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

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Executive Summary

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

Summary of Changes in Assessment Inputs

<u>Changes in the input data:</u>

1) Catch data have been updated through October 16, 2016.
2) New biomass estimates from the 2016 eastern Bering Sea (EBS) shelf, EBS slope, and Aleutian Islands bottom trawl surveys have been added.
3) The Alaska skate model now incorporates EBS shelf survey biomass estimates through 2016, EBS shelf size compositions through 2016, fishery length compositions through 2015, catch data through 2016, and an additional length-at-age dataset from vertebrae collected during 2015 on the EBS shelf trawl survey.

<u>Changes in assessment methodology:</u>

1) There were no changes to the assessment methodology. Model 14.2, approved in 2014, continues to be the author's preferred model. Model 14.2 was updated to include new catch and survey data as well as a new length-at-age dataset.
2) The random effects model continues to be used for estimating biomass for the "other skates" group, and was updated to include 2015 and 2016 survey biomass estimates.

Summary of results

1) The results of the Alaska skate were similar to those presented in 2014. Although the 2016 EBS shelf survey biomass estimate was substantially higher that in 2014, the model predicted a slight decline in spawning biomass. As a result the harvest recommendations are slightly lower than in 2015.
2) Total skate biomass increased on the EBS shelf after 2014, while it declined in the Aleutian Islands. Total skate biomass on the EBS slope was slightly lower in 2016 relative to 2012.
3) Skate catches and retention in 2015 and 2016 were similar to recent years.
4) The project model indicates that Alaska skate is not overfished, subject to overfishing, or approaching an overfished condition.

Alaska skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year for: 2017*	2018*
M (natural mortality rate)	*0.13*	*0.13*	**0.13**	0.13
Tier	*3a*	*3a*	**3a**	3a
Projected total (age 0+) biomass (t)	*527,932*	*498,546*	**506,921**	487,035
Female spawning biomass (t)				
Projected	*115,378*	*112,087*	**110,180**	110,159
$B_{100\%}$	*186,923*	*186,923*	**180,556**	180,556
$B_{40\%}$	*74,769*	*74,769*	**72,222**	72,222
$B_{35\%}$	*65,423*	*65,423*	**63,195**	63,195
F_{OFL}	*0.090*	*0.090*	**0.092**	0.092
$maxF_{ABC}$	*0.077*	*0.077*	**0.079**	0.079
F_{ABC}	*0.077*	*0.077*	**0.079**	0.079
OFL (t)	*39,847*	*37,306*	**39,162**	37,365
maxABC (t)	*34,358*	*32,167*	**33,731**	32,183
ABC (t)	*34,358*	*32,167*	**33,731**	32,183
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

* Projections are based on catches equal to the estimated total Alaska skate catch for 2016 (25,139 t); see the Data-Catch section of the Alaska skate assessment.

other skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year for: 2017	2018
M (natural mortality rate)	*0.1*	*0.1*	**0.1**	0.1
Tier	*5*	*5*	**5**	5
Biomass (t)	*103,682*	*103,682*	**100,130**	100,130
F_{OFL}	*0.1*	*0.1*	**0.10**	0.10
$maxF_{ABC}$	*0.075*	*0.075*	**0.075**	0.075
F_{ABC}	*0.075*	*0.075*	**0.075**	0.075
OFL (t)	*10,368*	*10,368*	**10,013**	10,013
maxABC (t)	*7,776*	*7,776*	**7,510**	7,510
ABC (t)	*7,776*	*7,776*	**7,510**	7,510
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a

aggregate harvest recommendations for the BSAI complex				
	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2016	2017	2017	2018
OFL (t)	*50,215*	*47,674*	**49,063**	46,583
ABC (t)	*42,134*	*39,943*	**41,144**	39,008

Responses to SSC and Plan Team Comments on Assessments in General

There were no relevant comments in general from either the Plan Team or SSC.

Responses to SSC and Plan Team Comments Specific to this Assessment

From the November 2014 BSAI Plan Team minutes:
For Alaska skates, the Team concurred with the author and recommended Model 2. However, concern about the change in estimated spawning biomass between the two assessments led the Team to recommend rolling over the lower 2014 ABC for 2015 and 2016. The Team also recommends, for September 2015, an evaluation of the optimum starting year, age composition data, and recruitment variability. Recruitment variability may help explain the change in the estimates of spawning biomass. The Team reminds the author to include a retrospective analysis and harvest scenarios next year.

> *Response*: The author presented a more detailed evaluation of the differences between the 2014 old and new models (14.1 and 14.2, respectively) during the September 2016 Plan Team meeting, and the results of that evaluation are included in this report as an appendix. Model 14.4, including in this assessment for purposes of comparison to the preferred model (14.2), explores the effect of a 1977 start year. Age composition data are not included in the assessment. Recruitment variability has not been addressed further than was done during the original preparation of model 14.2, which involved considering a greater capacity for recruitment variability in Alaska skate. This report includes a thorough retrospective analysis of model 14.2 and full reporting of harvest scenarios and status determination.

From the December 2014 SSC report:
Acceptance of Model 2 is contingent upon having accurate historical catches between 1950 and 1977. It is unclear if the author addressed a primary concern of the SSC regarding the evaluation of historical catch data in regard to the assumptions on the proportion of gear-specific effort and species compositions. Further evaluation of selectivity as a function of age and/or length is also warranted.

> *Response*: The author believes that the approach to estimating historical skate catches used in model 14.2 (the preferred model) relies on the best scientific information. The use of current species composition to apportion early catches is consistent with the model estimates of high skate biomass during the early part of the timeseries, and analysis of

fishing effort during the 1970s and 1980s supports the prevalence of trawl effort relative to longline effort. In addition, the early catch history appears to have little influence on the model's output: Model 14.4 (presented here with updated data for purposes of comparison and to explore assumptions in the model) begins in 1977, thus eliminating the earlier catches from the data. It produces parameter fits and biomass estimates that are very similar to model 14.2.

From the September 2016 BSAI Plan Team minutes:
The Team recommends that the author bring forward Model 14.2 for the November assessment, and include the work presented here as an appendix. Within the appendix the Team recommends showing exploitation rate (at age and overall) using FOFL, selectivity, and biomass at age, just as a simple spreadsheet, to make it easier to understand why OFL went up while spawning biomass and FOFL both went down.

Response: The author performed the exploitation rate exercise suggested by the Plan Team and the results are included as an appendix in this report.

The Team also recommends that the author revisit the list of recommendations made by the Team and the SSC in 2014/2015 to ensure that all recommendations are addressed in the November assessment. The author can bring forward new models in November at his discretion, as a result of any previous recommendations not addressed during this presentation.

Response: Please see the response to the original 2014 Plan Team comments above.

General Introduction

Contents of this report
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

Description, scientific names, and general distribution
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. 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. 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 2014 and the model accepted for use in that year was used again in 2016 and is the author's preferred model. Two alternative models are presented only to explore some of the assumptions in the preferred model.

Data

Summary of data used in the Alaska skate model

source	data	years
AKRO Catch Accounting System	catch	2003-2016
KRO historical catch record	catch	1954-2002
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	biomass index	1982- 2016
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	length composition	2000-2016
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	length-at-age	2003, 2007-2009, 2015
NMFS Fishery Monitoring & Analysis program- observed skate catch	length composition	2009-2015

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.

Three models are included in this report and are described below. Models 14.2 and 14.3 used catch data from 1954-2016; model 14.3 used catch data from 1977-2016. 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).
- *1997-2016*: 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 1999-2016 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 2016 were available only through October 16, so the 2016 data are incomplete. To estimate the full 2016 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 that was applied to the incomplete 2016 data to estimate full-year 2016 catch.

Fishery length compositions

Fishery length compositions from 2009-2015 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.

Survey biomass

Three bottom trawl surveys are conducted in the BSAI region: EBS shelf, EBS slope, and the Aleutian Islands. Because the Alaska skate population is concentrated on the EBS shelf, and the EBS shelf survey provides yearly estimates of biomass, 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 1982-2016 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 1999-2016 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.

Survey length compositions

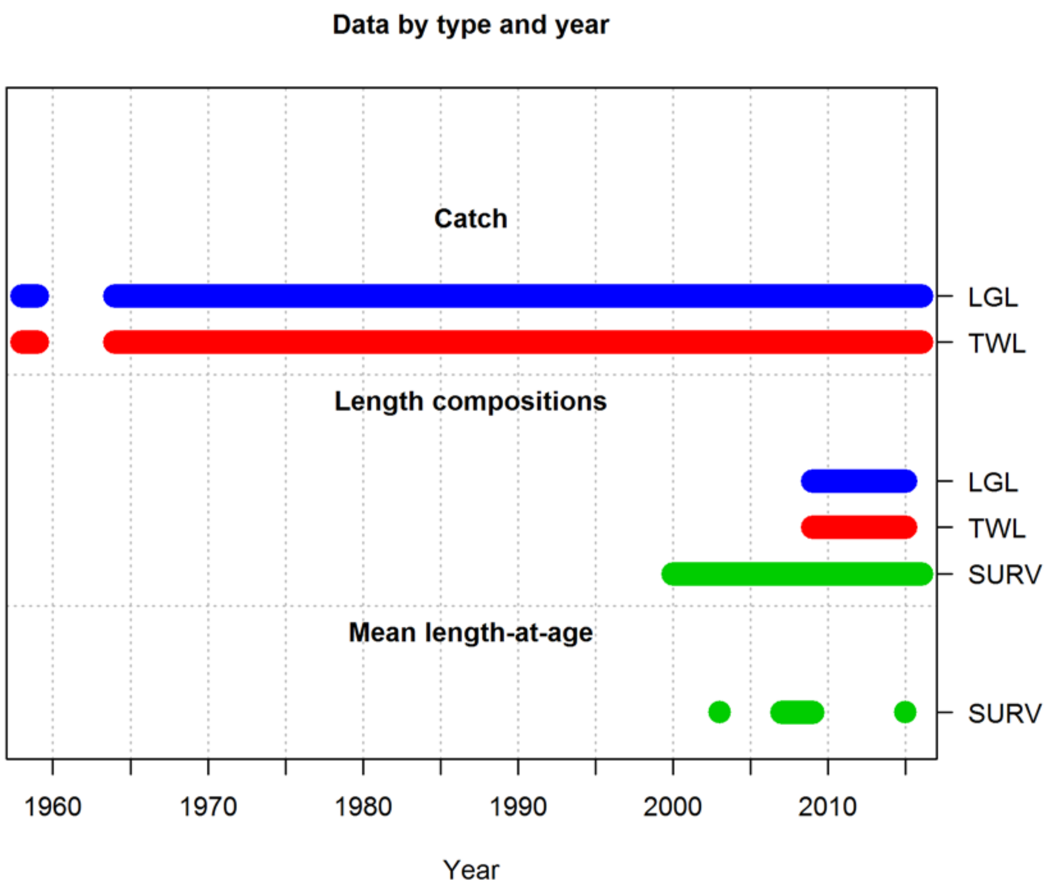
Length composition data from the EBS shelf survey were available from 2000-2016 (Table 10). The survey takes length measurements for every skate in each haul. The haul-specific data are then weighted by the number of skates in each haul to produce an estimate of numbers at length for the entire EBS population. The length data were aggregated into 4-cm bins and converted to proportions for inclusion in the model. Sample size is discussed below.

Length at age

Five LAA datasets from the years 2003 (N=182), 2007 (N=237), 2008 (N=165), 2009 (N=330), and 2015 (N=313) were included in the model. Age was determined through examination of annual growth rings in vertebral thin sections following hatching from the eggcase. All five 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.

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

All models 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.

[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]

Model 14.2 was accepted by the Plan Team and SSC in 2014 and is again the author's preferred model. Two alternatives are again included in this report for the purpose of exploring assumptions in the preferred model regarding selectivity and historical catch.

- Model 14.2: Base version of the model, with features described below. **Author's preferred model.**
- Model 14.3: 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 14.4: Base model 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 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 ($W = aTL^b$, 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
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 $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$, respectively; and κ and γ are parameters that control the shape of the growth curve. In SS3, κ is referred to as the von Bertalanffy *k* parameter and γ is referred to as the Richards coefficient. All growth parameters were estimated within the model, as were the two uncertainty parameters (CV of LAA at ages $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$).

Length selectivity
For models 14.2 and 14.4, 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 14.3, 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 1950-2016; in SS3 each deviation is considered a separate parameter.

Initial fishing mortality
For model 14.4. only, initial fishing mortality was estimated within the model for each of the two fisheries.

Results

Model Evaluation

<u>Model evaluation criteria</u>

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

1) Comparison of –log(likelihood) values.
2) The standard deviation of the parameter estimates was converted to CV; a lower CV indicated a better fit.
3) 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.
4) Comparison of effective sample sizes (N_{eff}) for length compositions, with higher N_{eff} indicating better fit to the data.
5) Comparison of effective sample sizes (N_{eff}) for LAA datasets, with higher N_{eff} indicating better fit to the data.
6) Visual inspection of model fits to length compositions and LAA data.
7) Reasonable estimates of fishery length selectivity parameters.
8) The preferred model was analyzed for retrospective patterns.

<u>Evaluation of model criteria</u>

1) Model 14.2 has the lowest –log(likelihood) of the three models, despite having a greater number of parameters than model 14.3.
2) Although model 14.2 had the highest CVs, CVs were similar among all models and neither model 14.3 or model 14.4 consistently had the lowest CV. (Table 12).
3) All of the models showed good fits to the survey data. Model 14.2 had the highest number of model estimates within the 95% survey biomass confidence interval. The RMSE, correlation, and residuals were very similar among models.
4) Effective Ns for the length compositions were much greater than one for all the models. The highest effective Ns were observed in model 14.2.
5) Visually, model 14.2 had the best fits to the length composition data (Figure 15), although the fit for all models were similar.
6) Model 14.2 fit the LAA data well (Figure 16), although it continues to underestimate length at age for some ages.
7) There were differences in the selectivity curves produced by the models (Figure 17). Model 14.2 has a greater degree of dome-shaped selectivity than does model 14.4 (model 14.3 was parameterized so that selectivity was asymptotic.

<u>Discussion of model evaluation and designation of preferred model</u>

Model 14.2 had the best overall fit (Table 12 & Figs. 18-21) and continues to be the author's preferred model. Differences among the models included in this assessment were smaller than between the versions created in 2014, suggesting that the assumptions of dome-shaped selectivity and historical catch patterns are not having a large effect on the model.

The retrospective pattern for spawning biomass and recruitment (Figure 22), as well as the associated statistics (see table below) suggest that the model has some retrospective bias bit generally stable, with a high level of agreement among years. The earliest retrospective years (2007-2008) had the greatest divergence, likely because fishery length compositions are available starting only in 2009. The model was unable to produce meaningful results for the retrospective year 2006 and that year was not included in the analysis.

	$\rho_{\text{rev Mohn}}$	$\rho_{\text{Woods Hole}}$	RMSE
spawning biomass	0.111	0.124	0.142
recruitment	0.060	0.044	0.187

Time series results

Results presented below are for the preferred model, Model 14.2.

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.

Biomass time series

Time series of total biomass and spawning biomass estimates from 1950-2013 are reported in Table 13. Spawning biomass is also shown in Figure 23. 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, increasing until ~ 1995. It then declined slightly and has been increasing since the mid-2000s.

Recruitment

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, declined during the late 2000s, and has been consistently low since 2010.

Exploitation rate

A time series of exploitation (catch/total biomass) is given in Table 14. 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.

Numbers at age

Model 14.2 indicates that the large year classes that occurred in the 1980s are essentially gone from the population and that the moderately-sized year classes of the 2000s are beginning to show up in the older population (Table 15 and Figure 25).

Phase-plane plot

The trajectory of relative spawning biomass vs. relative fishing mortality (Figure 26) reflects the high F and decrease in biomass during the 1970s, as well the subsequent increase in biomass. In recent years the relationship between the two variables has been consistent, with spawning biomass well above 35% and F well below F35%.

Harvest recommendations

Reference points and tier assignment

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

3a) Stock status: $B/B_{40\%} > 1$

$F_{OFL} = F_{35\%}$

$F_{ABC} \leq F_{40\%}$

3b) Stock status: $0.05 < B/B_{40\%} < 1$

$F_{OFL} = F_{35\%}$ H $(B/B_{40\%} - 0.05) \times 1/0.95$

$F_{ABC} < F_{40\%}$ H $(B/B_{40\%} - 0.05) \times 1/0.95$

3c) Stock status: B/B40% < 0.05

$F_{OFL} = 0$

$F_{ABC} = 0$

Specification of OFL and ABC

The 2017 estimate of female spawning biomass for BSAI Alaska skates is 108,926 t. The estimate of $B_{40\%}$ is 72,222 t, so $B/B_{40\%}$ is 1.51 and 2017-2018 Alaska skate harvest levels can be assigned according to subtier 3a. Therefore, $F_{OFL}= F_{35\%} = 0.092$ and maximum $F_{ABC}= F_{40\%} = 0.079$. The corresponding 2017 OFL is 39,050 t and maximum allowable ABC is 33,634 t. For 2018, OFL is projected to be 36,570 t and maximum allowable ABC will be 31,498 t. The author recommends setting ABC at the maximum permissible value.

Alaska skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year for: 2017	2018
M (natural mortality rate)	*0.13*	*0.13*	**0.13**	0.13
Tier	*3a*	*3a*	**3a**	3a
Projected total (age 0+) biomass (t)	*527,932*	*498,546*	**505,487**	477,146
Female spawning biomass (t)				
Projected	*115,378*	*112,087*	**108,926**	106,871
$B_{100\%}$	*186,923*	*186,923*	**180,556**	180,556
$B_{40\%}$	*74,769*	*74,769*	**72,222**	72,222
$B_{35\%}$	*65,423*	*65,423*	**63,195**	63,195
F_{OFL}	*0.090*	*0.090*	**0.092**	0.092
$maxF_{ABC}$	*0.077*	*0.077*	**0.079**	0.079
F_{ABC}	*0.077*	*0.077*	**0.079**	0.079
OFL (t)	*39,847*	*37,306*	**39,050**	36,570
maxABC (t)	*34,358*	*32,167*	**33,634**	31,498
ABC (t)	*34,358*	*32,167*	**33,634**	31,498
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Results of the projection exercise are in Table 16.

For each scenario, the projections begin with the vector of 2016 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2017 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2016. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are sometimes used in Environmental Assessments. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2017, are as follows ("max F_{ABC}" = maximum permissible F_{ABC} under Amendment 56):

Scenario 1 (Table 16a): In all future years, F is set equal to max F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2 (Table 16b): In all future years, F is set equal to a constant fraction of max F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2016 recommended in the assessment to the max F_{ABC} for 2016. (Rationale: When F_{ABC} is set at a value below max F_{ABC}, it is often set at the value recommended in the stock assessment). For Alaska skates the recommended F_{ABC} is typically the max F_{ABC}, however the total catch is usually well below ABC (Table 3). Therefore, for Scenario 2 the catch in 2017 and 2018 is set equal to the estimate of 2016 total catch used in the model.

Scenario 3 (Table 16c): In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4 (Table 16d): In all future years, F is set equal to the 2011-2015 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5 (Table 16e): In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6 (Table 16f): In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2017 and above its MSY level in 2029 under this scenario, then the stock is not overfished.)

Scenario 7 (Table 16g): In 2017 and 2018, F is set equal to max F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2029 under this scenario, then the stock is not approaching an overfished condition.)

Status: The projections for Scenarios 6 & 7 indicate that the Alaska skate stock will be above $B_{35\%}$ in 2029, so Alaska skates are not currently in an overfished condition and are not approaching an overfished condition.

OTHER SKATES – Tier 5 assessment

Data

Survey biomass

The biomass of the skate assemblage as a whole has increased since the early 1980s (Tables 17-21 & Figs. 27-30). 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

The random effects (RE) model for other skates produced reasonable results in all regions (Table 22 & Fig. 31). For the EBS shelf, the higher survey biomass estimates in 2015 and 2016 increased the RE estimate but it was below the survey values. The RE model matched the EBS slope survey biomass estimate very closely and paralleled the reduction in other skate biomass observed in the Aleutian Islands.

