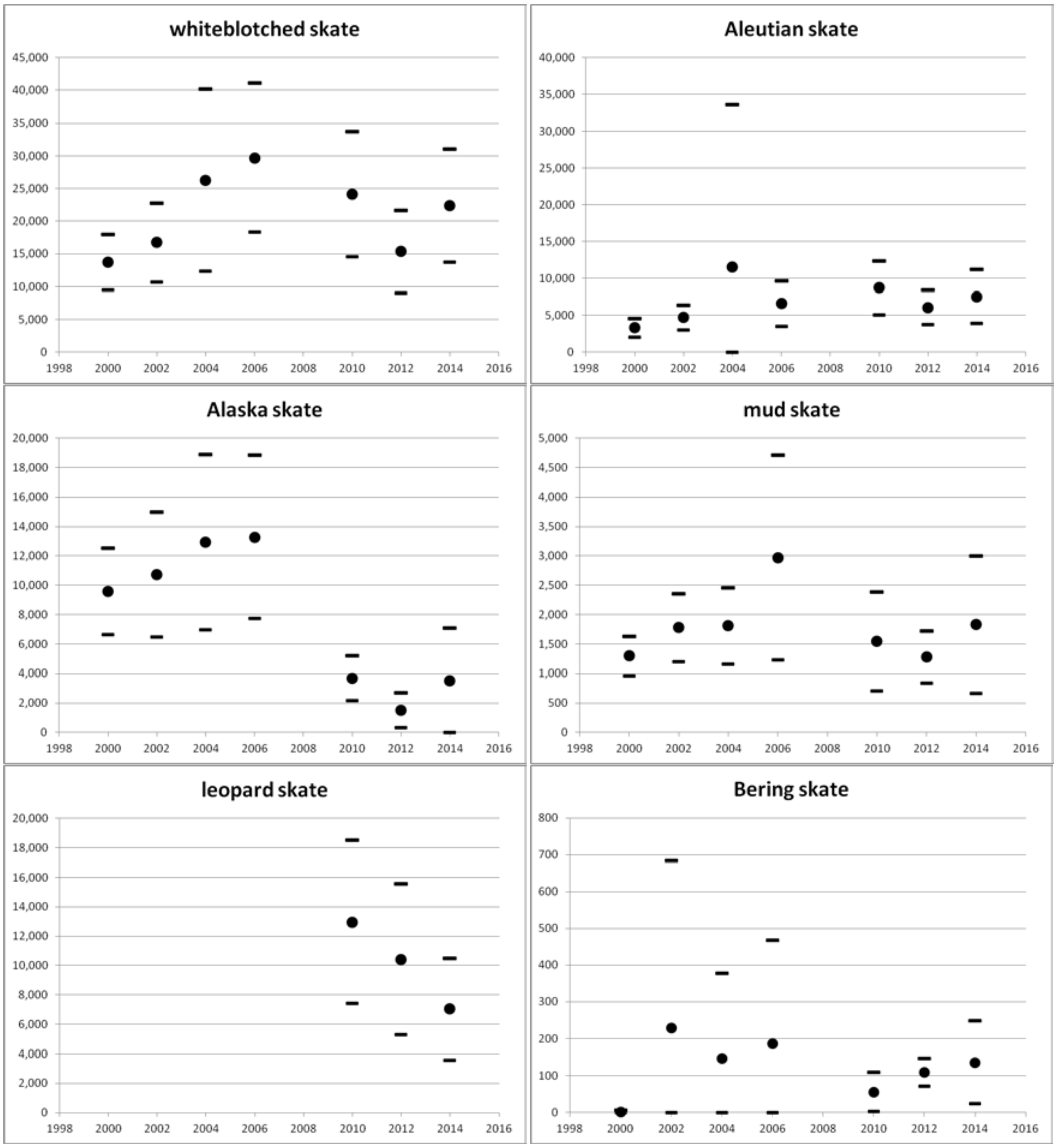

Figure 33. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates in the Aleutian Islands. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, from top left.