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	2016	2017	2017	2018
M (natural mortality rate)	*0.1*	*0.1*	**0.1**	0.1
Tier	*5*	*5*	**5**	5
Biomass (t)	*103,682*	*103,682*	**100,130**	100,130
F_{OFL}	*0.1*	*0.1*	**0.10**	0.10
$maxF_{ABC}$	*0.075*	*0.075*	**0.075**	0.075
F_{ABC}	*0.075*	*0.075*	**0.075**	0.075
OFL (t)	*10,368*	*10,368*	**10,013**	10,013
maxABC (t)	*7,776*	*7,776*	**7,510**	7,510
ABC (t)	*7,776*	*7,776*	**7,510**	7,510
	As determined *last* year for:		As determined *this* year for:	
Status	2014	2015	2015	2016
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 2016, the last year in which all BSAI areas were surveyed within the same year.

skate species	EBS shelf		EBS slope		Aleutian Islands		total BSAI	
	biomass estimate (t)	CV	biomass estimate (t)	CV	biomass estimate (t)	CV	biomass estimate (t)	CV
Alaska	531,676	0.04	8,965	0.30	1,808	0.46	542,449	0.04
Aleutian	14,449	0.27	23,204	0.20	3,703	0.21	41,355	0.15
whiteblotched	245	1.00	5,065	0.21	15,380	0.19	20,690	0.15
Bering	10,981	0.12	1,963	0.20	50	0.55	12,994	0.11
big	10,668	0.54	-	-	1,306	0.87	11,974	0.49
commander	-	-	5,511	0.16	29	1.00	5,540	0.16
leopard	-	-	-	-	4,220	0.40	4,220	0.40
roughtail	-	-	2,283	0.14	-	-	2,283	0.14
mud	506	0.54	577	0.22	1,165	0.20	2,248	0.17
whitebrow	-	-	1,359	0.15	-	-	1,359	0.15
deepsea	-	-	223	0.54	-	-	223	0.54
butterfly	-	-	-	-	86	0.31	86	0.31
Bathyraja sp.	-	-	0.1	1.00	21	0.85	21	0.84
skate unID	-	-	2	1.00	-	-	2	1.00
longnose	-	-	-	-	-	-	-	-
all skates	568,525	0.04	49,152	0.11	27,768	0.14	645,444	0.04

Table 3. Time series of OFL, ABC, TAC, catch, and retention for the BSAI skate complex, 2011-2016*. 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	27,450	30%
2015	49,575	41,658	25,700	28,117	28%
*2016**	50,215	42,134	26,000	*22,517*	*21%*

*2016 data are incomplete; retrieved October 16, 2016

Table 4. Estimated catch (t) of all skate species combined by BSAI area, 1997 - 2016*. 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	20,474	670	21,143
2004	21,445	885	22,329
2005	22,388	696	23,084
2006	19,283	966	20,250
2007	17,612	1,011	18,623
2008	20,276	1,401	21,677
2009	19,390	1,206	20,596
2010	16,369	1,333	17,702
2011	22,416	732	23,148
2012	23,741	1,083	24,824
2013	25,965	1,056	27,021
2014	26,327	1,123	27,450
2015	26,866	1,252	28,117
*2016**	21,598	919	22,517

. *2016 data are incomplete; retrieved October 16, 2016.

Table 5. Estimated catch (t) of all skate species combined by target fishery, 2003 – 2016*. Source: Alaska Regional Office.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	***2016****
Pacific Cod	16,719	18,369	19,456	15,115	13,463	14,311	12,698	11,431	16,692	18,487	20,498	21,896	24,366	*19,981*
Yellowfin Sole	1,598	594	943	1,133	1,409	1,303	1,784	1,912	2,107	2,232	2,683	1,970	1,073	*655*
Pollock	571	841	732	1,308	1,287	2,758	3,856	1,881	2,353	2,018	1,757	813	824	*464*
Atka Mackerel	103	143	140	141	153	179	185	246	269	510	345	490	495	*459*
Halibut	278	282	130	84	20	1,370	0	20	10	48	329	801	376	*249*
Rock Sole	537	500	422	930	996	555	964	1,204	709	634	526	689	284	*232*
Greenland Turbot	223	136	168	121	176	69	209	369	382	357	51	43	209	*163*
Rockfish	73	23	29	37	72	63	91	53	103	97	232	163	171	*114*
Arrowtooth Flounder	103	64	135	282	81	297	191	184	116	207	183	160	98	*69*
Kamchatka Flounder									92	101	49	57	68	*53*
Flathead Sole	630	1,192	839	852	768	663	360	304	112	76	206	272	101	*45*
Sablefish	58	12	26	123	62	41	131	86	138	46	114	77	18	*17*
Other Species	225	94	21	109	69	63	33	0	23			20	16	*12*
Alaska Plaice				1	2	2	1	5	38	9	45	0	12	*3*
Other Flatfish	26	78	42	7	64	2	14	4	3	3	0		6	*1*
Total	**21,143**	**22,329**	**23,084**	**20,250**	**18,623**	**21,677**	**20,596**	**17,702**	**23,148**	**24,824**	**27,021**	**27,450**	**28,117**	***22,517***

*2016 data incomplete; retrieved October 16, 2016.

Table 6. Estimated catch (t) of all skate species combined by reporting area, 2003 – 2016*. Source: Alaska Regional Office.

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	*2016**
EBS	**508**	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*
	509	2,099	2,189	3,271	3,537	3,584	4,040	5,009	2,791	6,088	6,148	8,259	3,796	1,962	*1,541*
	512	26	205	15	0	0	28	16	13	7	161	50	21	66	*3*
	513	2,856	2,747	3,902	2,607	2,321	2,048	2,503	1,885	3,086	1,811	3,416	4,534	5,144	*3,054*
	514	284	67	196	221	445	83	134	78	150	1,588	230	939	1,204	*555*
	516	137	408	239	253	398	488	575	664	243	777	968	399	182	*117*
	517	3,056	3,020	3,772	2,459	2,175	2,467	3,200	2,809	2,615	3,294	4,724	4,206	4,968	*2,747*
	518	26	6	16	11	5	459	57	40	28	20	54	97	85	*77*
	519	190	140	104	69	109	240	56	80	103	122	64	146	105	*50*
	521	10,301	10,369	8,513	8,383	7,120	7,755	6,181	6,601	8,673	8,024	7,169	10,817	11,180	*9,353*
	522	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*
	523	320	324	243	282	333	242	264	395	268	1,066	868	656	392	*222*
	524	1,180	1,970	2,116	1,462	1,122	2,426	1,396	1,014	1,156	730	162	715	1,579	*3,879*
	530	0	0	0	0	0	0	1	0	0	0	0	0	0	*0*
AI	**541**	308	466	488	563	340	492	452	460	501	776	608	908	795	*542*
	542	239	280	125	337	400	566	335	446	185	272	364	167	245	*156*
	543	123	139	83	67	271	343	419	427	45	35	84	49	212	*220*
EBS total		20,474	21,445	22,388	19,283	17,612	20,276	19,390	16,369	22,416	23,741	25,965	26,327	26,866	*21,598*
AI total		670	885	696	966	1,011	1,401	1,206	1,333	732	1,083	1,056	1,123	1,252	*919*
BSAI total		**21,143**	**22,329**	**23,084**	**20,250**	**18,623**	**21,677**	**20,596**	**17,702**	**23,148**	**24,824**	**27,021**	**27,450**	**28,117**	***22,517***

*2016 data incomplete; retrieved October 16, 2016.

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

year	longline	trawl	year	Longline	trawl
1955	0	0	1986	1,301	3,675
1956	0	0	1987	1,062	3,006
1957	0	0	1988	1,443	4,287
1958	8	61	1989	588	1,752
1959	21	156	1990	688	2,009
1960	0	0	1991	6,246	1,372
1961	0	0	1992	12,586	2,815
1962	0	0	1993	9,072	2,029
1963	0	0	1994	10,554	2,361
1964	43	304	1995	11,050	2,472
1965	150	928	1996	9,381	2,098
1966	130	924	1997	13,059	2,932
1967	537	1,967	1998	14,100	3,178
1968	1,539	9,252	1999	10,288	2,318
1969	690	4,365	2000	13,362	3,055
1970	1,220	6,502	2001	14,244	3,291
1971	856	5,613	2002	15,943	3,571
1972	1,377	4,916	2003	15,580	3,693
1973	3,264	23,062	2004	16,308	3,892
1974	3,700	24,994	2005	17,661	3,405
1975	3,348	22,736	2006	14,907	3,347
1976	1,702	10,897	2007	13,638	3,069
1977	2,559	15,090	2008	15,742	3,556
1978	3,864	25,571	2009	15,031	3,388
1979	2,609	16,207	2010	12,745	2,891
1980	4,578	12,310	2011	17,261	3,852
1981	4,503	12,553	2012	18,335	4,110
1982	2,349	6,437	2013	20,030	4,482
1983	1,971	5,456	2014	20,318	4,550
1984	1,072	2,995	2015	20,752	4,653
1985	1,443	4,045	2016	20,539	4,599

Table 8. Alaska skate length compositions from the BSAI longline and trawl fisheries, 2009-2015. 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	2014	2015	2009	2010	2011	2012	2013	2014	2015
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	0.000	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
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.002
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.004	0.002	0.002	0.001	0.001	0.003
24	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.011	0.011	0.012	0.003	0.006	0.007	0.010
28	0.000	0.000	0.000	0.003	0.000	0.001	0.000	0.024	0.018	0.020	0.010	0.009	0.012	0.015
32	0.001	0.001	0.000	0.007	0.000	0.002	0.000	0.034	0.031	0.026	0.011	0.010	0.015	0.032
36	0.001	0.001	0.001	0.010	0.001	0.002	0.000	0.051	0.037	0.034	0.017	0.020	0.020	0.040
40	0.003	0.002	0.003	0.013	0.002	0.004	0.001	0.063	0.053	0.049	0.034	0.039	0.031	0.049
44	0.006	0.006	0.007	0.018	0.003	0.005	0.003	0.064	0.055	0.059	0.042	0.047	0.031	0.046
48	0.011	0.014	0.014	0.021	0.008	0.008	0.006	0.056	0.050	0.052	0.052	0.050	0.040	0.055
52	0.020	0.024	0.020	0.025	0.013	0.014	0.011	0.051	0.042	0.047	0.049	0.051	0.041	0.048
56	0.025	0.032	0.027	0.030	0.022	0.021	0.017	0.044	0.041	0.040	0.043	0.045	0.046	0.043
60	0.034	0.046	0.041	0.041	0.031	0.033	0.030	0.043	0.043	0.038	0.044	0.042	0.050	0.042
64	0.044	0.056	0.050	0.053	0.038	0.040	0.039	0.048	0.048	0.039	0.046	0.043	0.046	0.047
68	0.058	0.069	0.064	0.068	0.056	0.055	0.055	0.049	0.056	0.053	0.054	0.050	0.054	0.052
72	0.063	0.070	0.077	0.072	0.069	0.063	0.059	0.048	0.053	0.060	0.069	0.055	0.060	0.049
76	0.068	0.062	0.074	0.072	0.079	0.071	0.064	0.041	0.049	0.059	0.070	0.058	0.051	0.040
80	0.068	0.071	0.077	0.080	0.093	0.083	0.075	0.052	0.054	0.059	0.080	0.068	0.070	0.061
84	0.067	0.067	0.076	0.077	0.097	0.087	0.081	0.044	0.054	0.053	0.071	0.069	0.076	0.061
88	0.081	0.071	0.082	0.087	0.105	0.107	0.097	0.059	0.056	0.060	0.077	0.080	0.087	0.065
92	0.094	0.090	0.095	0.094	0.115	0.125	0.125	0.059	0.069	0.069	0.073	0.081	0.089	0.083
96	0.124	0.103	0.112	0.098	0.117	0.121	0.135	0.056	0.068	0.068	0.069	0.077	0.086	0.074
100	0.119	0.104	0.106	0.078	0.089	0.094	0.115	0.049	0.055	0.058	0.051	0.058	0.055	0.053
104	0.067	0.057	0.049	0.034	0.040	0.043	0.052	0.029	0.029	0.025	0.022	0.029	0.021	0.021
108	0.030	0.028	0.018	0.013	0.013	0.015	0.019	0.010	0.013	0.010	0.008	0.007	0.005	0.005
112	0.009	0.013	0.004	0.003	0.003	0.004	0.006	0.006	0.004	0.002	0.002	0.002	0.002	0.002
116	0.005	0.006	0.001	0.001	0.002	0.001	0.003	0.002	0.003	0.002	0.000	0.001	0.001	0.001
120	0.001	0.004	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.001	0.000	0.001	0.000	0.000
124	0.001	0.001	0.000	0.000	0.000	0.000	0.001	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	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001
132	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.001
N	67	65	72	77	85	87	88	56	61	56	50	61	54	45

Table 9. Estimates of Alaska skate biomass (t) from the EBS shelf bottom trawl survey, 1982-2016. Estimates and CVs in bold (1999-2016) 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 1999-2016.

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	**312,998**	**0.17**
2000	**299,151**	**0.06**
2001	**402,909**	**0.06**
2002	**347,874**	**0.07**
2003	**353,600**	**0.05**
2004	**402,141**	**0.05**
2005	**461,897**	**0.05**
2006	**424,465**	**0.05**
2007	**458,112**	**0.07**
2008	**346,735**	**0.06**
2009	**338,823**	**0.07**
2010	**351,704**	**0.06**
2011	**392,502**	**0.05**
2012	**351,608**	**0.06**
2013	**375,161**	**0.06**
2014	**392,427**	**0.05**
2015	**433,406**	**0.06**
2016	**531,676**	**0.04**

Table 10. Alaska skate EBS shelf survey length compositions, 2000-2016. 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	2015	2016
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	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	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	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	0.000	0.000
20	0.005	0.010	0.008	0.005	0.003	0.005	0.004	0.008	0.004	0.010	0.003	0.004	0.004	0.003	0.003	0.006	0.003
24	0.035	0.031	0.026	0.027	0.015	0.019	0.026	0.029	0.017	0.021	0.016	0.015	0.009	0.012	0.008	0.014	0.006
28	0.044	0.045	0.035	0.023	0.024	0.021	0.025	0.019	0.018	0.020	0.016	0.021	0.015	0.012	0.017	0.016	0.008
32	0.037	0.045	0.048	0.038	0.026	0.028	0.031	0.027	0.025	0.032	0.016	0.026	0.017	0.020	0.014	0.015	0.011
36	0.048	0.042	0.049	0.036	0.029	0.036	0.031	0.038	0.036	0.042	0.027	0.027	0.020	0.027	0.027	0.017	0.013
40	0.047	0.044	0.052	0.043	0.044	0.043	0.041	0.051	0.046	0.050	0.035	0.040	0.029	0.031	0.027	0.025	0.018
44	0.046	0.049	0.055	0.047	0.050	0.052	0.047	0.046	0.056	0.053	0.045	0.054	0.043	0.042	0.034	0.026	0.026
48	0.055	0.043	0.052	0.083	0.059	0.054	0.052	0.058	0.054	0.052	0.039	0.061	0.049	0.047	0.046	0.036	0.030
52	0.062	0.052	0.062	0.049	0.068	0.051	0.049	0.050	0.062	0.061	0.048	0.062	0.056	0.065	0.041	0.038	0.035
56	0.061	0.047	0.053	0.039	0.053	0.060	0.054	0.054	0.063	0.064	0.053	0.060	0.057	0.060	0.054	0.049	0.040
60	0.061	0.057	0.047	0.043	0.055	0.061	0.057	0.049	0.060	0.068	0.053	0.064	0.057	0.055	0.064	0.049	0.041
64	0.042	0.047	0.041	0.040	0.044	0.051	0.056	0.060	0.061	0.057	0.060	0.061	0.060	0.056	0.057	0.059	0.058
68	0.036	0.048	0.049	0.053	0.052	0.044	0.050	0.057	0.049	0.050	0.067	0.060	0.059	0.051	0.065	0.060	0.051
72	0.036	0.047	0.043	0.042	0.048	0.048	0.050	0.052	0.050	0.052	0.058	0.061	0.068	0.062	0.064	0.055	0.051
76	0.028	0.039	0.043	0.047	0.052	0.041	0.050	0.045	0.051	0.045	0.057	0.053	0.069	0.066	0.055	0.055	0.052
80	0.039	0.033	0.030	0.048	0.041	0.041	0.039	0.046	0.047	0.048	0.056	0.048	0.065	0.064	0.052	0.051	0.057
84	0.031	0.028	0.027	0.039	0.044	0.041	0.046	0.037	0.043	0.043	0.063	0.048	0.048	0.054	0.058	0.065	0.069
88	0.037	0.038	0.046	0.046	0.048	0.053	0.040	0.043	0.047	0.046	0.059	0.047	0.067	0.062	0.078	0.071	0.084
92	0.054	0.067	0.056	0.056	0.061	0.054	0.063	0.065	0.057	0.051	0.073	0.055	0.066	0.068	0.088	0.094	0.114
96	0.074	0.074	0.070	0.080	0.074	0.066	0.071	0.063	0.059	0.057	0.074	0.059	0.066	0.071	0.071	0.086	0.104
100	0.065	0.071	0.058	0.061	0.069	0.071	0.064	0.059	0.056	0.048	0.048	0.048	0.049	0.043	0.046	0.070	0.082
104	0.040	0.029	0.030	0.037	0.030	0.041	0.040	0.030	0.026	0.022	0.025	0.018	0.019	0.023	0.022	0.033	0.034
108	0.013	0.013	0.012	0.012	0.008	0.012	0.012	0.011	0.009	0.006	0.007	0.006	0.005	0.005	0.005	0.008	0.009
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	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	0.001	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	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	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	0.000	0.000
132	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
N	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Table 11. Input parameter values for the preferred model (Model 14.2). 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 type	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	0.50	
	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)	9.00×10^{-6}			X
	exponent (b)	2.962			X
length at maturity	length at 50% maturity (a)	93.28			X
	slope (b)	-0.548			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[b]	longline fishery F	0.030	0	1	
	trawl fishery F	0.005	0	1	

[a] In model 14.3, p6 was fixed at the starting value for all fleets.

[b] These parameters were only used in model 14.4, which started in 1977. For models 14.2 and 14.3, initial fishing mortality in 1950 was assumed to be zero.

Table 12. Results from models 14.2, 14.3, and 14.4 for use in model comparison and evaluation.

model number		14.2	14.3	14.4
Description		base model (accepted 2014)	base model w/ asymptotic selectivity	base model starting in 1977
likelihood components				
	survey	-13.9165	-14.0857	14.6939
	length comps	100.518	104.976	100.97
	LAA	156.543	158.112	158.106
	recruitment	-41.0821	-41.2108	-42.5632
	total	202.087	207.815	201.852
# of parameters estimated		91	88	91
L_amin		14.0	14.4	14.1
	CV	*0.032*	*0.0293*	*0.0311*
L_amax		102.0	102.2	102.0
	CV	*0.003*	*0.0025*	*0.0026*
K		0.38	0.37	0.38
	CV	*0.019*	*0.0158*	*0.0181*
CV young		0.35	0.35	0.35
	CV	*0.0001*	*0.0004*	*0.00013*
CV old		0.05	0.05	0.05
	CV	*0.052*	*0.0003*	*0.0014*
ln (Rzero)		10.12	10.02	10.13
	CV	*0.004*	*0.0023*	*0.0035*
unfished spawning biomass_		334,622	301,665	337,425
	CV	*0.043*	*0.024*	*0.038*
unfished recruitment		24,738	22,550	25,096
	CV	*0.040*	*0.024*	*0.036*
RMSE_survey		0.141	0.142	0.140
% within survey CI		70.6%	64.7%	67.6%
correlation obs-pred		0.764	0.763	0.766
average standardized residual		0.852	0.828	0.824
mean longline input N		77.3	77.3	77.3
mean longline eff N		1000.4	851.1	979.6
mean longline effN/N		12.94	11.01	12.67
mean trawl input N		54.7	54.7	54.7
mean trawl eff N		705.4	571.2	633.8
mean trawl effN/N		12.89	10.44	11.6
mean survey input N		200.0	200.0	200.0
mean survey eff N		887.6	797.4	887.7
mean survey effN/N		4.44	3.99	4.44
mean LAA N		223.8	223.8	223.8
mean LAA eff N		2976.2	2627.0	2970.0
mean LAA eff N/N		13.30	11.74	13.27

Table 13. Time series of spawning biomass (t) and the number of age 0 recruits (1000s) predicted by Model 14.2. CV = coefficient of variation

	spawning biomass		recruits			spawning biomass		recruits	
	estimate	**CV**	**estimate**	**CV**		**estimate**	**CV**	**estimate**	**CV**
unfished	334,622	0.04	24,738	0.04	1983	113,545	0.13	39,675	0.57
1950	334,622	0.04	21,314	0.39	1984	111,608	0.12	29,749	0.45
1951	334,622	0.04	21,146	0.39	1985	112,613	0.11	24,665	0.40
1952	334,622	0.04	20,960	0.39	1986	114,589	0.10	22,110	0.38
1953	334,622	0.04	20,755	0.39	1987	118,810	0.10	21,084	0.37
1954	334,622	0.04	20,531	0.38	1988	126,101	0.09	20,945	0.36
1955	334,622	0.04	20,286	0.38	1989	136,806	0.08	21,495	0.37
1956	334,622	0.04	20,021	0.38	1990	155,263	0.09	22,792	0.37
1957	334,622	0.04	19,737	0.38	1991	184,447	0.07	23,074	0.36
1958	334,622	0.04	19,438	0.37	1992	211,500	0.07	20,170	0.35
1959	333,171	0.05	19,125	0.37	1993	230,773	0.07	20,368	0.34
1960	330,754	0.05	18,803	0.37	1994	245,935	0.07	25,555	0.35
1961	327,616	0.06	18,476	0.36	1995	253,273	0.07	31,018	0.32
1962	323,873	0.06	18,147	0.36	1996	254,465	0.07	26,491	0.34
1963	319,781	0.07	17,821	0.36	1997	252,926	0.07	28,839	0.33
1964	315,536	0.07	17,500	0.35	1998	246,477	0.07	31,319	0.33
1965	311,036	0.08	17,190	0.35	1999	238,713	0.07	33,493	0.31
1966	306,096	0.08	16,900	0.35	2000	233,977	0.07	36,177	0.28
1967	301,204	0.09	16,642	0.35	2001	226,481	0.07	30,427	0.27
1968	295,426	0.09	16,415	0.34	2002	218,605	0.07	27,572	0.29
1969	284,504	0.09	16,208	0.34	2003	211,840	0.07	33,819	0.29
1970	277,200	0.09	15,998	0.34	2004	208,672	0.07	41,340	0.29
1971	268,258	0.09	15,786	0.34	2005	205,882	0.07	38,579	0.32
1972	260,177	0.09	15,611	0.34	2006	204,521	0.07	40,668	0.30
1973	252,287	0.10	15,517	0.33	2007	206,550	0.07	32,152	0.35
1974	232,198	0.10	15,554	0.33	2008	211,270	0.07	39,826	0.29
1975	210,961	0.10	15,768	0.34	2009	216,781	0.07	33,109	0.30
1976	191,762	0.11	16,273	0.34	2010	221,966	0.07	26,151	0.31
1977	181,277	0.11	17,271	0.35	2011	227,299	0.07	20,293	0.31
1978	168,290	0.11	19,105	0.36	2012	230,952	0.07	18,655	0.30
1979	149,089	0.12	22,372	0.38	2013	236,675	0.06	17,476	0.31
1980	136,944	0.12	28,138	0.43	2014	241,848	0.06	18,571	0.32
1981	126,660	0.13	38,659	0.55	2015	247,994	0.06	18,429	0.36
1982	117,337	0.13	56,006	0.62	2016	251,012	0.06	24,738	0.04

Table 14. Time series of exploitation rates (catch/total biomass) as estimated by the preferred model (14.2).

year	longline	trawl	total F	year	longline	trawl	total F
1950	0.000	0.000	0.000	**1984**	0.005	0.014	0.019
1951	0.000	0.000	0.000	**1985**	0.007	0.017	0.023
1952	0.000	0.000	0.000	**1986**	0.005	0.013	0.019
1953	0.000	0.000	0.000	**1987**	0.004	0.010	0.014
1954	0.000	0.000	0.000	**1988**	0.005	0.013	0.017
1955	0.000	0.000	0.000	**1989**	0.002	0.005	0.006
1956	0.000	0.000	0.000	**1990**	0.002	0.005	0.007
1957	0.000	0.000	0.000	**1991**	0.015	0.003	0.018
1958	0.000	0.000	0.000	**1992**	0.030	0.007	0.037
1959	0.000	0.000	0.000	**1993**	0.021	0.005	0.026
1960	0.000	0.000	0.000	**1994**	0.025	0.006	0.031
1961	0.000	0.000	0.000	**1995**	0.027	0.006	0.033
1962	0.000	0.000	0.000	**1996**	0.023	0.005	0.028
1963	0.000	0.000	0.000	**1997**	0.033	0.008	0.040
1964	0.000	0.001	0.001	**1998**	0.036	0.009	0.045
1965	0.000	0.002	0.003	**1999**	0.027	0.006	0.033
1966	0.000	0.002	0.003	**2000**	0.035	0.008	0.044
1967	0.001	0.005	0.006	**2001**	0.038	0.009	0.047
1968	0.004	0.024	0.027	**2002**	0.043	0.010	0.052
1969	0.002	0.012	0.013	**2003**	0.042	0.010	0.052
1970	0.003	0.018	0.021	**2004**	0.043	0.010	0.054
1971	0.002	0.016	0.018	**2005**	0.046	0.009	0.055
1972	0.004	0.014	0.018	**2006**	0.038	0.009	0.047
1973	0.009	0.070	0.079	**2007**	0.034	0.008	0.042
1974	0.011	0.083	0.094	**2008**	0.039	0.009	0.048
1975	0.011	0.082	0.094	**2009**	0.036	0.008	0.044
1976	0.006	0.042	0.048	**2010**	0.030	0.007	0.037
1977	0.010	0.061	0.071	**2011**	0.039	0.009	0.048
1978	0.016	0.112	0.128	**2012**	0.041	0.009	0.050
1979	0.012	0.077	0.089	**2013**	0.044	0.010	0.054
1980	0.022	0.062	0.084	**2014**	0.044	0.010	0.054
1981	0.023	0.065	0.088	**2015**	0.045	0.010	0.056
1982	0.012	0.033	0.046	**2016**	0.046	0.011	0.056
1983	0.010	0.027	0.037				

Table 15. Numbers at age, 1950-2016, as estimated by Model 14.2.

year	0	1	2	3	4	5	6	7	8	9	10	11	12
1950	21,314	21,722	19,074	16,749	14,707	12,914	11,340	9,958	8,744	7,678	6,742	5,920	5,198
1951	21,146	18,715	19,074	16,749	14,707	12,914	11,340	9,958	8,744	7,678	6,742	5,920	5,198
1952	20,960	18,568	16,434	16,749	14,707	12,914	11,340	9,958	8,744	7,678	6,742	5,920	5,198
1953	20,755	18,405	16,305	14,431	14,707	12,914	11,340	9,958	8,744	7,678	6,742	5,920	5,198
1954	20,531	18,225	16,161	14,317	12,671	12,914	11,340	9,958	8,744	7,678	6,742	5,920	5,198
1955	20,286	18,028	16,003	14,191	12,572	11,127	11,340	9,958	8,744	7,678	6,742	5,920	5,198
1956	20,021	17,813	15,830	14,053	12,461	11,039	9,770	9,958	8,744	7,678	6,742	5,920	5,198
1957	19,737	17,580	15,641	13,900	12,339	10,942	9,693	8,579	8,744	7,678	6,742	5,920	5,198
1958	19,438	17,331	15,437	13,734	12,206	10,835	9,608	8,512	7,533	7,678	6,742	5,920	5,198
1959	19,125	17,068	15,218	13,555	12,059	10,717	9,513	8,436	7,473	6,614	6,741	5,919	5,198
1960	18,803	16,793	14,987	13,362	11,900	10,586	9,407	8,350	7,405	6,560	5,806	5,917	5,196
1961	18,476	16,511	14,746	13,160	11,733	10,449	9,296	8,260	7,332	6,502	5,760	5,098	5,196
1962	18,147	16,224	14,498	12,949	11,556	10,303	9,175	8,163	7,253	6,439	5,709	5,058	4,476
1963	17,821	15,935	14,246	12,731	11,370	10,147	9,047	8,057	7,167	6,369	5,654	5,013	4,441
1964	17,500	15,649	13,993	12,509	11,179	9,984	8,910	7,944	7,075	6,294	5,593	4,964	4,402
1965	17,190	15,367	13,740	12,284	10,980	9,810	8,761	7,818	6,970	6,207	5,522	4,907	4,356
1966	16,900	15,094	13,491	12,058	10,774	9,624	8,595	7,674	6,848	6,105	5,437	4,837	4,299
1967	16,642	14,840	13,251	11,839	10,575	9,443	8,432	7,529	6,722	5,998	5,347	4,763	4,237
1968	16,415	14,614	13,025	11,620	10,367	9,248	8,250	7,363	6,573	5,867	5,235	4,668	4,158
1969	16,208	14,414	12,802	11,362	10,071	8,929	7,932	7,061	6,296	5,619	5,017	4,479	3,996
1970	15,998	14,232	12,642	11,205	9,914	8,761	7,751	6,879	6,121	5,457	4,871	4,350	3,885
1971	15,786	14,048	12,475	11,047	9,744	8,580	7,558	6,676	5,920	5,267	4,696	4,193	3,746
1972	15,611	13,862	12,316	10,907	9,616	8,447	7,418	6,525	5,761	5,108	4,545	4,053	3,621
1973	15,517	13,708	12,155	10,772	9,502	8,345	7,309	6,409	5,633	4,971	4,408	3,923	3,500
1974	15,554	13,626	11,953	10,468	9,100	7,881	6,838	5,955	5,208	4,575	4,040	3,587	3,199
1975	15,768	13,658	11,866	10,258	8,782	7,470	6,377	5,494	4,770	4,169	3,664	3,241	2,885
1976	16,273	13,845	11,894	10,185	8,608	7,211	6,047	5,126	4,404	3,821	3,341	2,942	2,608
1977	17,271	14,290	12,106	10,324	8,738	7,303	6,074	5,074	4,295	3,688	3,201	2,802	2,470
1978	19,105	15,165	12,471	10,452	8,763	7,298	6,034	4,990	4,159	3,518	3,022	2,626	2,302
1979	22,372	16,776	13,167	10,616	8,627	7,022	5,735	4,696	3,867	3,220	2,725	2,347	2,046
1980	28,138	19,645	14,618	11,319	8,934	7,113	5,712	4,633	3,782	3,112	2,592	2,198	1,897
1981	38,659	24,708	17,142	12,617	9,600	7,444	5,849	4,657	3,759	3,062	2,519	2,100	1,784
1982	56,006	33,946	21,553	14,781	10,680	7,976	6,099	4,750	3,763	3,030	2,468	2,033	1,698
1983	39,675	49,179	29,707	18,749	12,737	9,114	6,757	5,143	3,994	3,161	2,545	2,074	1,710
1984	29,749	34,838	43,064	25,888	16,213	10,927	7,773	5,741	4,360	3,383	2,676	2,156	1,758
1985	24,665	26,122	30,549	37,669	22,556	14,070	9,454	6,712	4,952	3,758	2,916	2,307	1,860
1986	22,110	21,659	22,899	26,700	32,767	19,525	12,134	8,134	5,766	4,251	3,226	2,504	1,982
1987	21,084	19,415	18,992	20,032	23,267	28,443	16,897	10,480	7,017	4,972	3,665	2,782	2,160
1988	20,945	18,514	17,031	16,631	17,493	20,261	24,714	14,661	9,086	6,081	4,308	3,177	2,412
1989	21,495	18,391	16,236	14,902	14,501	15,197	17,554	21,375	12,668	7,847	5,251	3,721	2,745
1990	22,792	18,875	16,142	14,238	13,051	12,683	13,278	15,327	18,656	11,055	6,848	4,583	3,248
1991	23,074	20,013	16,566	14,154	12,467	11,411	11,077	11,589	13,372	16,274	9,643	5,973	3,999
1992	20,170	20,261	17,565	14,529	12,395	10,890	9,932	9,605	10,019	11,540	14,035	8,315	5,151
1993	20,368	17,711	17,775	15,387	12,688	10,769	9,396	8,507	8,178	8,500	9,778	11,887	7,043
1994	25,555	17,885	15,542	15,580	13,458	11,056	9,337	8,103	7,305	7,005	7,274	8,365	10,170
1995	31,018	22,440	15,692	13,619	13,617	11,711	9,564	8,027	6,931	6,230	5,967	6,195	7,125
1996	26,491	27,237	19,688	13,749	11,899	11,842	10,121	8,211	6,855	5,900	5,297	5,072	5,266
1997	28,839	23,261	23,899	17,254	12,020	10,361	10,257	8,716	7,038	5,860	5,039	4,522	4,331
1998	31,319	25,324	20,404	20,929	15,058	10,430	8,922	8,760	7,395	5,949	4,945	4,251	3,816
1999	33,493	27,501	22,211	17,863	18,252	13,049	8,962	7,597	7,405	6,225	4,999	4,154	3,571
2000	36,177	29,410	24,128	19,460	15,606	15,872	11,276	7,692	6,486	6,302	5,290	4,248	3,530
2001	30,427	31,767	25,795	21,124	16,974	13,529	13,645	9,609	6,509	5,465	5,301	4,449	3,572
2002	27,572	26,717	27,860	22,579	18,417	14,701	11,613	11,602	8,108	5,468	4,583	4,444	3,730
2003	33,819	24,211	23,429	24,380	19,672	15,928	12,588	9,839	9,746	6,777	4,561	3,821	3,705
2004	41,340	29,696	21,231	20,502	21,239	17,014	13,642	10,670	8,270	8,152	5,657	3,806	3,189
2005	38,579	36,300	26,040	18,575	17,855	18,359	14,558	11,547	8,953	6,904	6,792	4,711	3,170
2006	40,668	33,876	31,834	22,790	16,187	15,443	15,711	12,316	9,679	7,464	5,743	5,647	3,918
2007	32,152	35,710	29,711	27,868	19,873	14,023	13,258	13,361	10,393	8,131	6,259	4,814	4,734
2008	39,826	28,232	31,324	26,018	24,318	17,240	12,068	11,313	11,321	8,772	6,851	5,272	4,055
2009	33,109	34,971	24,761	27,420	22,685	21,063	14,798	10,258	9,542	9,506	7,351	5,739	4,417
2010	26,151	29,073	30,673	21,680	23,920	19,668	18,108	12,607	8,676	8,036	7,992	6,178	4,824
2011	20,293	22,963	25,506	26,870	18,934	20,785	16,971	15,510	10,734	7,361	6,808	6,769	5,233
2012	18,655	17,819	20,140	22,327	23,429	16,400	17,840	14,425	13,080	9,011	6,168	5,703	5,670
2013	17,476	16,381	15,627	17,628	19,462	20,281	14,063	15,143	12,146	10,961	7,536	5,157	4,768
2014	18,571	15,345	14,364	13,674	15,356	16,828	17,358	11,906	12,709	10,142	9,133	6,277	4,296
2015	18,429	16,307	13,456	12,568	11,910	13,275	14,398	14,690	9,988	10,606	8,446	7,603	5,226
2016	24,738	16,183	14,299	11,772	10,944	10,290	11,348	12,171	12,306	8,322	8,819	7,020	6,320

Table 15 continued. Numbers at age, 1950-2016, as estimated by Model 14.2.

year	13	14	15	16	17	18	19	20	21	22	23	24	25
1950	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1951	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1952	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1953	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1954	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1955	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1956	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1957	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1958	4,565	4,008	3,520	3,091	2,714	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1959	4,564	4,008	3,519	3,090	2,713	2,383	2,092	1,837	1,613	1,417	1,244	1,092	7,868
1960	4,562	4,006	3,518	3,089	2,713	2,382	2,092	1,837	1,613	1,416	1,243	1,092	7,865
1961	4,562	4,006	3,518	3,089	2,713	2,382	2,092	1,837	1,613	1,416	1,243	1,092	7,865
1962	4,562	4,006	3,518	3,089	2,713	2,382	2,092	1,837	1,613	1,416	1,243	1,092	7,865
1963	3,931	4,006	3,518	3,089	2,713	2,382	2,092	1,837	1,613	1,416	1,243	1,092	7,865
1964	3,900	3,452	3,518	3,089	2,712	2,382	2,092	1,837	1,613	1,416	1,243	1,092	7,865
1965	3,863	3,422	3,029	3,087	2,711	2,380	2,090	1,835	1,612	1,415	1,243	1,091	7,860
1966	3,816	3,384	2,998	2,654	2,705	2,375	2,086	1,831	1,608	1,412	1,240	1,089	7,844
1967	3,766	3,343	2,965	2,627	2,325	2,370	2,081	1,828	1,605	1,409	1,238	1,087	7,828
1968	3,700	3,289	2,920	2,590	2,295	2,031	2,071	1,818	1,597	1,402	1,231	1,081	7,788
1969	3,562	3,172	2,821	2,506	2,223	1,970	1,744	1,778	1,562	1,371	1,204	1,058	7,619
1970	3,467	3,092	2,754	2,449	2,176	1,931	1,711	1,515	1,545	1,357	1,191	1,046	7,538
1971	3,347	2,989	2,666	2,376	2,114	1,878	1,667	1,477	1,308	1,334	1,171	1,029	7,412
1972	3,237	2,893	2,584	2,306	2,055	1,829	1,625	1,442	1,279	1,132	1,154	1,014	7,305
1973	3,128	2,797	2,501	2,235	1,995	1,778	1,582	1,406	1,248	1,106	980	999	7,198
1974	2,860	2,561	2,294	2,054	1,837	1,641	1,463	1,303	1,158	1,028	911	807	6,753
1975	2,579	2,312	2,074	1,860	1,668	1,493	1,334	1,190	1,060	942	836	742	6,153
1976	2,327	2,086	1,873	1,683	1,511	1,356	1,214	1,085	968	863	767	681	5,615
1977	2,192	1,958	1,757	1,579	1,419	1,275	1,144	1,025	916	818	728	648	5,317
1978	2,033	1,808	1,617	1,452	1,306	1,175	1,056	948	849	760	678	604	4,945
1979	1,800	1,594	1,422	1,274	1,146	1,032	929	835	750	672	601	537	4,394
1980	1,657	1,461	1,297	1,158	1,039	935	842	759	682	613	549	491	4,030
1981	1,542	1,350	1,192	1,059	946	850	765	689	621	559	502	450	3,702
1982	1,445	1,251	1,097	970	862	771	693	624	562	507	456	409	3,388
1983	1,430	1,218	1,055	926	819	728	651	585	527	475	428	385	3,209
1984	1,451	1,214	1,035	897	787	696	620	554	498	449	404	364	3,059
1985	1,517	1,252	1,048	893	775	680	602	535	479	430	388	349	2,959
1986	1,598	1,304	1,077	902	769	667	586	518	461	412	371	334	2,849
1987	1,711	1,380	1,127	930	779	665	577	506	448	398	356	320	2,751
1988	1,873	1,484	1,197	978	808	676	577	500	439	389	346	309	2,666
1989	2,085	1,620	1,284	1,036	846	699	585	499	433	380	336	299	2,576
1990	2,396	1,820	1,414	1,121	905	739	610	511	436	378	332	294	2,512
1991	2,834	2,091	1,589	1,235	978	790	645	533	446	381	330	290	2,449
1992	3,448	2,445	1,804	1,371	1,065	844	681	556	460	385	328	285	2,363
1993	4,364	2,922	2,072	1,529	1,162	903	716	578	472	390	327	278	2,245
1994	6,027	3,735	2,501	1,774	1,309	995	773	613	494	404	334	280	2,161
1995	8,664	5,135	3,183	2,131	1,512	1,116	848	659	522	422	344	284	2,080
1996	6,057	7,367	4,367	2,707	1,813	1,286	949	721	561	444	359	293	2,012
1997	4,497	5,173	6,293	3,731	2,313	1,549	1,099	811	616	479	380	306	1,970
1998	3,655	3,796	4,368	5,314	3,151	1,953	1,308	928	685	521	405	321	1,923
1999	3,206	3,072	3,191	3,673	4,468	2,650	1,643	1,100	780	576	438	340	1,887
2000	3,035	2,726	2,612	2,713	3,123	3,800	2,253	1,397	936	664	490	372	1,894
2001	2,969	2,554	2,294	2,198	2,284	2,629	3,199	1,897	1,176	788	559	413	1,908
2002	2,996	2,491	2,143	1,925	1,845	1,917	2,207	2,685	1,592	987	661	469	1,948
2003	3,111	2,499	2,078	1,788	1,607	1,540	1,600	1,842	2,242	1,330	824	552	2,019
2004	3,093	2,598	2,088	1,736	1,494	1,342	1,287	1,337	1,540	1,874	1,111	689	2,149
2005	2,657	2,578	2,166	1,741	1,448	1,246	1,120	1,073	1,116	1,284	1,563	927	2,367
2006	2,637	2,210	2,145	1,802	1,449	1,205	1,037	932	894	929	1,069	1,301	2,742
2007	3,285	2,211	1,854	1,800	1,512	1,216	1,011	871	782	750	779	897	3,394
2008	3,989	2,768	1,864	1,563	1,517	1,275	1,025	853	734	660	632	657	3,619
2009	3,399	3,343	2,321	1,563	1,311	1,273	1,069	860	715	616	553	531	3,587
2010	3,713	2,858	2,812	1,952	1,315	1,103	1,071	900	723	602	518	466	3,465
2011	4,087	3,147	2,422	2,383	1,655	1,115	935	908	763	613	510	439	3,332
2012	4,385	3,425	2,638	2,031	1,998	1,388	935	784	761	640	514	428	3,163
2013	4,742	3,668	2,866	2,207	1,700	1,673	1,162	782	656	637	536	431	3,007
2014	3,973	3,952	3,058	2,390	1,841	1,417	1,395	969	653	548	532	447	2,867
2015	3,577	3,310	3,293	2,548	1,992	1,534	1,182	1,163	808	544	456	443	2,763
2016	4,345	2,975	2,753	2,740	2,121	1,658	1,277	983	968	672	453	380	2,669

Table 16a. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 1**.