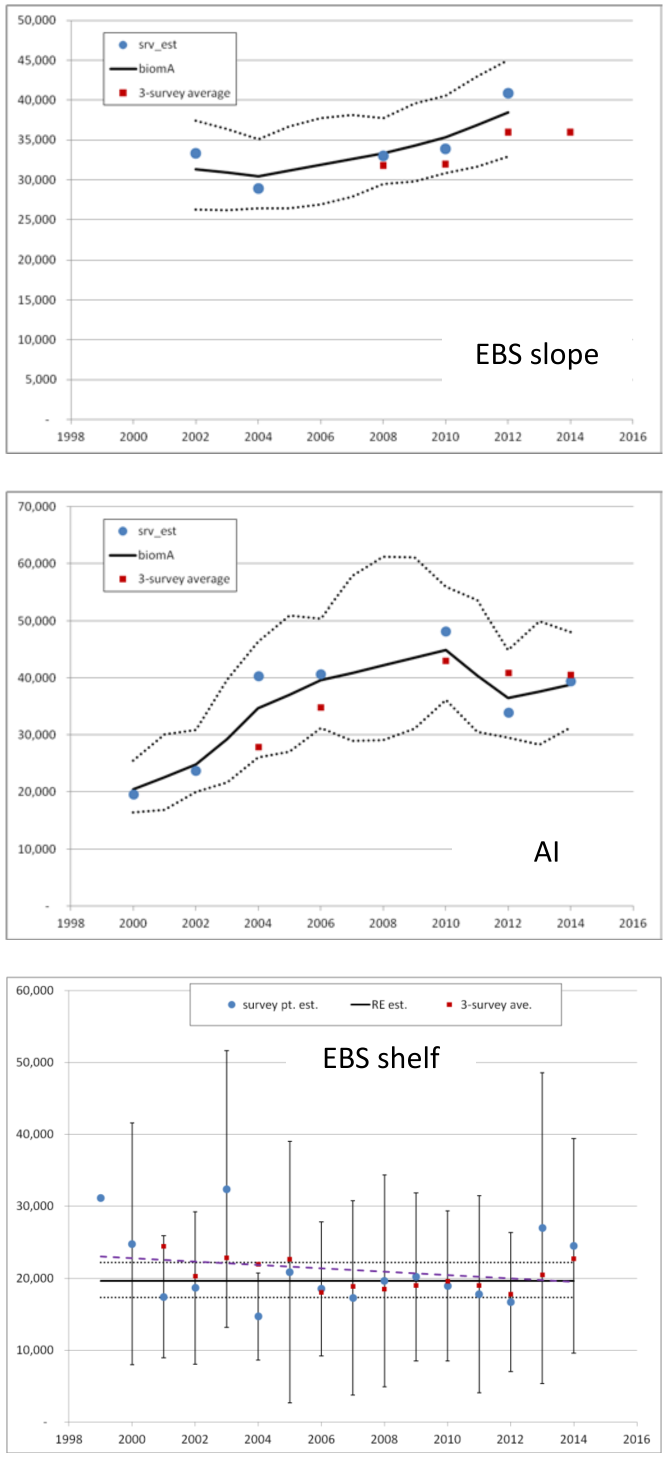

Figure 34. Estimates of "other skate" biomass from different sources for each of the 3 bottom trawl surveys conducted in the BSAI region (EBS slope, top; Aleutian Islands, middle; EBS shelf, bottom). Estimates are: point estimates from the bottom trawl survey (blue circles), 3-survey running averages (red squares), and random effects (RE) model results (black line). Dashed black lines indicate 95% confidence interval for the RE estimate. For the EBS shelf plot, error bars are the 95% confidence interval for the survey point estimates and the purple dashed line indicates the linear fit to the survey point estimates.