projected catch (t) – Scenario 1					
year	L90%CI	median	mean	U90%CI	SD
2017	33,635	33,635	33,635	33,635	0
2018	31,498	31,502	31,502	31,507	3
2019	29,368	29,384	29,386	29,408	13
2020	27,426	27,483	27,490	27,563	46
2021	25,791	25,956	25,977	26,183	131
2022	24,528	24,891	24,938	25,395	285
2023	23,650	24,263	24,352	25,131	493
2024	23,051	24,081	24,117	25,230	709
2025	22,558	23,946	23,991	25,373	970
2026	21,401	23,074	23,160	24,841	1,202
2027	20,853	22,941	22,955	25,262	1,451
2028	20,806	23,048	23,178	25,958	1,702
2029	21,029	23,602	23,620	27,338	1,889

projected female spawning biomass (t) – Scenario 1					
year	L90%CI	median	mean	U90%CI	SD
2017	108,926	108,926	108,926	108,926	0
2018	106,871	106,871	106,871	106,871	0
2019	103,699	103,699	103,699	103,699	0
2020	99,294	99,294	99,294	99,294	0
2021	93,832	93,832	93,832	93,832	0
2022	87,765	87,766	87,766	87,768	1
2023	81,678	81,695	81,698	81,722	14
2024	76,104	76,218	76,234	76,391	89
2025	71,465	71,839	71,891	72,372	306
2026	68,023	68,922	69,034	70,130	703
2027	65,911	67,439	67,672	69,681	1,233
2028	64,729	67,317	67,407	70,179	1,770
2029	64,508	67,771	67,804	70,873	2,218

projected fishing mortality rate – Scenario 1					
year	L90%CI	median	mean	U90%CI	SD
2017	0.079	0.079	0.079	0.079	0.000
2018	0.079	0.079	0.079	0.079	0.000
2019	0.079	0.079	0.079	0.079	0.000
2020	0.079	0.079	0.079	0.079	0.000
2021	0.079	0.079	0.079	0.079	0.000
2022	0.079	0.079	0.079	0.079	0.000
2023	0.079	0.079	0.079	0.079	0.000
2024	0.079	0.079	0.079	0.079	0.000
2025	0.078	0.079	0.079	0.079	0.000
2026	0.074	0.075	0.075	0.077	0.001
2027	0.072	0.074	0.074	0.076	0.001
2028	0.070	0.073	0.074	0.077	0.002
2029	0.070	0.074	0.074	0.078	0.002

Table 16b. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 2**.

projected catch - Scenario 2					
year	L90%CI	median	mean	U90%CI	SD
2017	25,139	25,139	25,139	25,139	0
2018	25,139	25,139	25,139	25,139	0
2019	30,456	30,472	30,475	30,497	13
2020	28,380	28,437	28,444	28,516	47
2021	26,613	26,778	26,800	27,006	131
2022	25,228	25,592	25,639	26,096	285
2023	24,239	24,853	24,942	25,722	493
2024	23,543	24,573	24,609	25,723	710
2025	23,180	24,488	24,517	25,781	902
2026	22,294	24,036	24,116	25,857	1,239
2027	21,519	23,656	23,665	26,012	1,482
2028	21,288	23,558	23,688	26,501	1,714
2029	21,371	23,957	23,959	27,420	1,866

projected female spawning biomass - Scenario 2					
year	L90%CI	median	mean	U90%CI	SD
2017	110,180	110,180	110,180	110,180	0
2018	110,159	110,159	110,159	110,160	0
2019	107,955	107,956	107,956	107,957	1
2020	103,333	103,334	103,334	103,335	1
2021	97,584	97,585	97,585	97,586	0
2022	91,177	91,179	91,179	91,181	1
2023	84,717	84,735	84,738	84,763	14
2024	78,762	78,877	78,893	79,051	90
2025	73,728	74,116	74,169	74,662	315
2026	69,854	70,778	70,893	72,015	722
2027	67,319	68,865	69,100	71,124	1,245
2028	65,796	68,390	68,473	71,261	1,775
2029	65,287	68,537	68,572	71,637	2,218

projected fishing mortality rate - Scenario 2					
year	L90%CI	median	mean	U90%CI	SD
2017	0.058	0.058	0.058	0.058	0.000
2018	0.061	0.061	0.061	0.061	0.000
2019	0.079	0.079	0.079	0.079	0.000
2020	0.079	0.079	0.079	0.079	0.000
2021	0.079	0.079	0.079	0.079	0.000
2022	0.079	0.079	0.079	0.079	0.000
2023	0.079	0.079	0.079	0.079	0.000
2024	0.079	0.079	0.079	0.079	0.000
2025	0.079	0.079	0.079	0.079	0.000
2026	0.076	0.077	0.078	0.079	0.001
2027	0.073	0.075	0.075	0.078	0.001
2028	0.072	0.075	0.075	0.078	0.002
2029	0.071	0.075	0.075	0.078	0.002

Table 16c. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 3**.

projected catch (t) - Scenario 3					
year	L90%CI	median	mean	U90%CI	SD
2017	23,224	23,224	23,224	23,224	0
2018	22,247	22,250	22,250	22,253	2
2019	21,194	21,205	21,206	21,221	9
2020	20,189	20,228	20,233	20,282	32
2021	19,322	19,435	19,450	19,592	90
2022	18,652	18,904	18,936	19,255	198
2023	18,200	18,632	18,695	19,245	346
2024	17,906	18,643	18,670	19,474	505
2025	17,827	18,764	18,787	19,708	651
2026	17,858	18,928	18,985	20,198	778
2027	17,903	19,148	19,224	20,710	888
2028	18,101	19,446	19,476	21,186	979
2029	18,342	19,587	19,719	21,533	1,043

projected female spawning biomass (t) - Scenario 3					
year	L90%CI	median	mean	U90%CI	SD
2017	110,036	110,036	110,036	110,036	0
2018	110,617	110,617	110,617	110,617	0
2019	109,963	109,963	109,963	109,963	0
2020	107,844	107,844	107,844	107,844	0
2021	104,332	104,332	104,332	104,332	0
2022	99,828	99,829	99,829	99,830	1
2023	94,921	94,939	94,942	94,967	14
2024	90,207	90,327	90,344	90,510	94
2025	86,170	86,585	86,642	87,171	338
2026	83,039	84,082	84,215	85,488	818
2027	80,960	82,822	83,105	85,578	1,498
2028	79,754	82,973	83,048	86,675	2,244
2029	79,339	83,545	83,670	87,856	2,931

projected fishing mortality rate - Scenario 3					
year	L90%CI	median	mean	U90%CI	SD
2017	0.054	0.054	0.054	0.054	0.000
2018	0.054	0.054	0.054	0.054	0.000
2019	0.054	0.054	0.054	0.054	0.000
2020	0.054	0.054	0.054	0.054	0.000
2021	0.054	0.054	0.054	0.054	0.000
2022	0.054	0.054	0.054	0.054	0.000
2023	0.054	0.054	0.054	0.054	0.000
2024	0.054	0.054	0.054	0.054	0.000
2025	0.054	0.054	0.054	0.054	0.000
2026	0.054	0.054	0.054	0.054	0.000
2027	0.054	0.054	0.054	0.054	0.000
2028	0.054	0.054	0.054	0.054	0.000
2029	0.054	0.054	0.054	0.054	0.000

Table 16d. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 4**.

projected catch (t) - Scenario 4					
year	L90%CI	median	mean	U90%CI	SD
2017	17,946	17,946	17,946	17,946	0
2018	17,386	17,388	17,388	17,391	1
2019	16,743	16,751	16,752	16,764	7
2020	16,108	16,138	16,142	16,180	25
2021	15,555	15,642	15,654	15,763	70
2022	15,131	15,326	15,351	15,599	154
2023	14,858	15,195	15,244	15,674	270
2024	14,696	15,274	15,294	15,930	397
2025	14,683	15,429	15,447	16,178	515
2026	14,767	15,616	15,658	16,603	618
2027	14,837	15,836	15,896	17,046	709
2028	15,058	16,129	16,141	17,530	786
2029	15,257	16,281	16,374	17,856	841

projected female spawning biomass (t) - Scenario 4					
year	L90%CI	median	mean	U90%CI	SD
2017	110,594	110,594	110,594	110,594	0
2018	112,532	112,532	112,532	112,532	0
2019	113,225	113,225	113,225	113,225	0
2020	112,377	112,377	112,377	112,377	0
2021	109,998	109,998	109,998	109,998	0
2022	106,449	106,450	106,450	106,451	1
2023	102,312	102,330	102,333	102,358	14
2024	98,203	98,327	98,344	98,514	96
2025	94,645	95,074	95,133	95,682	351
2026	91,905	92,997	93,137	94,472	857
2027	90,166	92,145	92,440	95,071	1,586
2028	89,300	92,710	92,800	96,658	2,400
2029	89,203	93,728	93,841	98,380	3,161

projected fishing mortality rate - Scenario 4					
year	L90%CI	median	mean	U90%CI	SD
2017	0.041	0.041	0.041	0.041	0.000
2018	0.041	0.041	0.041	0.041	0.000
2019	0.041	0.041	0.041	0.041	0.000
2020	0.041	0.041	0.041	0.041	0.000
2021	0.041	0.041	0.041	0.041	0.000
2022	0.041	0.041	0.041	0.041	0.000
2023	0.041	0.041	0.041	0.041	0.000
2024	0.041	0.041	0.041	0.041	0.000
2025	0.041	0.041	0.041	0.041	0.000
2026	0.041	0.041	0.041	0.041	0.000
2027	0.041	0.041	0.041	0.041	0.000
2028	0.041	0.041	0.041	0.041	0.000
2029	0.041	0.041	0.041	0.041	0.000

Table 16e. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 5**.

projected catch (t) - Scenario 5					
year	L90%CI	median	mean	U90%CI	SD
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0
2028	0	0	0	0	0
2029	0	0	0	0	0

projected female spawning biomass (t) - Scenario 5					
year	L90%CI	median	mean	U90%CI	SD
2017	112,463	112,463	112,463	112,463	0
2018	119,127	119,127	119,127	119,127	0
2019	124,755	124,755	124,755	124,755	0
2020	128,825	128,825	128,825	128,825	0
2021	131,100	131,100	131,100	131,100	0
2022	131,745	131,746	131,746	131,748	1
2023	131,258	131,277	131,280	131,307	15
2024	130,271	130,406	130,425	130,611	105
2025	129,404	129,886	129,952	130,572	396
2026	129,034	130,302	130,470	132,033	1,002
2027	129,459	131,887	132,217	135,403	1,921
2028	130,740	134,770	135,023	139,762	3,003
2029	132,463	138,369	138,508	144,563	4,069

projected fishing mortality rate - Scenario 5					
year	L90%CI	median	mean	U90%CI	SD
2017	0.000	0.000	0.000	0.000	0.000
2018	0.000	0.000	0.000	0.000	0.000
2019	0.000	0.000	0.000	0.000	0.000
2020	0.000	0.000	0.000	0.000	0.000
2021	0.000	0.000	0.000	0.000	0.000
2022	0.000	0.000	0.000	0.000	0.000
2023	0.000	0.000	0.000	0.000	0.000
2024	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000
2026	0.000	0.000	0.000	0.000	0.000
2027	0.000	0.000	0.000	0.000	0.000
2028	0.000	0.000	0.000	0.000	0.000
2029	0.000	0.000	0.000	0.000	0.000

Table 16f. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 6**.

projected catch (t) - Scenario 6					
year	L90%CI	median	mean	U90%CI	SD
2017	39,050	39,050	39,050	39,050	0
2018	36,135	36,139	36,139	36,145	3
2019	33,311	33,330	33,332	33,358	15
2020	30,786	30,852	30,861	30,945	54
2021	28,687	28,879	28,904	29,142	152
2022	27,076	27,497	27,551	28,078	330
2023	25,951	26,656	26,759	27,652	566
2024	24,276	25,451	25,495	26,792	808
2025	22,424	23,873	23,920	25,410	1,013
2026	21,401	23,117	23,213	24,940	1,245
2027	20,994	23,115	23,174	25,614	1,510
2028	21,107	23,463	23,580	26,470	1,777
2029	21,499	24,163	24,215	28,117	2,008

projected female spawning biomass (t) - Scenario 6					
year	L90%CI	median	mean	U90%CI	SD
2017	108,343	108,343	108,343	108,343	0
2018	104,940	104,940	104,940	104,940	0
2019	100,529	100,529	100,529	100,529	0
2020	95,046	95,046	95,046	95,046	0
2021	88,709	88,709	88,709	88,709	0
2022	81,985	81,986	81,986	81,987	1
2023	75,440	75,457	75,459	75,483	13
2024	69,665	69,772	69,787	69,935	84
2025	65,179	65,534	65,582	66,032	288
2026	62,091	62,950	63,053	64,090	667
2027	60,311	61,765	61,985	63,865	1,172
2028	59,430	61,877	61,975	64,553	1,679
2029	59,435	62,558	62,588	65,465	2,095

projected fishing mortality rate - Scenario 6					
year	L90%CI	median	mean	U90%CI	SD
2017	0.092	0.092	0.092	0.092	0.000
2018	0.092	0.092	0.092	0.092	0.000
2019	0.092	0.092	0.092	0.092	0.000
2020	0.092	0.092	0.092	0.092	0.000
2021	0.092	0.092	0.092	0.092	0.000
2022	0.092	0.092	0.092	0.092	0.000
2023	0.092	0.092	0.092	0.092	0.000
2024	0.089	0.089	0.089	0.089	0.000
2025	0.083	0.083	0.083	0.084	0.000
2026	0.079	0.080	0.080	0.081	0.001
2027	0.076	0.078	0.079	0.081	0.002
2028	0.075	0.078	0.079	0.082	0.002
2029	0.075	0.079	0.079	0.083	0.003

Table 16g. Projected catch, female spawning biomass, and fishing mortality rate for **Harvest Scenario 7**.

projected catch (t) - Scenario 7					
year	L90%CI	median	mean	U90%CI	SD
2017	33,635	33,635	33,635	33,635	0
2018	31,498	31,502	31,502	31,507	3
2019	34,098	34,116	34,119	34,144	15
2020	31,468	31,535	31,543	31,628	54
2021	29,270	29,462	29,487	29,725	152
2022	27,567	27,988	28,041	28,569	330
2023	26,360	27,065	27,168	28,061	567
2024	25,136	26,336	26,381	27,706	825
2025	23,045	24,518	24,566	26,078	1,029
2026	21,851	23,581	23,679	25,421	1,257
2027	21,311	23,431	23,500	25,961	1,517
2028	21,321	23,685	23,796	26,684	1,780
2029	21,635	24,289	24,345	28,238	2,006

projected female spawning biomass (t) - Scenario 7					
year	L90%CI	median	mean	U90%CI	SD
2017	108,926	108,926	108,926	108,926	0
2018	106,871	106,871	106,871	106,871	0
2019	103,144	103,144	103,144	103,144	0
2020	97,500	97,500	97,500	97,500	0
2021	90,964	90,964	90,964	90,964	0
2022	84,014	84,015	84,015	84,016	1
2023	77,229	77,246	77,248	77,272	13
2024	71,158	71,265	71,281	71,428	84
2025	66,338	66,692	66,740	67,188	287
2026	62,974	63,829	63,932	64,964	664
2027	60,965	62,411	62,630	64,498	1,165
2028	59,896	62,328	62,425	64,987	1,670
2029	59,745	62,850	62,881	65,740	2,083

projected fishing mortality rate - Scenario 7					
year	L90%CI	median	mean	U90%CI	SD
2017	0.079	0.079	0.079	0.079	0.000
2018	0.079	0.079	0.079	0.079	0.000
2019	0.092	0.092	0.092	0.092	0.000
2020	0.092	0.092	0.092	0.092	0.000
2021	0.092	0.092	0.092	0.092	0.000
2022	0.092	0.092	0.092	0.092	0.000
2023	0.092	0.092	0.092	0.092	0.000
2024	0.091	0.091	0.091	0.091	0.000
2025	0.084	0.085	0.085	0.086	0.000
2026	0.080	0.081	0.081	0.083	0.001
2027	0.077	0.079	0.079	0.082	0.002
2028	0.076	0.079	0.079	0.083	0.002
2029	0.076	0.080	0.080	0.084	0.003

Table 17. 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		2016	
	biomass	**CV**	**biomass**	**CV**	**biomass**	**CV**	**biomass**	**CV**	**biomass**	**CV**
Alaska	394,544	0.11	419,311	0.05	356,681	0.06	372,213	0.06	542,449	0.04
other skates	75,474	0.08	83,411	0.11	99,941	0.08	90,787	0.06	102,996	0.09
all skates	470,018	0.09	502,722	0.04	456,622	0.05	463,000	0.05	645,444	0.04
other skates										
Aleutian	26,258	0.18	29,000	0.20	30,775	0.15	33,013	0.10	41,355	0.15
whiteblotched	20,893	0.15	29,697	0.22	28,339	0.17	21,455	0.16	20,690	0.15
Bering	15,642	0.13	13,310	0.10	13,726	0.12	13,379	0.13	12,994	0.11
big	1,692	0.53	901	0.59	4,081	0.57	1,356	0.61	11,974	0.49
commander	3,656	0.16	4,194	0.15	3,461	0.15	4,509	0.13	5,540	0.16
leopard					12,958	0.21	10,421	0.24	4,220	0.40
roughtail	1,624	0.14	1,678	0.12	2,103	0.16	2,299	0.15	2,283	0.14
mud	2,706	0.15	2,509	0.14	2,122	0.17	2,429	0.18	2,248	0.17
whitebrow	1,567	0.23	1,789	0.20	1,908	0.19	1,409	0.14	1,359	0.15
deepsea			164	0.73	345	0.64	90	1.00	223	0.54
butterfly					123	0.49	307	0.32	86	0.31
Bathyraja sp.	68	0.59	21	0.49	1	1.00			21	0.84
misc skates	37	0.84	139	0.39			1	0.00	2	1.00
longnose	915	0.71					120	1.00		
Okhotsk	415	0.56	8	1.00						

Table 18. 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	33,300	0.14	69,232	0.50
	2004	4,248	0.33	28,909	0.08	33,156	0.08
	2008	4,318	0.32	33,066	0.08	36,384	0.08
	2010	1,296	0.32	33,882	0.12	35,177	0.12
	2012	19,102	0.27	40,585	0.08	59,687	0.10
	2016	8,965	0.30	40,187	0.12	49,152	0.11
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	40,711	0.14	54,214	0.12
	2010	3,681	0.20	48,260	0.12	51,941	0.11
	2012	1,503	0.31	33,902	0.12	35,405	0.12
	2014	3,515	0.40	39,390	0.12	42,905	0.12
	2016	1,808	0.46	25,960	0.14	27,768	0.14
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	306,421	0.07	71,688	0.23	378,109	0.07
	1998	341,833	0.05	4,178	0.42	346,011	0.05
	1999	312,998	0.16	15,575	0.43	328,574	0.17
	2000	299,151	0.06	24,615	0.21	323,767	0.06
	2001	402,909	0.06	17,405	0.15	420,313	0.06
	2002	347,874	0.06	18,441	0.15	366,315	0.07
	2003	353,600	0.05	31,996	0.25	385,597	0.05
	2004	402,141	0.05	14,183	0.13	416,324	0.05
	2005	461,897	0.05	20,217	0.26	482,115	0.05
	2006	424,465	0.05	18,045	0.16	442,510	0.05
	2007	458,112	0.07	17,083	0.22	475,195	0.07
	2008	346,735	0.06	19,340	0.22	366,074	0.06
	2009	338,823	0.06	19,644	0.17	358,467	0.06
	2010	351,704	0.06	17,800	0.17	369,504	0.06
	2011	392,502	0.05	17,707	0.25	410,209	0.05
	2012	351,608	0.06	16,301	0.15	367,908	0.06
	2013	375,161	0.06	26,961	0.23	402,122	0.06
	2014	392,427	0.05	24,233	0.18	416,660	0.05
	2015	433,406	0.06	39,200	0.23	472,605	0.06
	2016	531,676	0.04	36,849	0.19	568,525	0.04

Table 19. Survey biomass estimates for miscellaneous, Aleutian, Bering, and whiteblotched skates by area and year (part of the "other skates" category in Table 16). Miscellaneous skates includes skates not identified to species; in the AI in 2010 and 2012 it also includes the leopard skate.

		misc skates		Aleutian		Bering		whiteblotched	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			18,655	0.24	2,873	0.18	3,928	0.23
	2004			14,987	0.14	1,953	0.11	3,450	0.16
	2008			16,682	0.15	2,443	0.16	4,441	0.17
	2010			18,721	0.22	2,780	0.16	4,055	0.14
	2012			22,377	0.12	3,442	0.16	5,753	0.20
	2016	2	1.00	23,204	0.20	1,963	0.20	5,065	0.21
AI	1980	3,044	0.30	86	1.00	91	1.00		
	1983	5,556	0.16	1,651	0.36	307	0.83	1,560	0.30
	1986	8,703	0.29	3,434	0.36	119	0.91	1,886	0.22
	1991	6,274	0.31	2,423	0.21	39	0.71	142	0.64
	1994	2,685	0.19	3,376	0.22	938	0.36	7,989	0.19
	1997	1,171	0.80	4,455	0.30	42	0.33	13,379	0.26
	2000	153	0.54	3,329	0.19	2	1.00	13,721	0.15
	2002	37	0.84	4,711	0.17	229	0.93	16,728	0.18
	2004	139	0.39	11,519	0.45	147	0.75	26,247	0.25
	2006	598	0.42	6,692	0.23	186	0.55	29,714	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
	2016			3,703	0.21	50	0.55	15,380	0.19
EBS shelf	1982	72,478	0.19	257	0.52				
	1983	38,491	0.14	16,410	0.21	2,710	0.51		
	1984	88,299	0.16	8,759	0.57	254	0.69		
	1985	95,400	0.10	6,495	0.46	1,121	0.45		
	1986	53,669	0.16	2,971	0.58	1,580	0.83		
	1987	69,548	0.22	5,096	0.44	31,089	0.26		
	1988	166,540	0.12	6,566	0.68	6,443	0.39		
	1989	370,237	0.08						
	1990	540,502	0.11						
	1991	384,972	0.09						
	1992	380,181	0.09			16	1.00		
	1993	388,950	0.07						
	1994	433,979	0.08						
	1995	404,460	0.08						
	1996	2,195	0.91	56,580	0.22	7,934	0.22		
	1997	12,880	0.60	65,427	0.25	7,495	0.19		
	1998	2,868	0.57	794	0.37	1,742	0.34		
	1999	2,159	0.55			9,084	0.21		
	2000	66	1.00	2,232	0.54	16,833	0.16		
	2001			1,232	0.61	14,263	0.14		
	2002			2,893	0.47	12,540	0.16	237	1.00
	2003			18,253	0.43	13,218	0.12		
	2004	1	1.00	2,494	0.41	11,209	0.12		
	2005			8,223	0.56	8,272	0.17	1,070	1.00
	2006			5,568	0.41	11,204	0.13	182	1.00
	2007			2,718	0.43	9,327	0.14	3,234	0.92
	2008			6,278	0.57	9,666	0.16	238	1.00
	2009			2,171	0.49	12,756	0.18	216	1.00
	2010			3,332	0.35	10,890	0.15	133	1.00
	2011			2,525	0.54	9,731	0.17		
	2012			4,565	0.37	9,827	0.17	342	1.00
	2013			11,483	0.35	12,099	0.28		
	2014			8,149	0.41	12,339	0.15		
	2015			11,084	0.40	12,146	0.13		
	2016			14,449	0.27	10,981	0.12	245	1.00

Table 20. 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	1,624	0.14	3,656	0.16	1,537	0.23
	2004			702	0.20	1,677	0.12	4,194	0.15	1,755	0.20
	2008			978	0.22	2,134	0.13	3,342	0.15	1,874	0.17
	2010			576	0.25	2,103	0.16	3,393	0.15	1,908	0.19
	2012			866	0.30	2,298	0.15	4,423	0.13	1,336	0.15
	2016			577	0.22	2,283	0.14	5,511	0.16	1,359	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						
	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	2,970	0.28			161	1.00		
	2010	637	0.83	1,546	0.22			68	1.00		
	2012	195	0.65	1,277	0.15	2	0.86	86	0.66	72	0.69
	2014			1,831	0.25					8	0.73
	2016	1,306	0.87	1,165	0.20	17	0.43	29	1.00		
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	882	1.00								
	1997										
	1998	1,642	1.00								
	1999	6,492	1.00								
	2000	5,155	0.83	394	0.53						
	2001	1,811	0.78								
	2002	1,489	0.59								
	2003			526	0.37						
	2004	479	1.00								
	2005	2,307	0.71	186	0.86						
	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	3,379	1.00								
	2014	3,596	0.60	149	1.00						
	2015	15,438	0.49	190	1.00						
	2016	10,668	0.54	506	0.54						

Table 21. 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			160	0.62				
	2010					345	0.64				
	2012					90	1.00				
	2016					223	0.54				
AI	1980										
	1983										
	1986										
	1991	97	0.99								
	1994	28	1.00								
	1997	368	1.00								
	2000										
	2002										
	2004										
	2006							4	1.00	385	0.40
	2010							12,958	0.21	123	0.49
	2012							10,421	0.24	307	0.32
	2014							7,040	0.23	409	0.37
	2016							4,220	0.21	86	0.31
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										
	2015	343	1.00								
	2016										

Table 22. 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.

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EBS slope	survey estimate				33,300		28,909				32,066		33,882		40,585				40,187
	RE estimate				31,314	30,936	30,563	31,142	31,732	32,333	32,945	34,054	35,199	36,724	38,314	38,550	38,787	39,026	39,266
	RE CV				0.087	0.081	0.071	0.081	0.083	0.078	0.065	0.070	0.067	0.071	0.069	0.084	0.092	0.095	0.094
AI	survey estimate		19,551		23,732		40,319		40,711				48,260		33,902		39,390		25,960
	RE estimate		20,377	22,458	24,750	29,446	35,032	37,372	39,869	41,134	42,439	43,786	45,175	40,313	35,974	36,418	36,867	32,270	28,247
	RE CV		0.111	0.153	0.112	0.162	0.150	0.168	0.123	0.185	0.200	0.181	0.112	0.150	0.106	0.149	0.106	0.155	0.133
EBS shelf	survey estimate	15,575	24,615	17,405	18,441	31,996	14,183	20,217	18,045	17,083	19,340	19,644	17,800	17,707	16,301	26,961	24,233	39,200	36,849
	RE estimate	19,532	20,034	18,784	18,819	19,213	16,645	17,613	17,880	18,018	18,564	18,815	18,542	18,787	19,410	23,122	26,026	30,577	32,617
	RE CV	0.177	0.135	0.104	0.100	0.120	0.101	0.114	0.105	0.115	0.116	0.108	0.110	0.122	0.118	0.116	0.115	0.144	0.161
total BSAI RE estimate					**74,883**		**82,240**				**93,949**		**98,916**		**93,698**				**100,130**

Figures

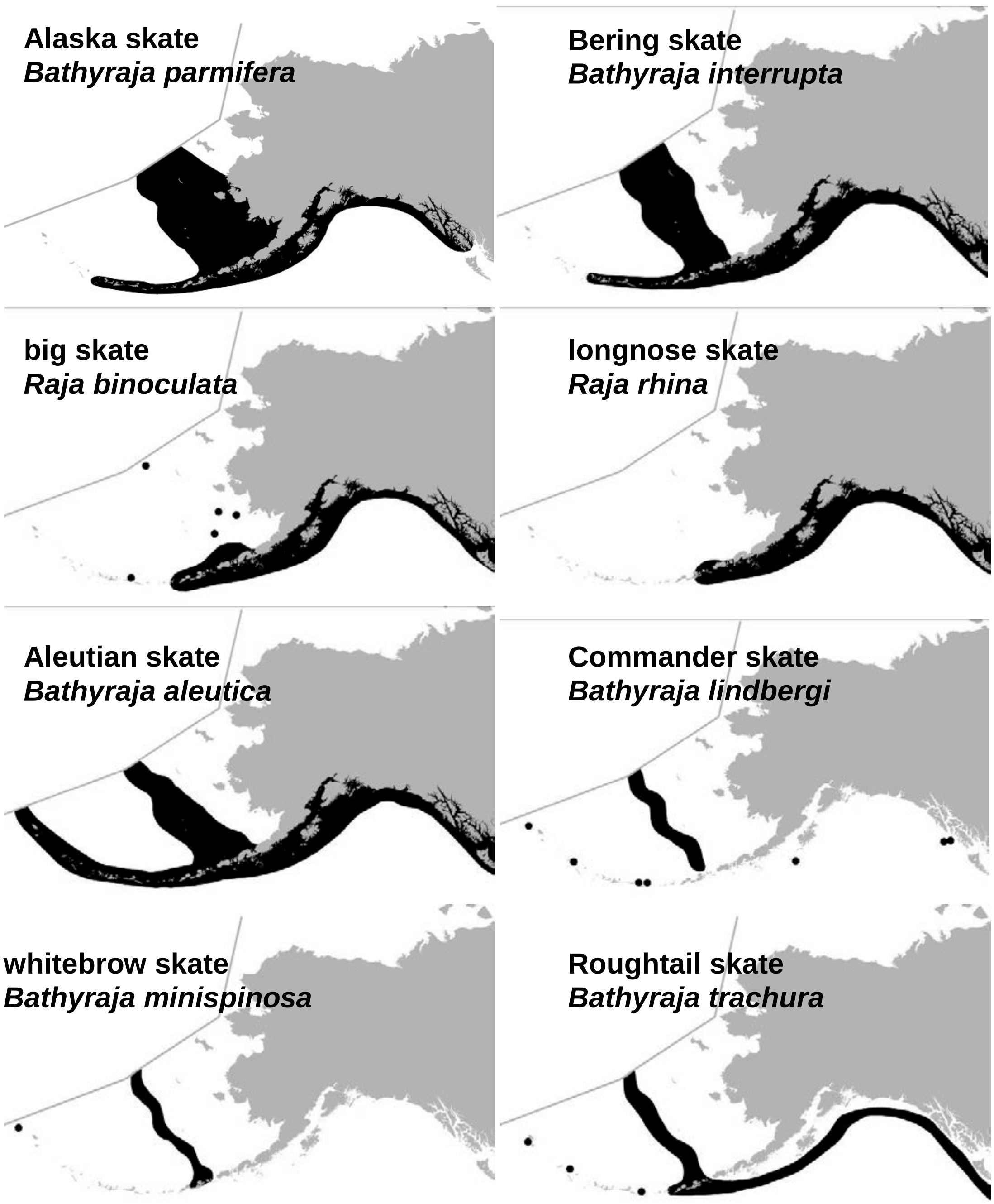


Figure 1. Distribution of skate species in Alaskan waters. These maps were created primarily using survey data, although observer records were included whenever positive species identification was possible (through voucher specimens or photographs). (Source: Stevenson et al. 2007)

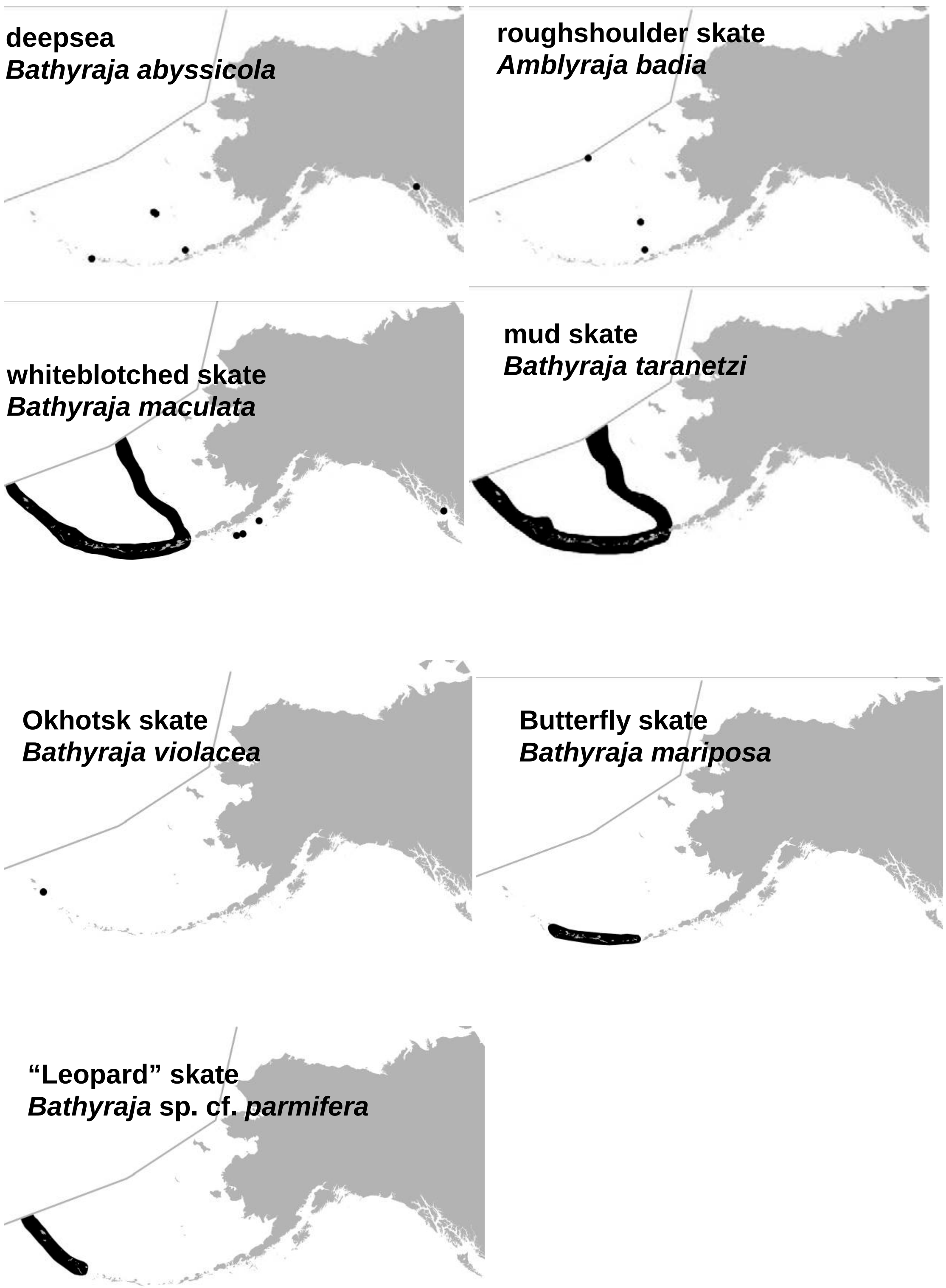


Figure 1 continued. Distribution of skate species in Alaskan waters. (Source: Stevenson et al. 2007)

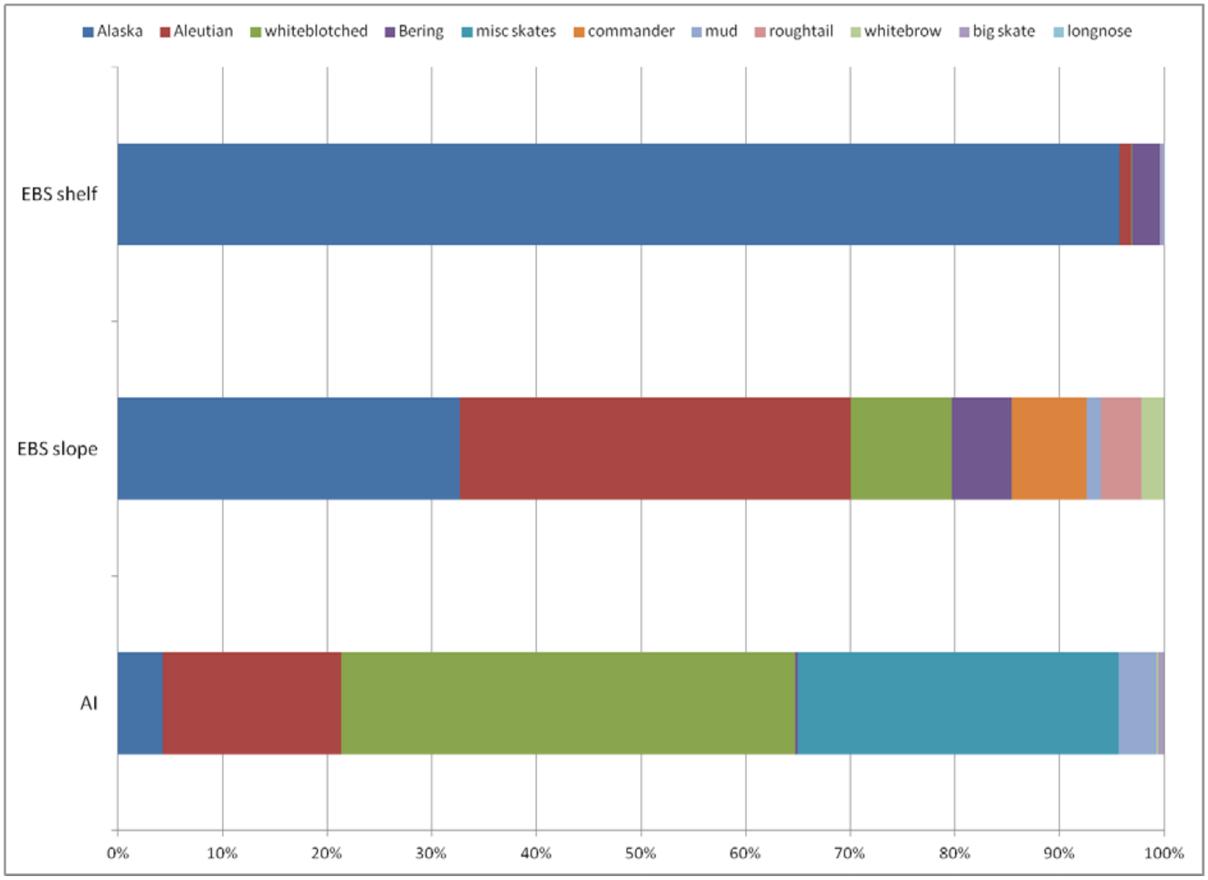


Figure 2. Skate species composition (by weight) by BSAI subregion, from surveys conducted in each region in 2012. In the AI, "misc skates" includes leopard skates.

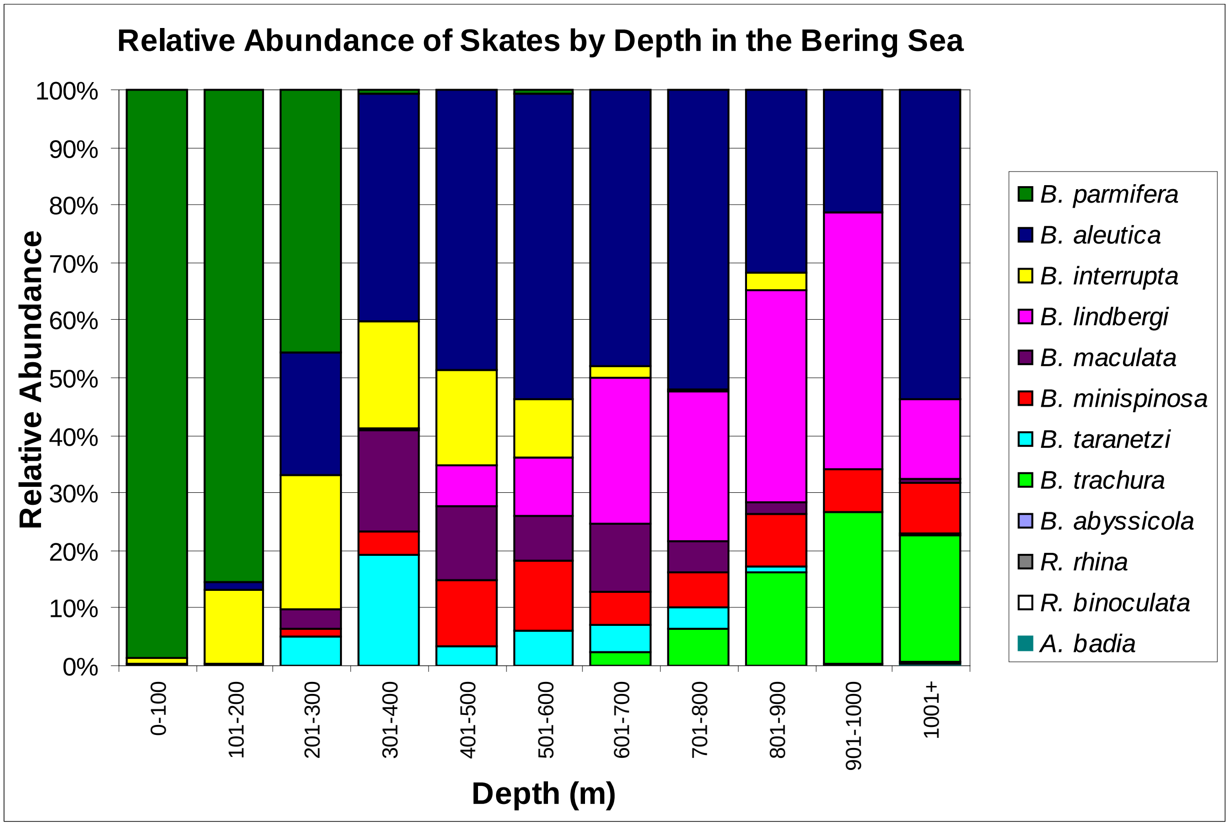


Figure 3. Relative abundance of skate species in the EBS by depth. (Source: Stevenson et al. 2006.)