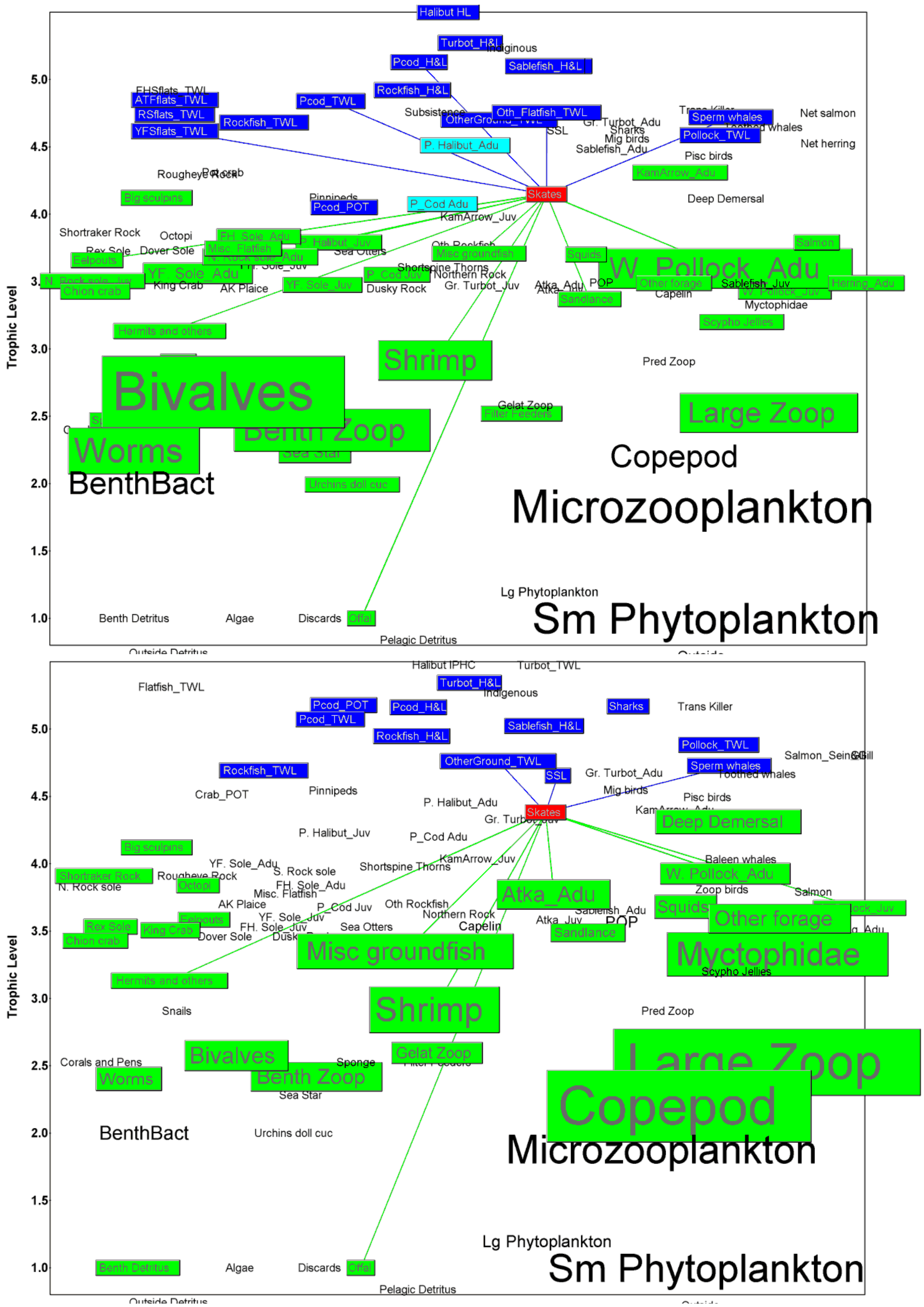

Figure 35. EBS (upper panel) and AI (lower panel) skate food webs derived from mass balance ecosystem models, with skate species aggregated in each area. Source: K. Aydin, AFSC, code available upon request.

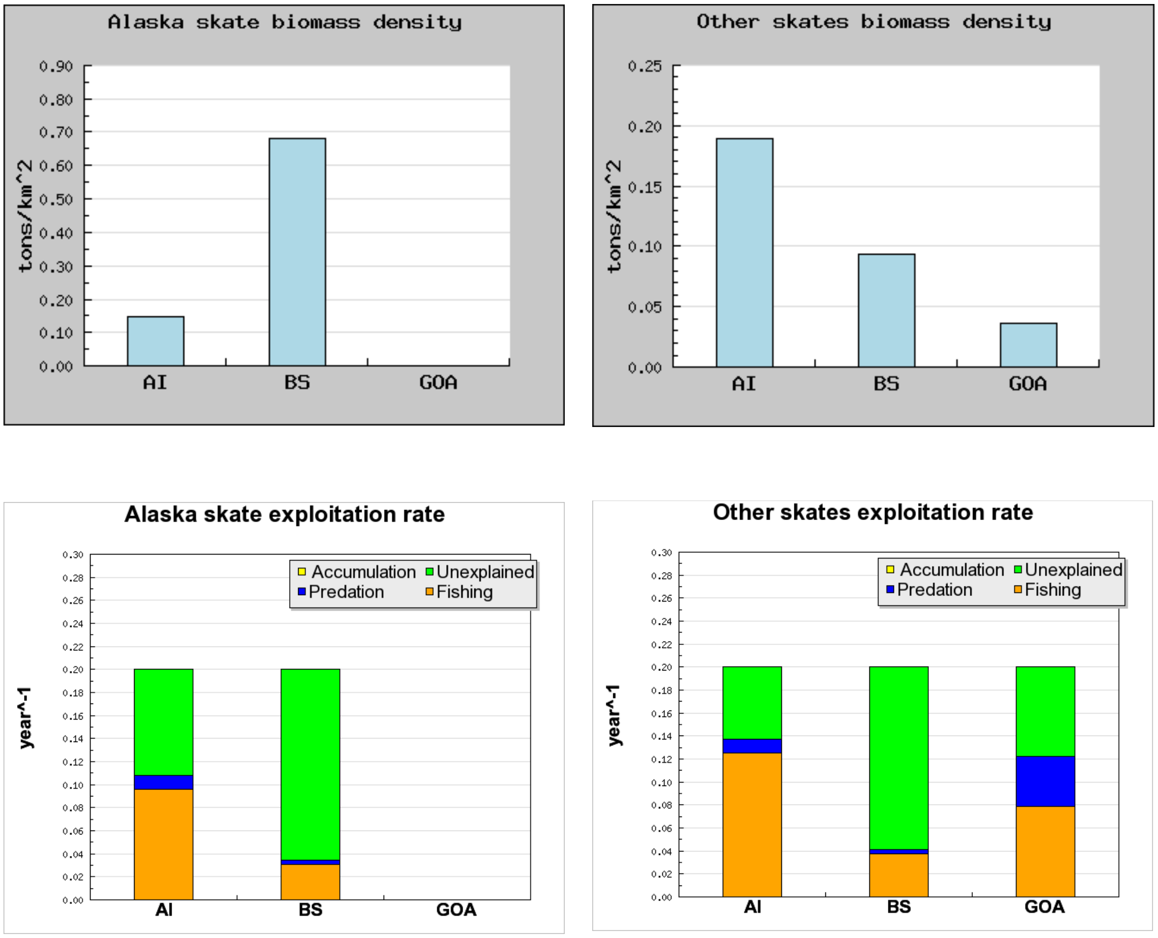

Figure 36. Comparative density (upper panels) and exploitation rate (lower panels) of Alaska (left panels) and all other *Bathyraja* (right panels) skates in the AI, EBS, and GOA (early 1990s, before fishery in GOA). (Alaska skates are a very small component of skate biomass in the GOA, and are therefore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