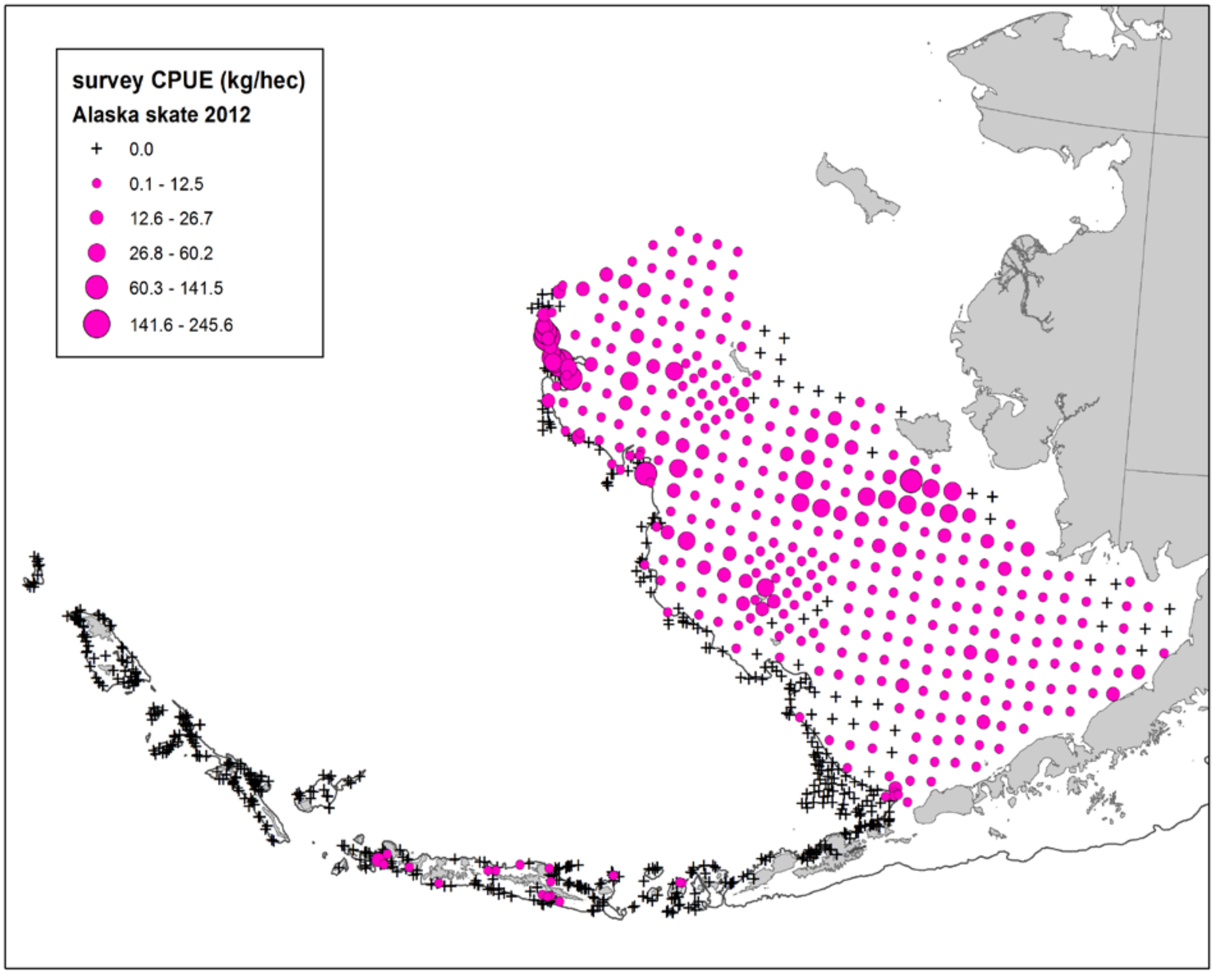


Figure 4. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Alaska skate in 2012. Symbol size is proportional to CPUE at each survey station and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

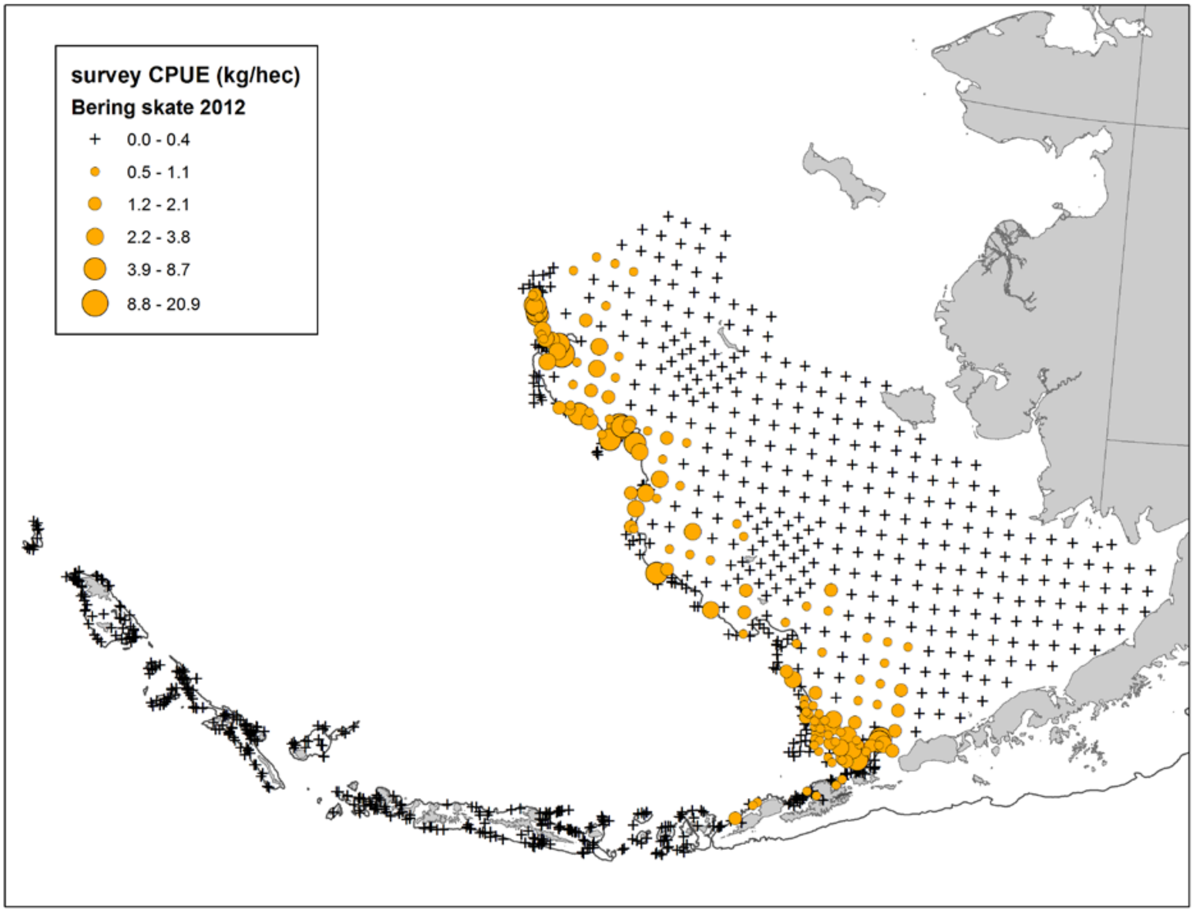


Figure 5. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Bering skate in 2012. Symbol size is proportional to CPUE at each survey station and crosses indicate no catch of Bering skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

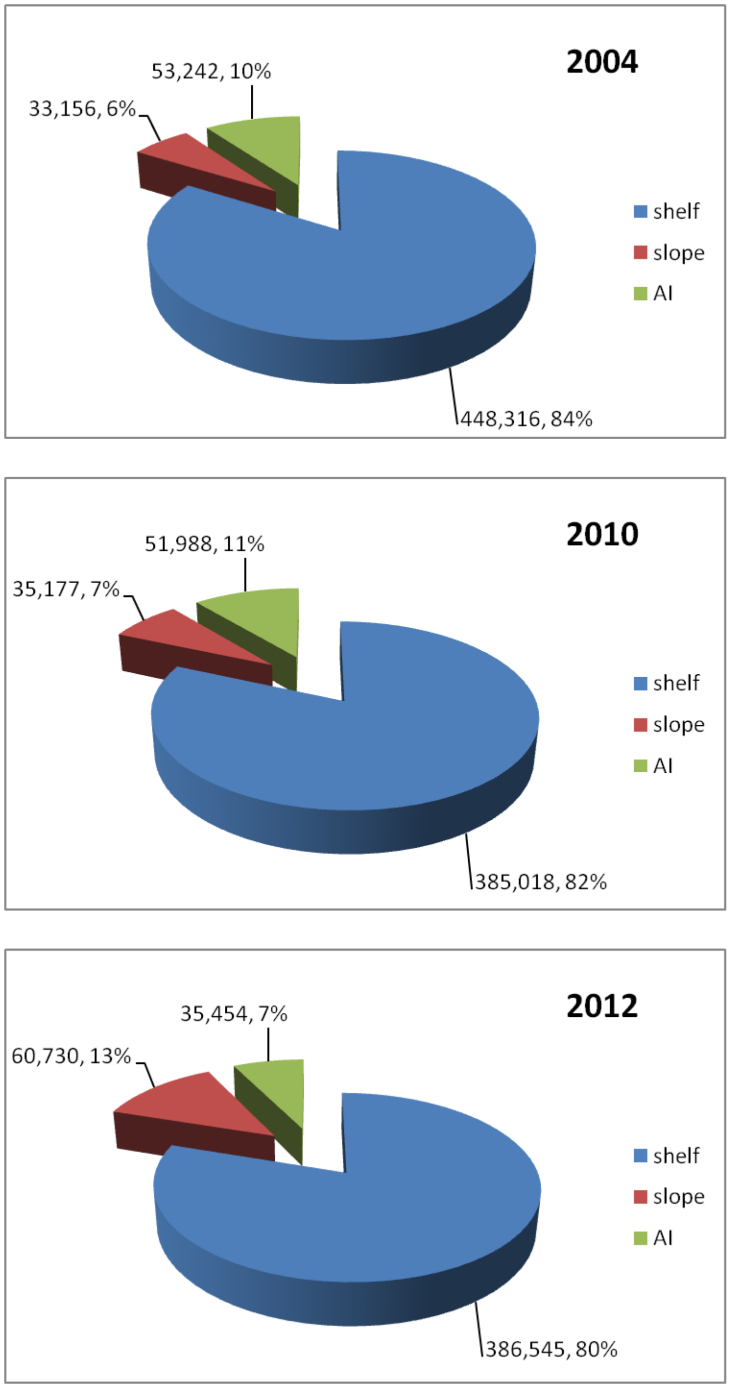


Figure 6. Distribution of skate biomass in the 3 subregions of the BSAI in 2004, 2010, and 2012. These are the 3 most recent years when all 3 surveys in the BSAI were conducted in the same year. Data are biomass estimates (t) and relative proportions from AFSC groundfish surveys.

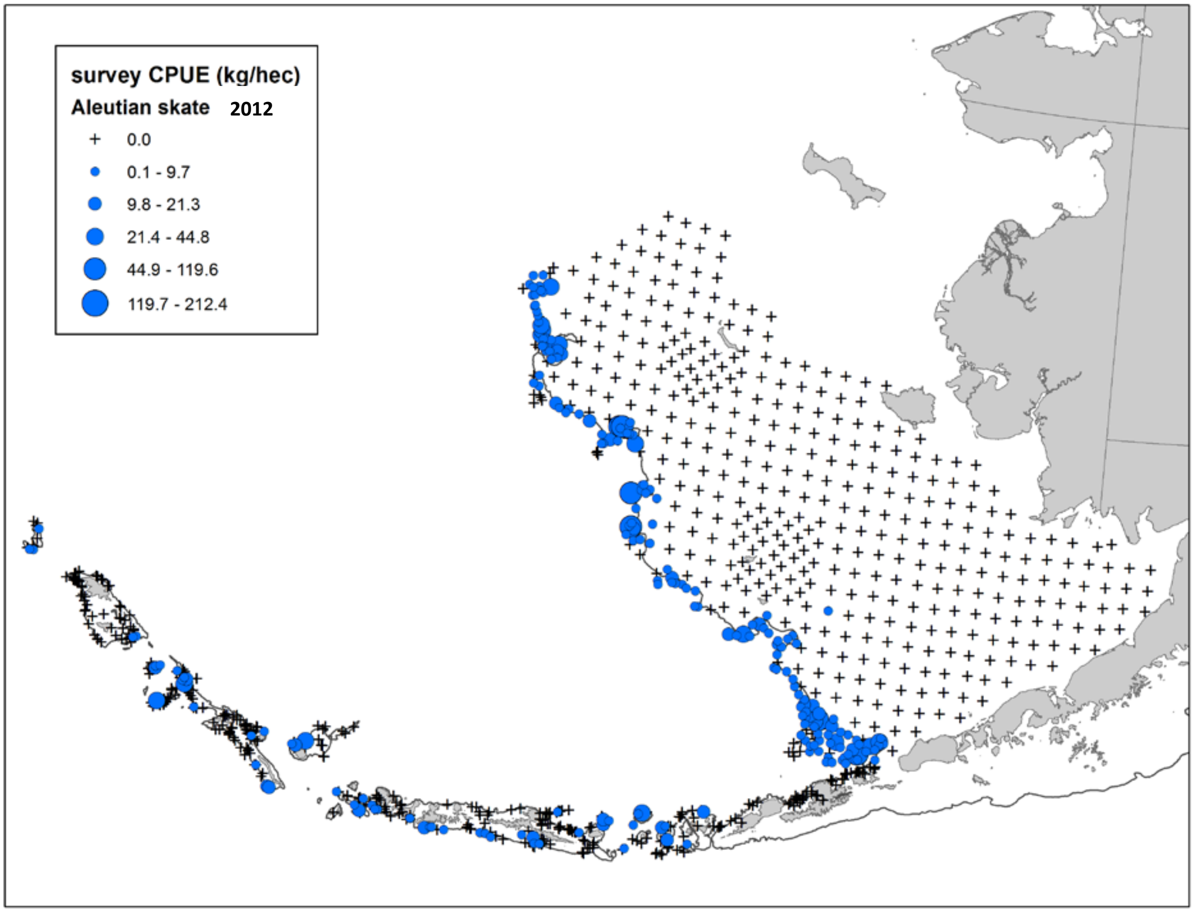


Figure 7. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Aleutian skate in 2012. Symbol size is proportional to CPUE at each survey station and crosses indicate no catch of Aleutian skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

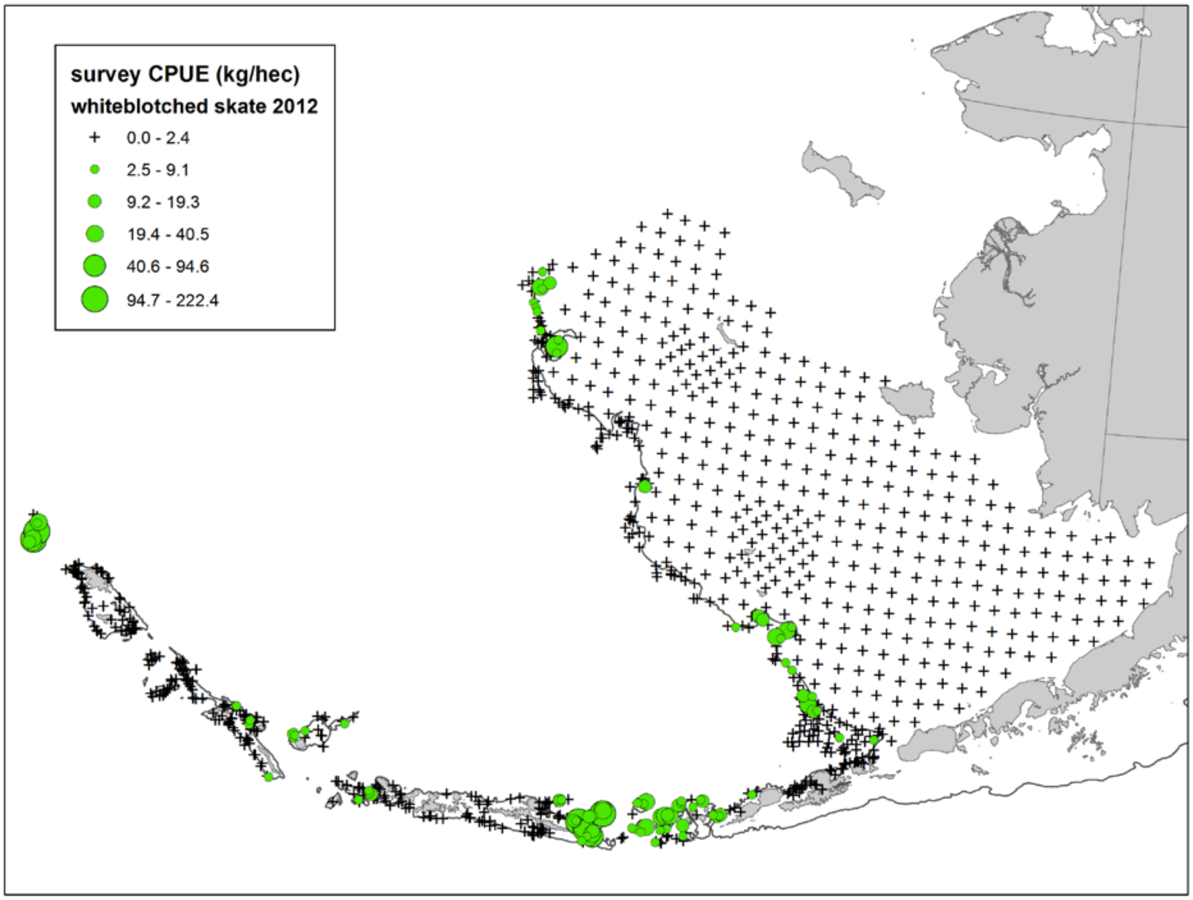


Figure 8. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of whiteblotched skate in 2012. Symbol size is proportional to CPUE at each survey station and crosses indicate no catch of whiteblotched skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

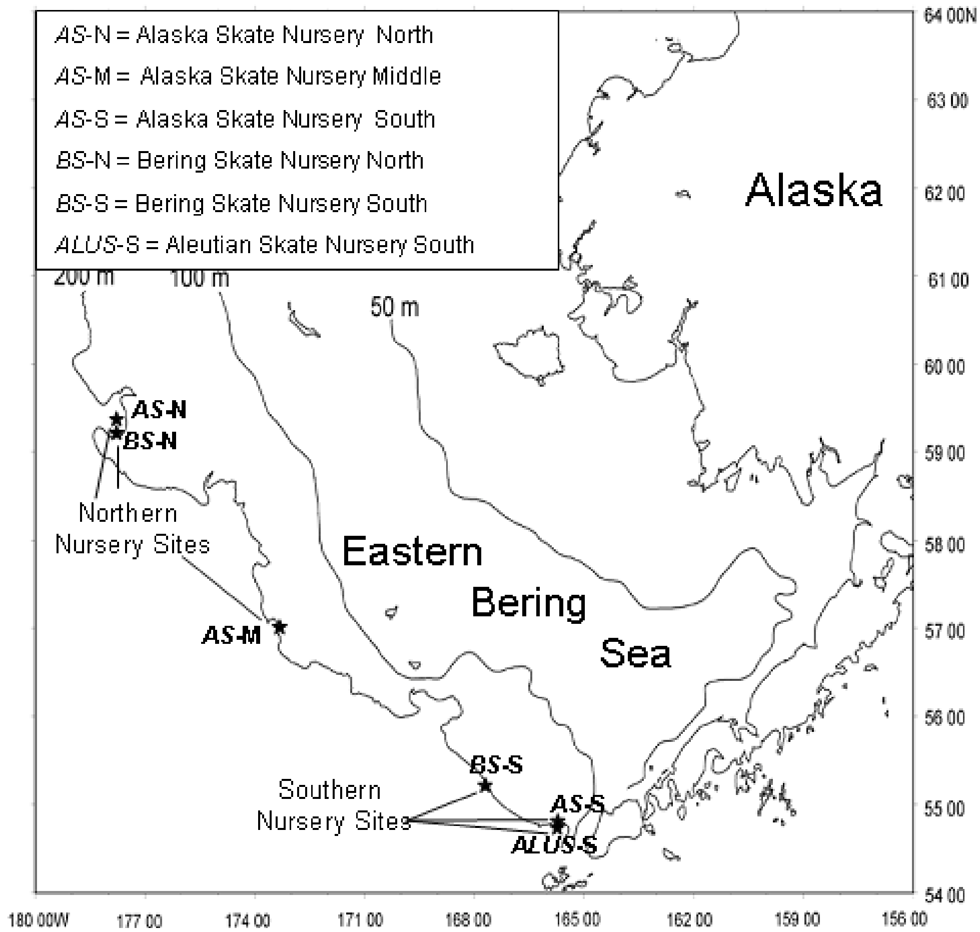


Figure 9. Map of the eastern Bering Sea with the six known skate nursery site locations and designations as a northern or southern nursery site. (See the legend for nursery site designation.) Source: Gerald Hoff, AFSC, unpublished data.