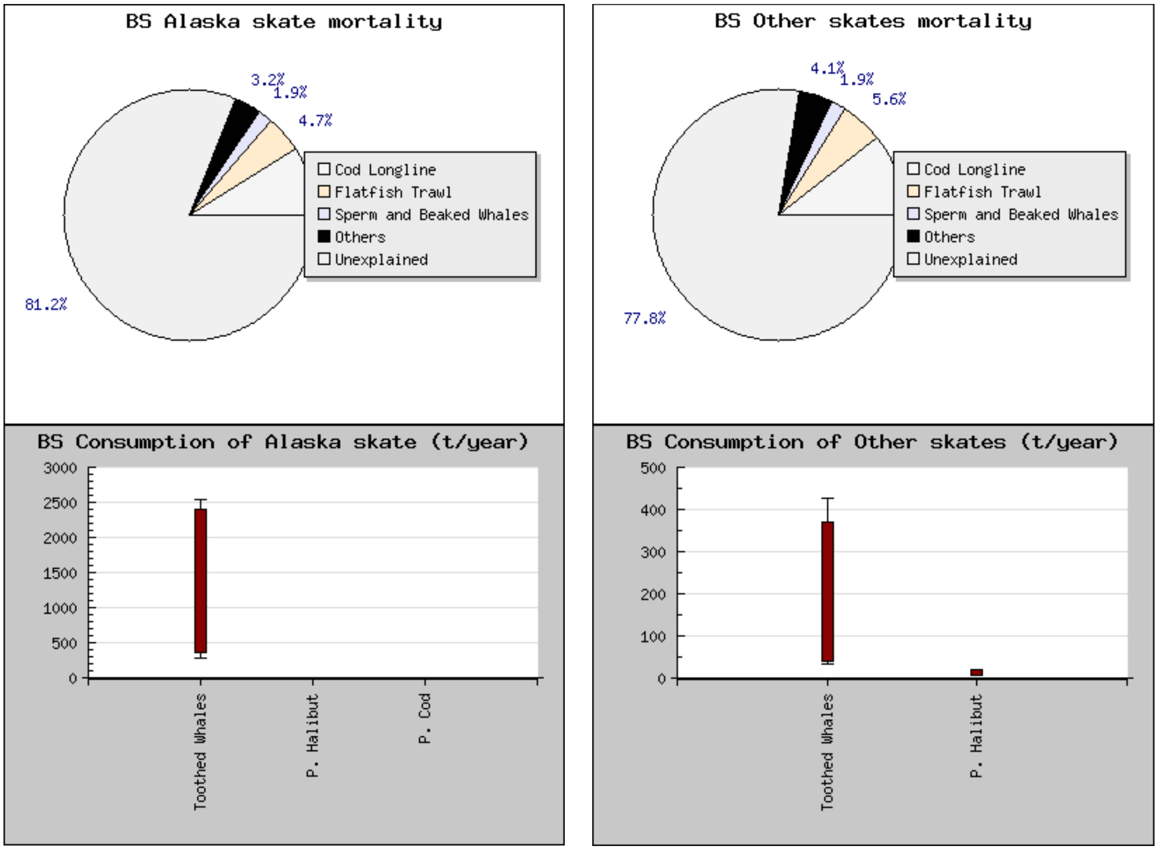

Figure 37. Mortality sources and consumption of skates in the EBS—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for EBS Alaska skates (left panels) and all other EBS skates (right panels). Model outputs were derived from diet compositions, production rates,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

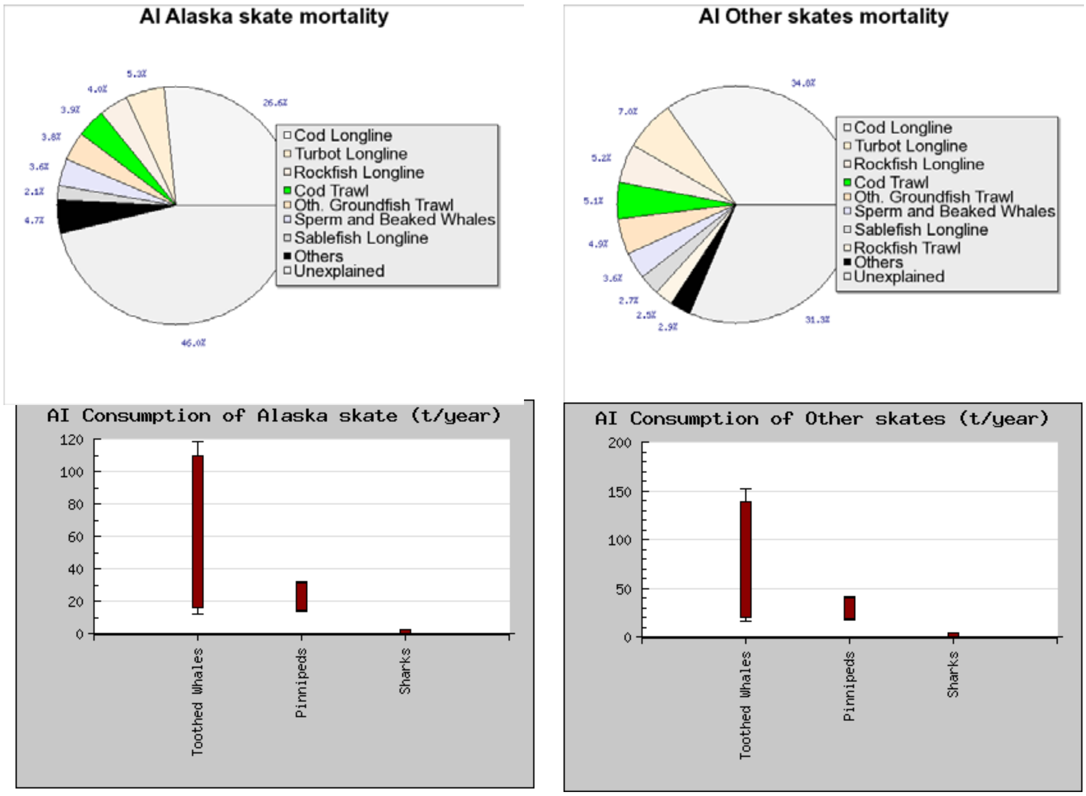

Figure 38. Mortality sources and consumption of skates in the AI—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for AI (former) Alaska skate (left panels) and AI Other Skates (right panels). Model outputs were derived from diet compositions, production rates,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

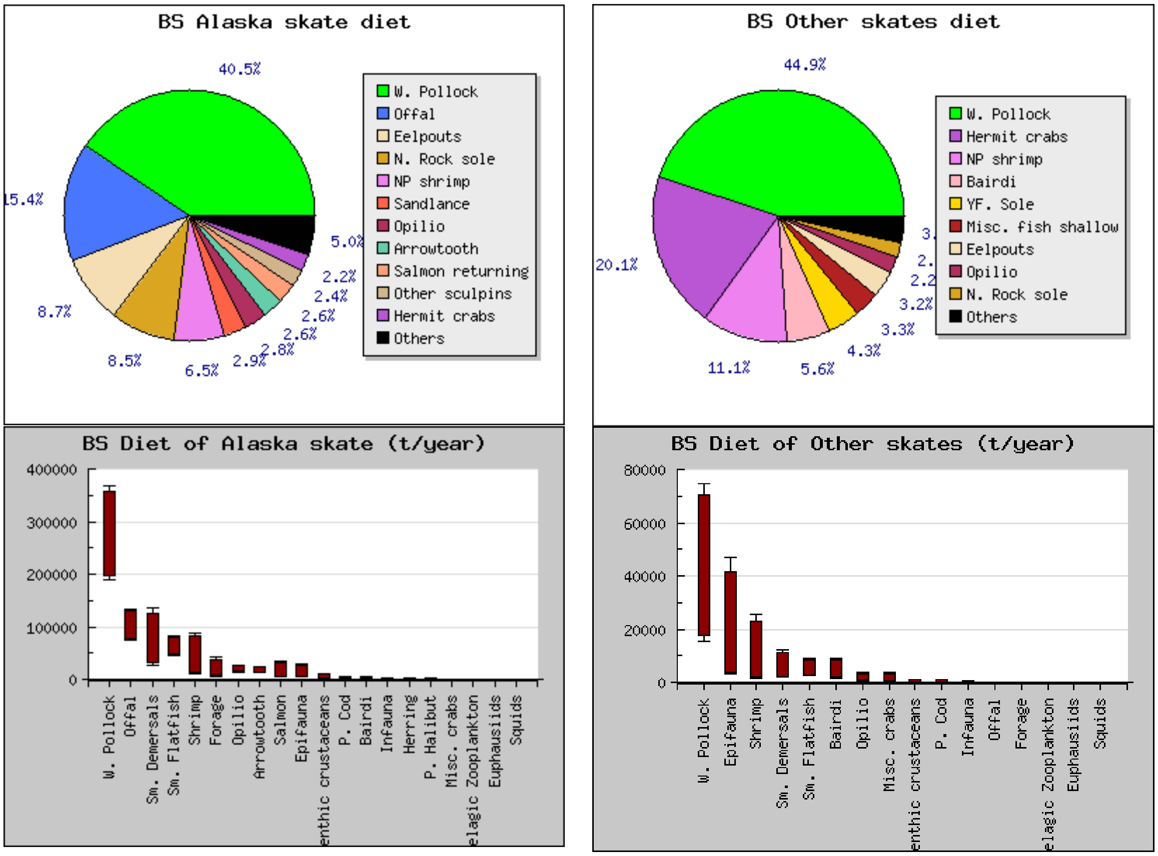

Figure 39. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for EBS Alaska skates (left panels) and Other Skates (right panels). Results were generated from stomach content collections occurring during RACE trawl surveys.