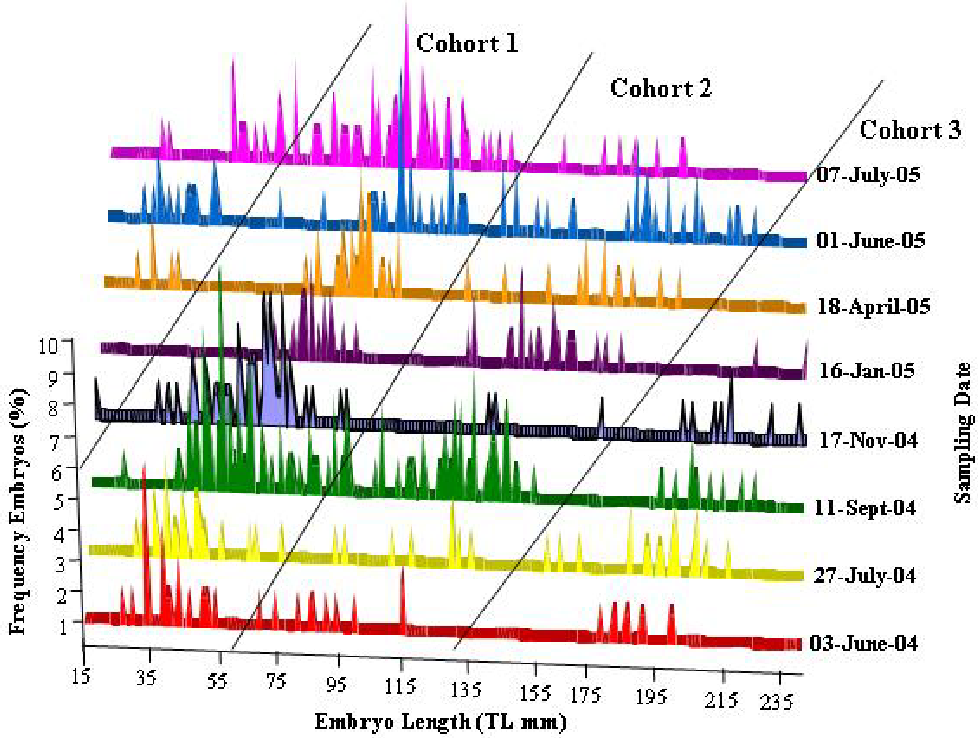


Figure 10. Embryo length composition data used in a cohort analysis of embryo development time. Figure is from G. Hoff (AFSC, pers. comm.).

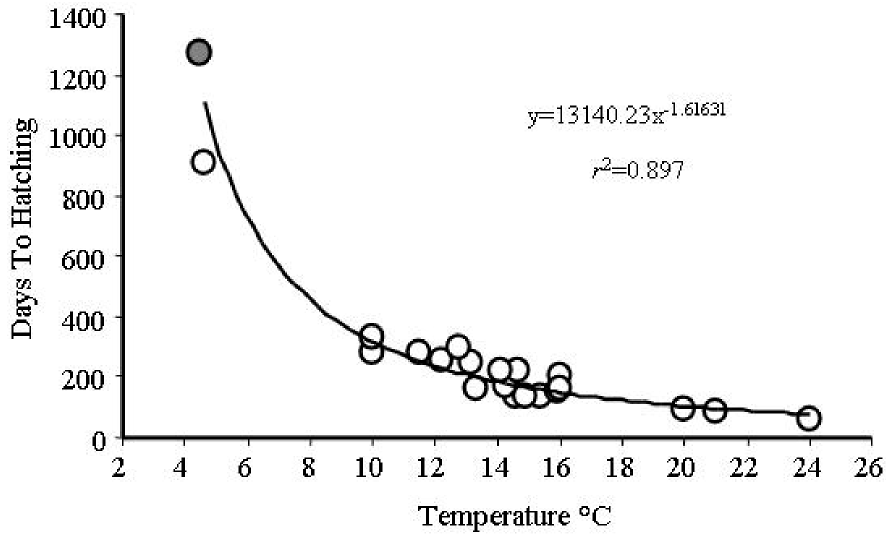


Figure 11. Ocean temperature versus embryo development time for 21 skate species. Dark grey circle is the Alaska skate. Equation and R^2 are the values of the fitted relationship. Figure is from G. Hoff (AFSC, pers. comm.)

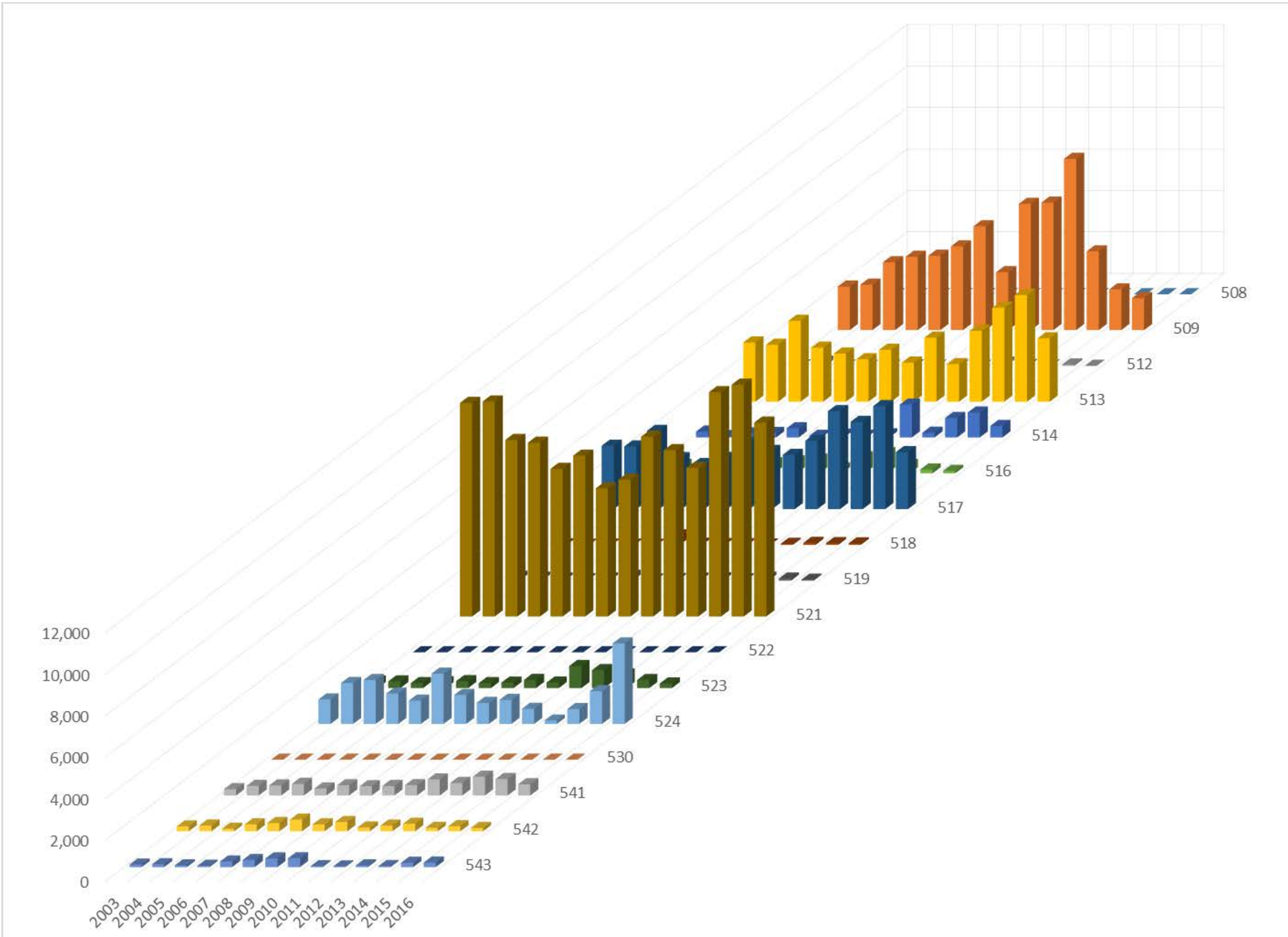


Figure 12. Total skate catch (all species combined) by FMP reporting area for both the EBS and the AI, 2003 - 2016. Source: AKRO CAS. 2016 data incomplete; retrieved October 16, 2016.

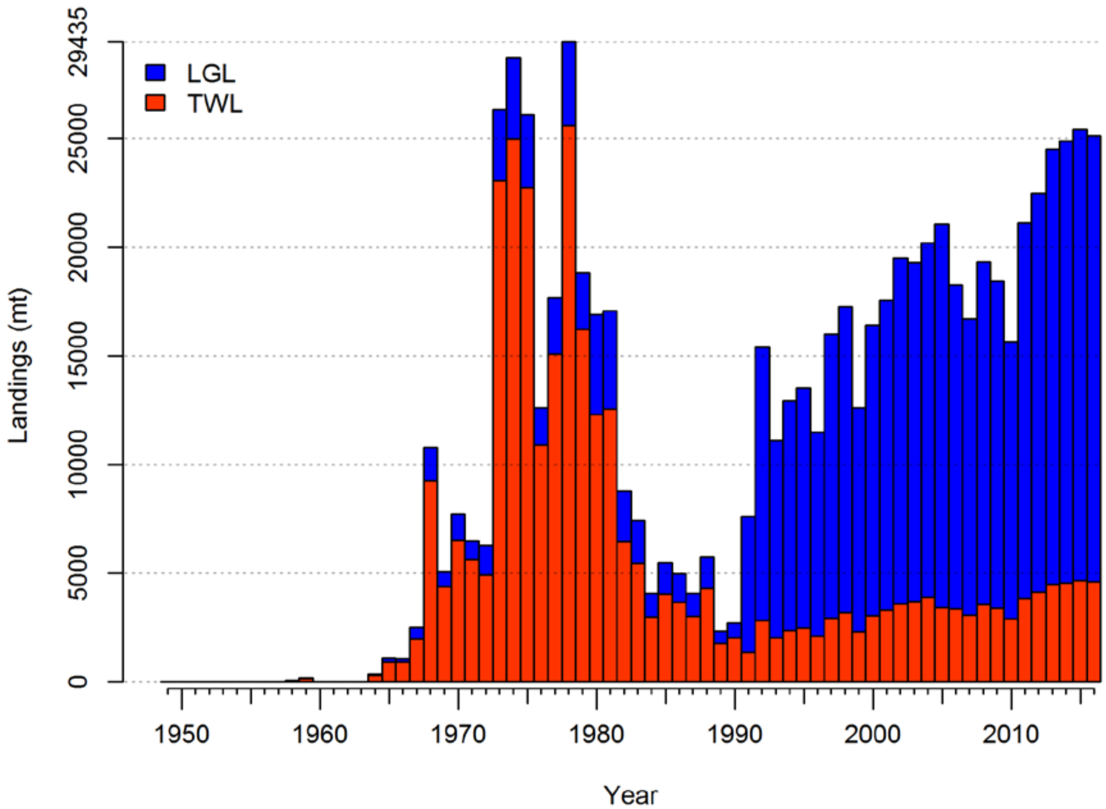


Figure 13. Estimated catch of Alaska skates (t) in the BSAI 1954-2016. LGL = longline fishery, TWL = trawl fishery.

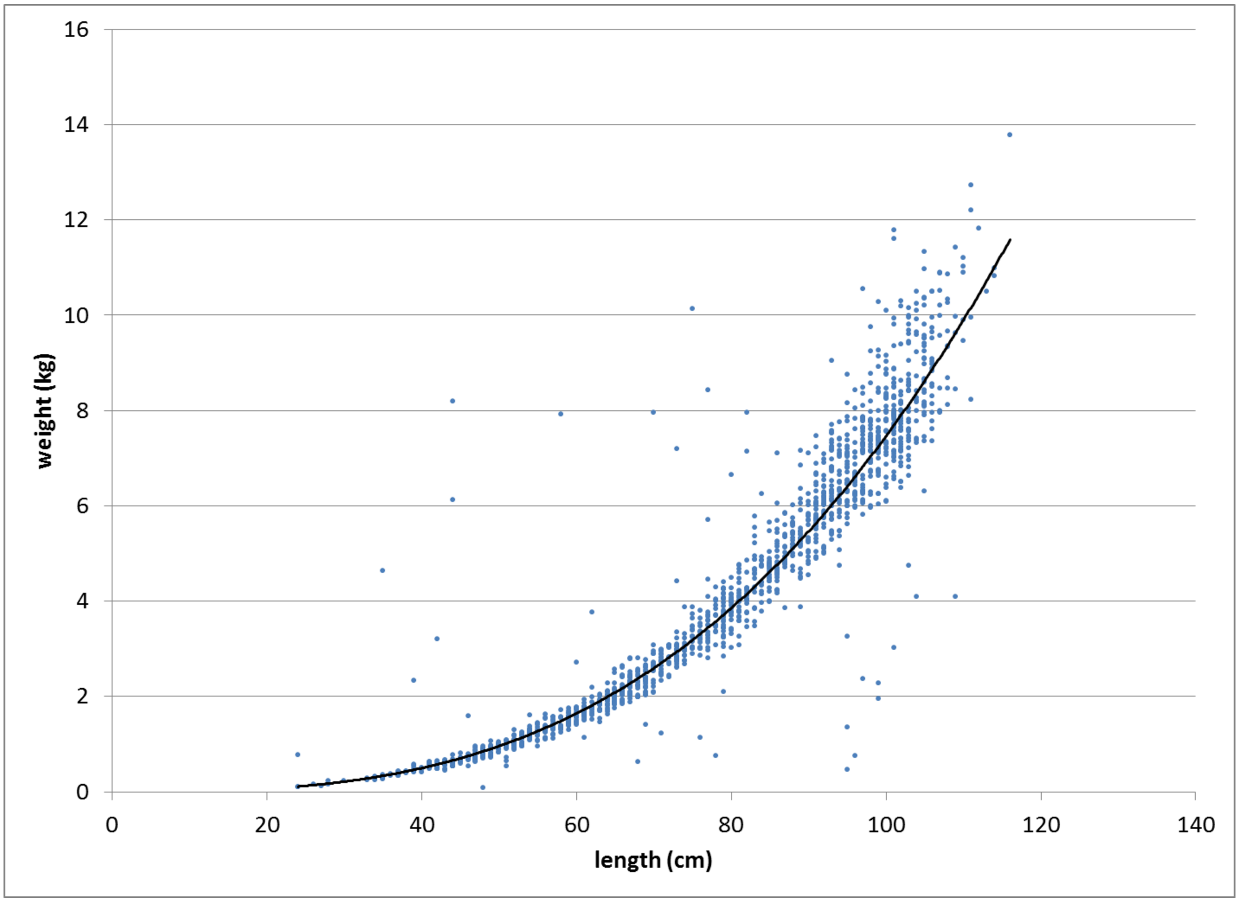


Figure 14. Length-weight relationship for Alaska skates captured in the EBS shelf trawl survey, 2008-2010. Black line indicates line of best fit to the data, r^2 = 0.93, N = 1,515.

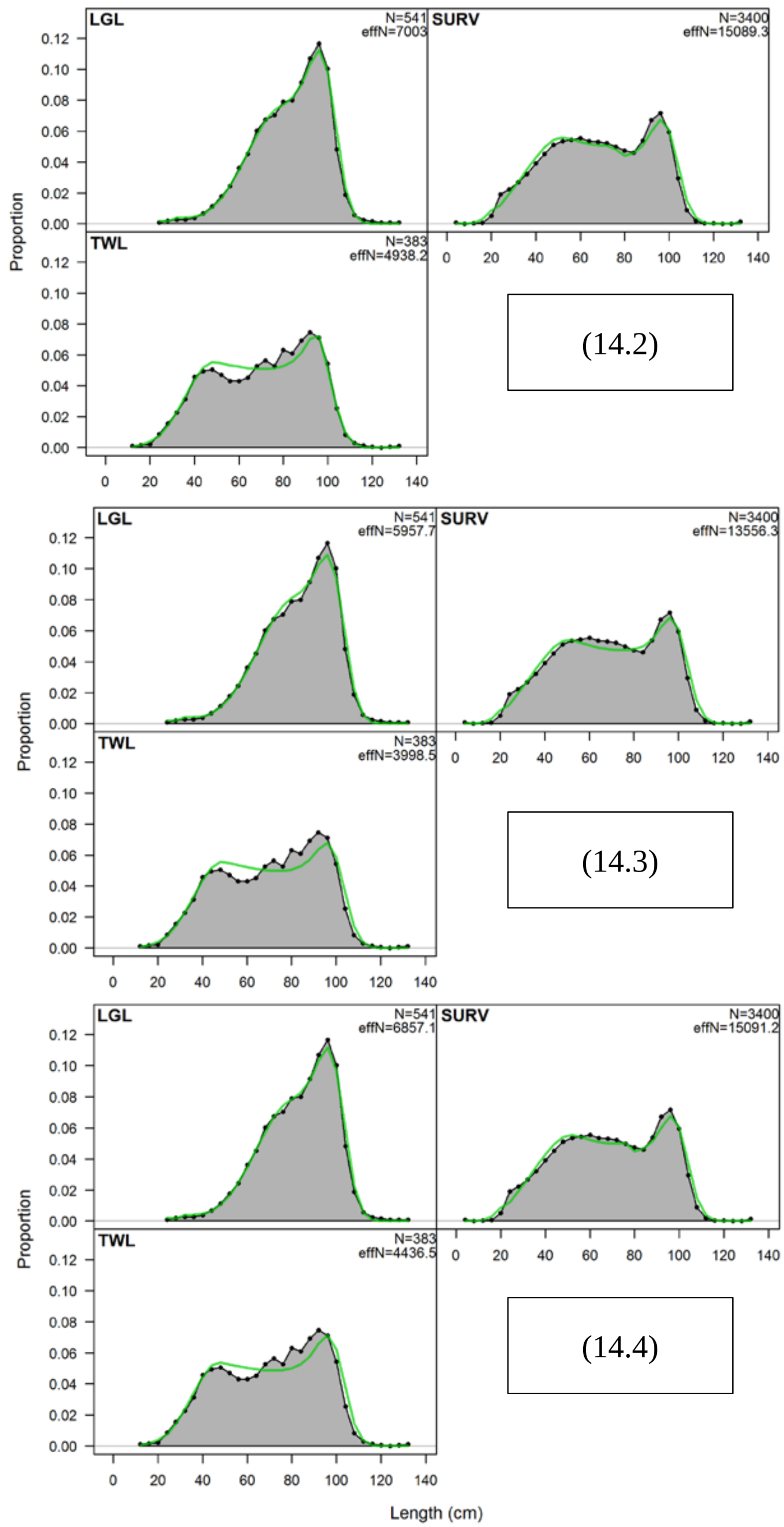


Figure 15. Fits to length composition data for the preferred model (14.2) and alternative models (14.3 and 14.4). For each fleet, observed data (grey) and model fit (green line) are aggregated across years. LGL = longline fishery, TWL = trawl fishery, SURV = trawl survey.

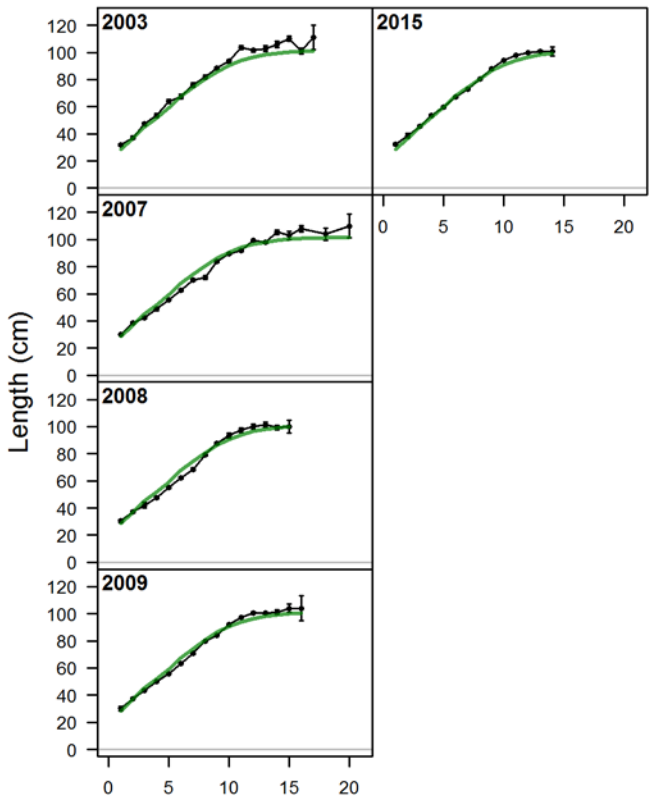
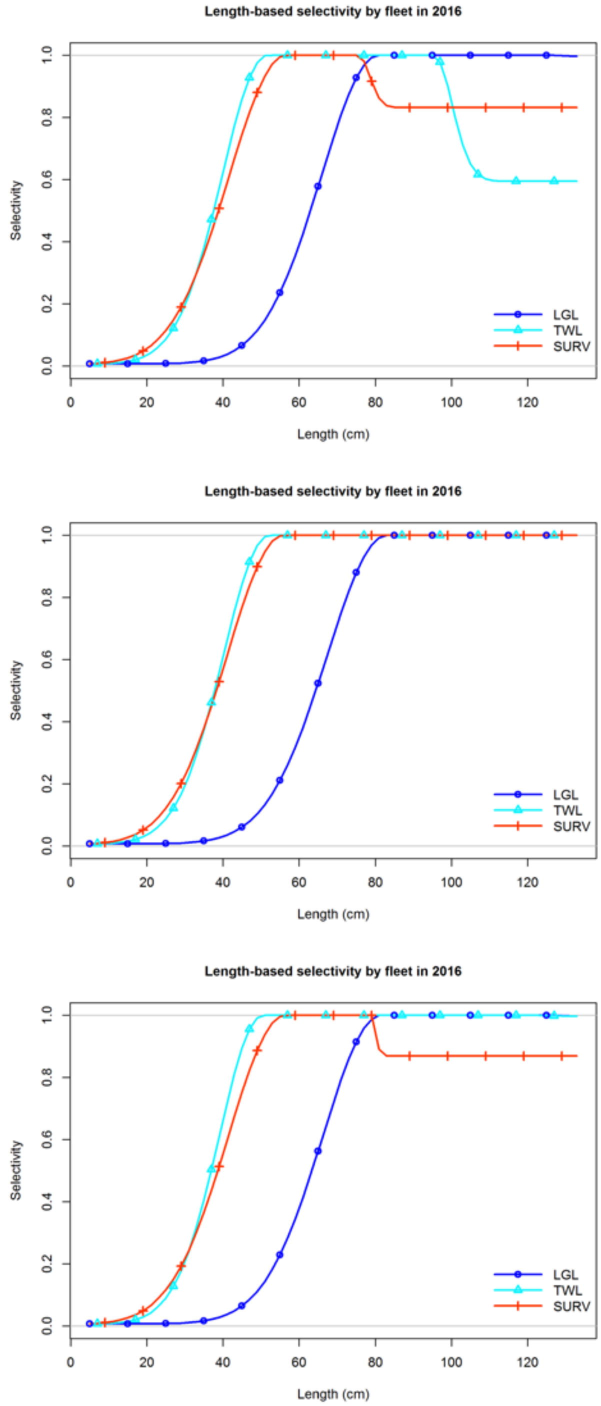


Figure 16. Observed (black circles) and model-predicted (red line) length-at-age for Model 14.2, the author's preferred model.