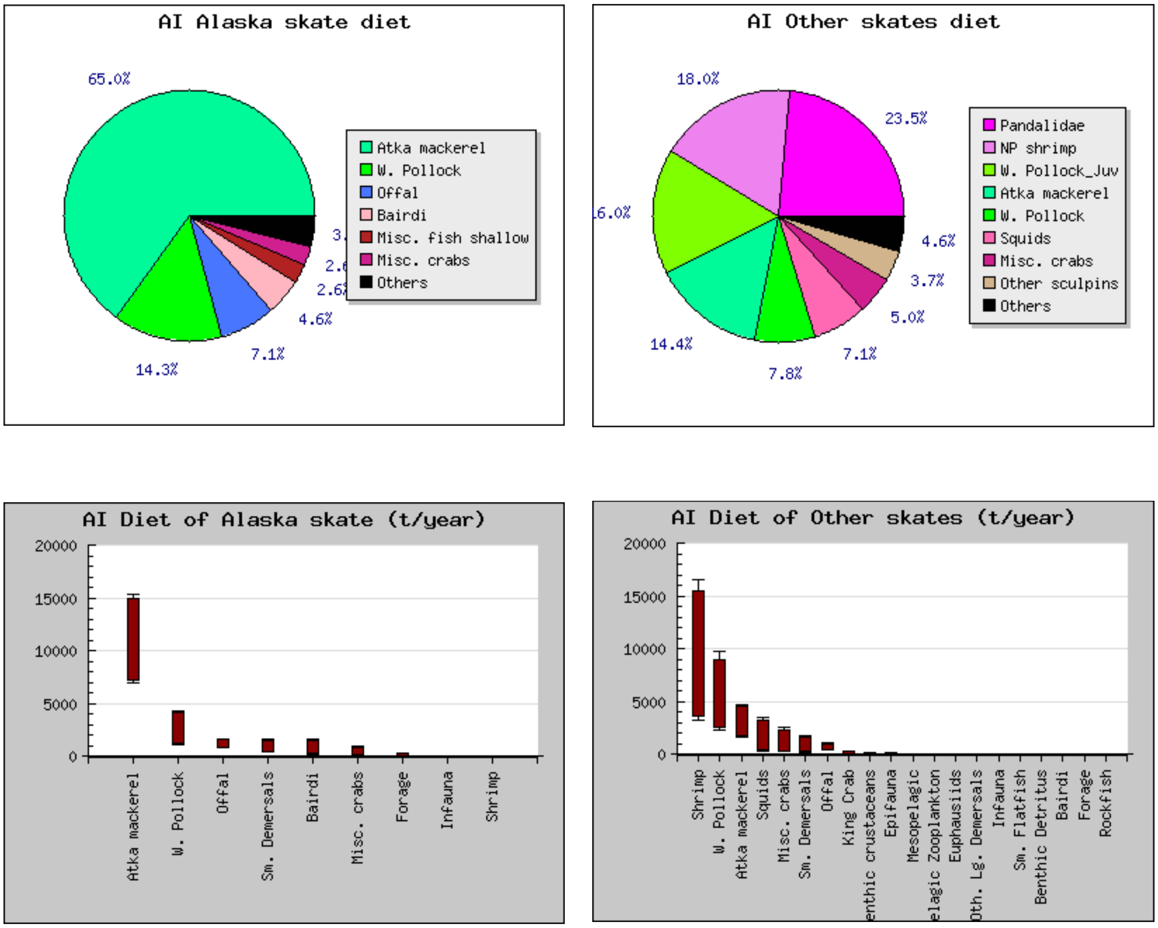

Figure 40. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for AI Alaska skates (left panels) and Other Skates (right panels). Consumption rates were estimated using published diet data from the Kuril Islands (Orlov 1998, 1999) and estimated prey densities.

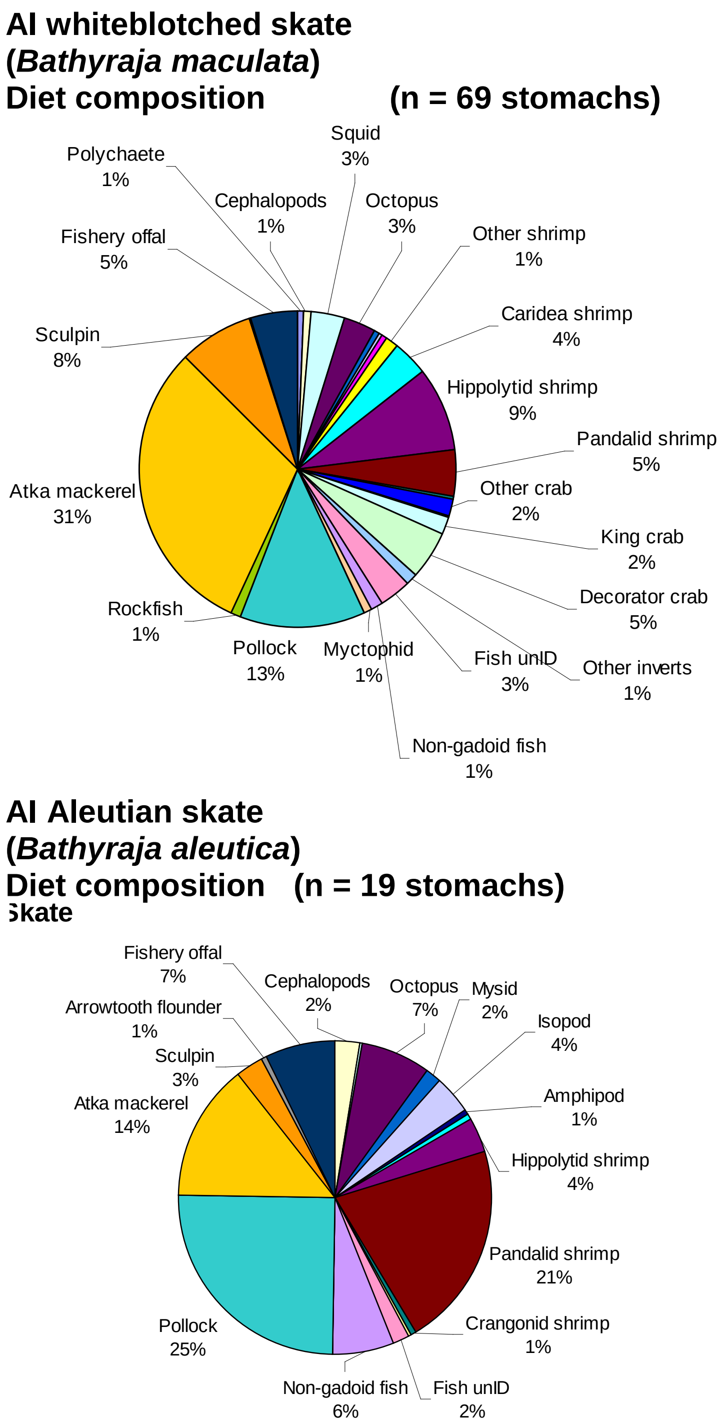

Figure 41. Diet composition (by weight) for the other two biomass-dominant skate species in the Aleutian Islands (AI,which are included in the “Other Skates” group in the previous figure): whiteblotched skate (top) and Aleutian skate (bottom). Results were generated from stomach content collections occurring 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.

	Aleutian Island Bottom Trawl Survey	Aleutian Islands Cooperative Acoustic Survey	Annual Longline Survey	Atka Tagging Survey	Bering Sea Bottom Trawl Survey	Bering Sea Slope Survey	Eastern Bering Sea Bottom Trawl Survey	Golden King Crab Pot Survey	Gulf of Alaska Bottom Trawl Survey	IPHC Annual Longline Survey	Large-Mesh Trawl Survey	Northern Bering Sea Bottom Trawl Survey	Pollock EFP 11-01	Pribilof Islands Crab Survey	St. Mathews Crab Survey	Summer EBS Survey with Russia	**Grand Total**
1996			5,359														**5,359**
1997			14,827														**14,827**
1998			10,849														**10,849**
1999			14,076														**14,076**
2000			8,926														**8,926**
2001			14,832														**14,832**
2002			8,104														**8,104**
2003			17,131														**17,131**
2004			6,886														**6,886**
2005			14,046														**14,046**
2006			10,570														**10,570**
2007			22,576														**22,576**
2008		3	11,326														**11,329**
2009			7,455														**7,455**
2010	7,675		6,093		31,118	9,567				41,976	232	4,929			568		**102,157**
2011			5,393	19,786			34,540		25	25,617	215		1,451	2			**87,029**
2012	4,889		7,459			17,593	29,330	23		27,786	139		1.1E+06			70	**1.2E+06**
2013			7,980				28,925		211	42,782	138						**80,036**
2014	6,166						29,396										**35,562**

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