(14.2)

(14.3)

(14.4)

Figure 17. Selectivity functions for the preferred model and alternatives. LGL = longline fishery, TWL = trawl fishery, SURV = trawl survey.

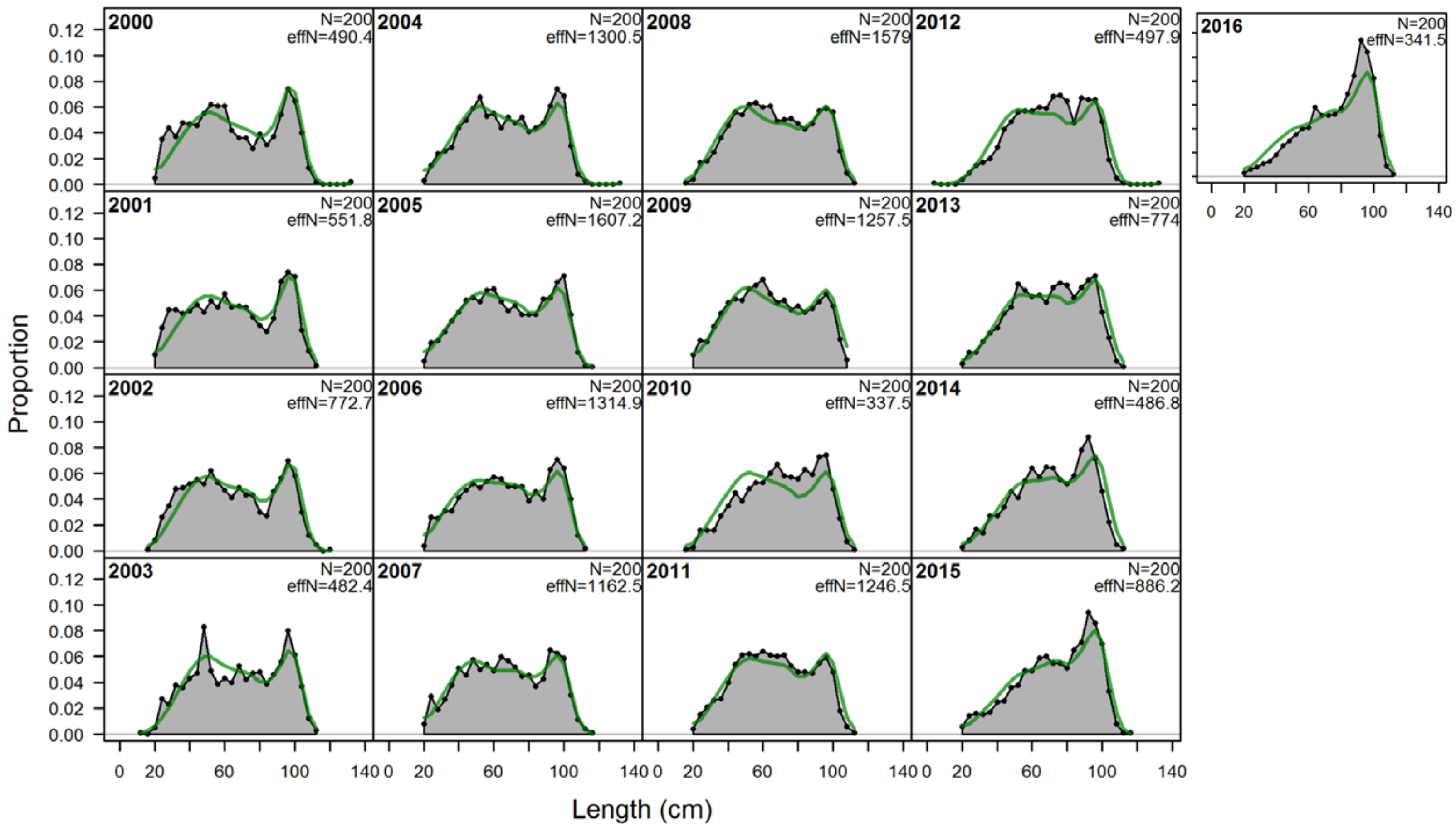


Figure 18. EBS shelf survey length compositions from 2000-2016. Grey shading = observed proportions; red line = model predictions. X-axis values are lengths in cm.

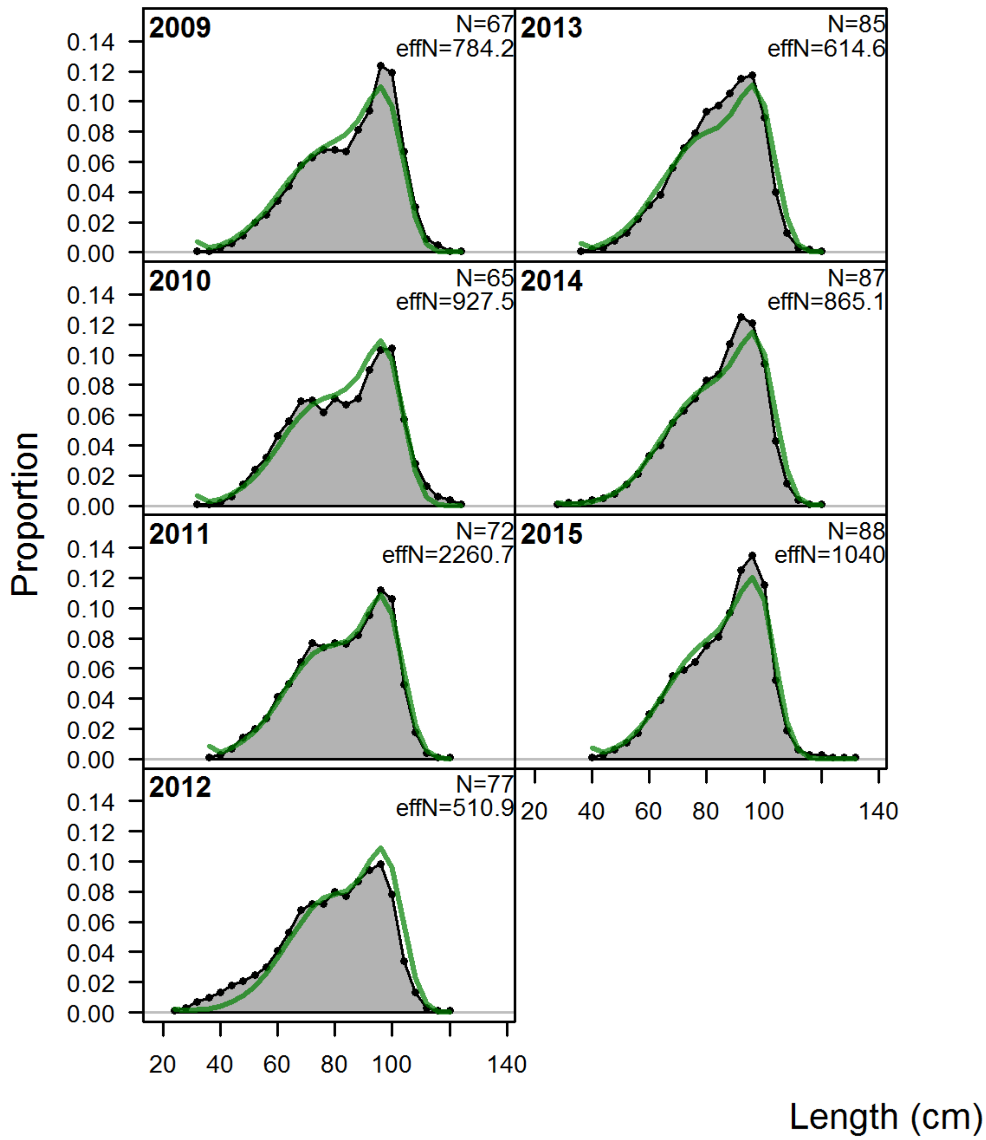


Figure 19. Observed and model-predicted length compositions from the 2009-2015 longline fisheries, with model predictions. Grey shading = observed proportions; green line = model predictions.

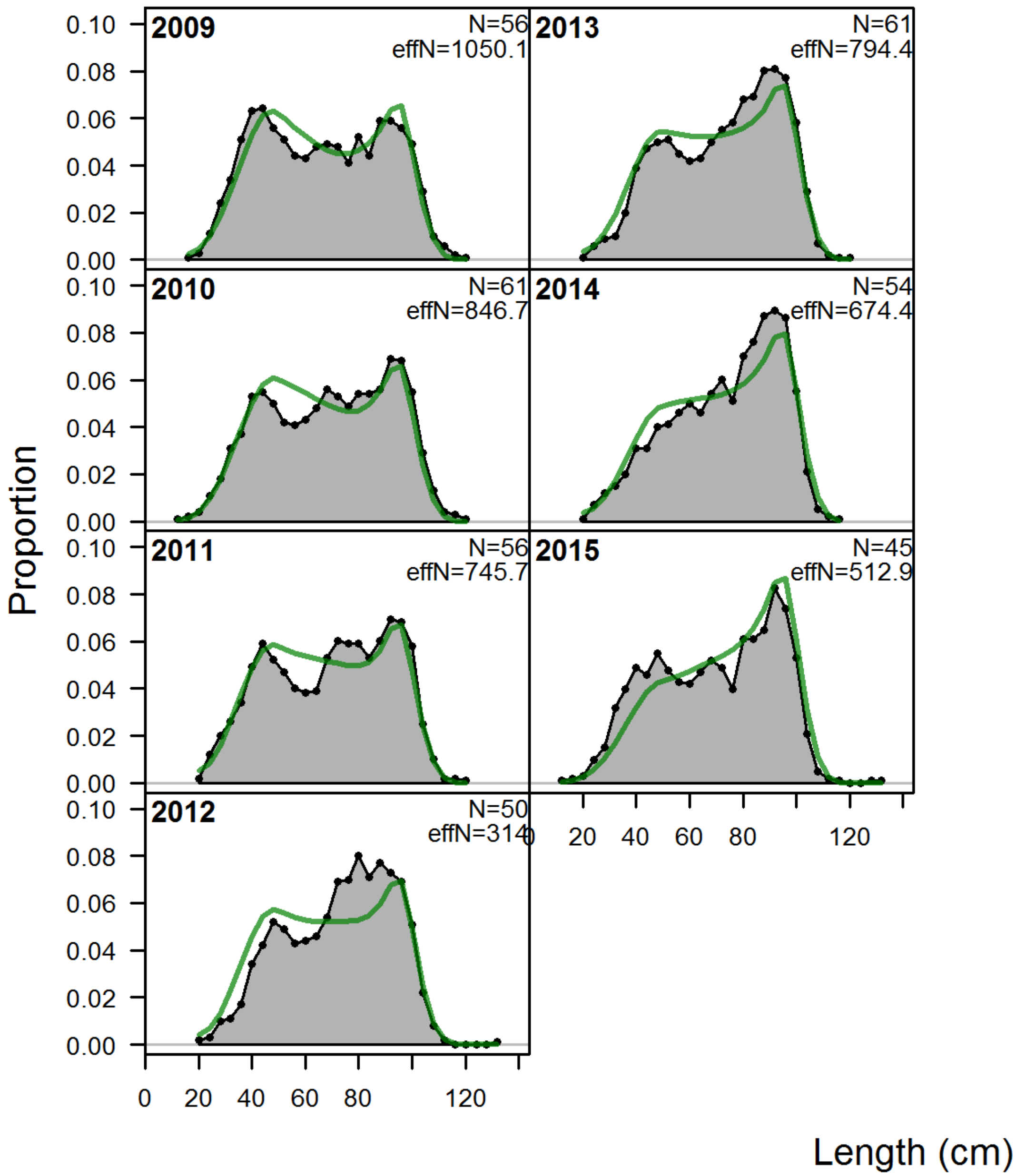


Figure 20. Observed and model-predicted length compositions from the 2009-2015 trawl fisheries, with model predictions. Grey shading = observed proportions; green line = model predictions.

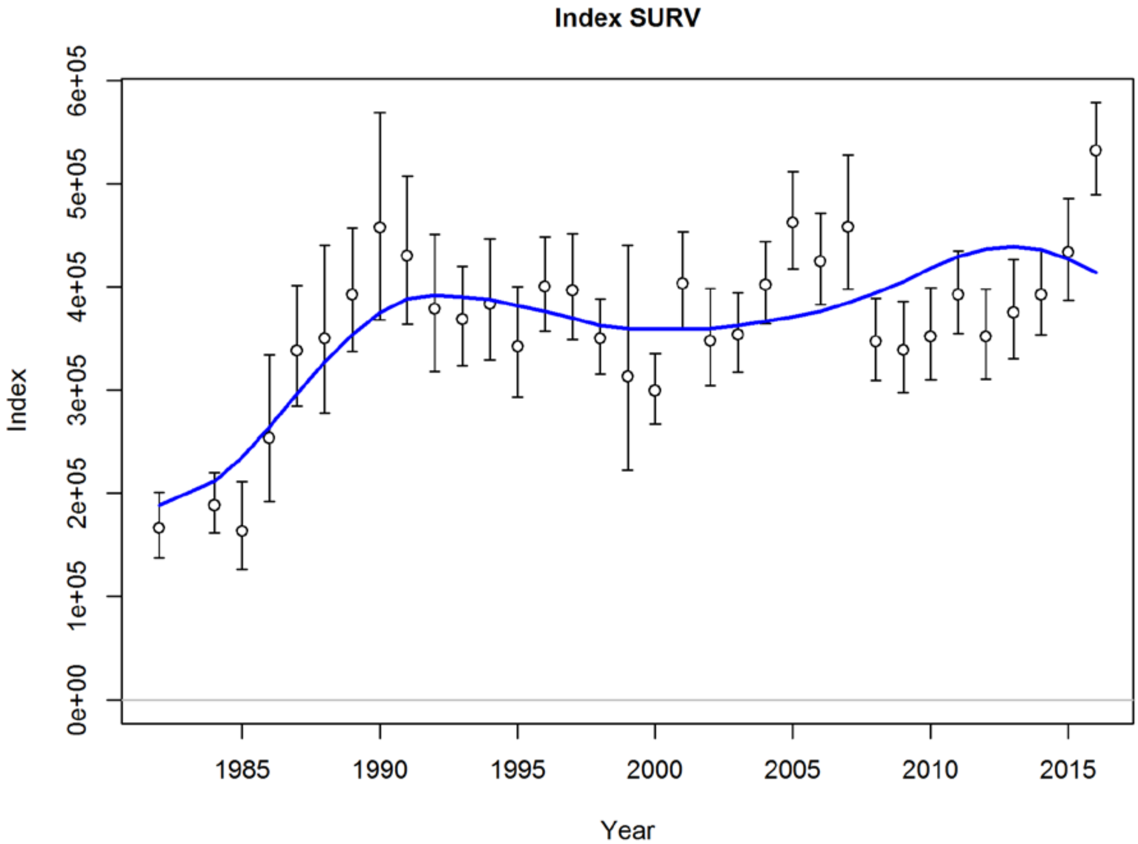


Figure 21. Observed biomass (circles) from EBS shelf surveys 1982-2016, with confidence intervals (± 2 SE), and predicted survey biomass from the model (blue line).

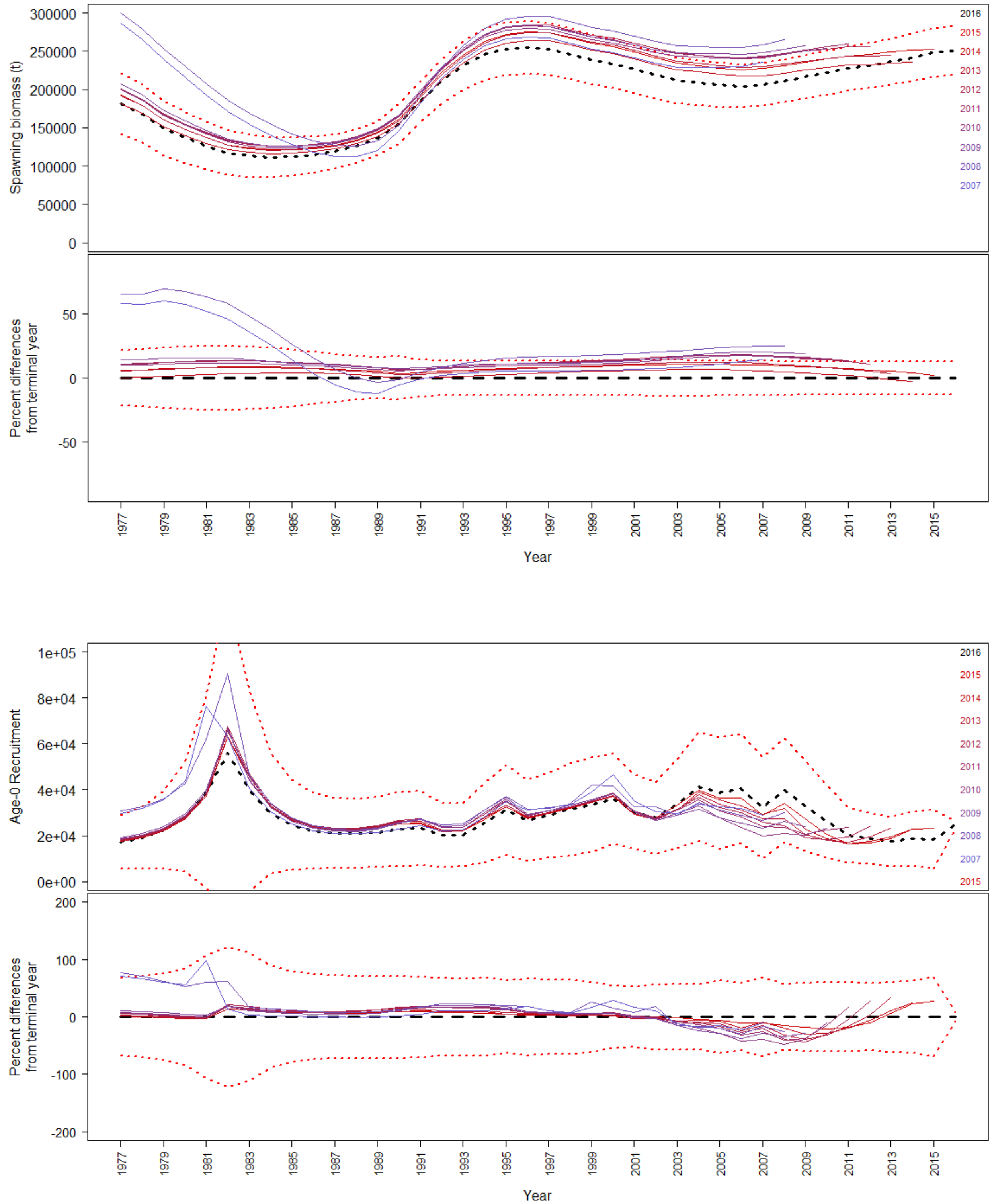


Figure 22. Retrospective analysis for estimates of spawning biomass (top 2 panels) and age-0 recruitment (bottom 2 panels) from model 14.2. For each quantity the upper panel contains the estimates and the lower panel displays % difference from the terminal year. Units for recruitment are in 1000s of individuals. Red dashed lines show 95% confidence intervals.

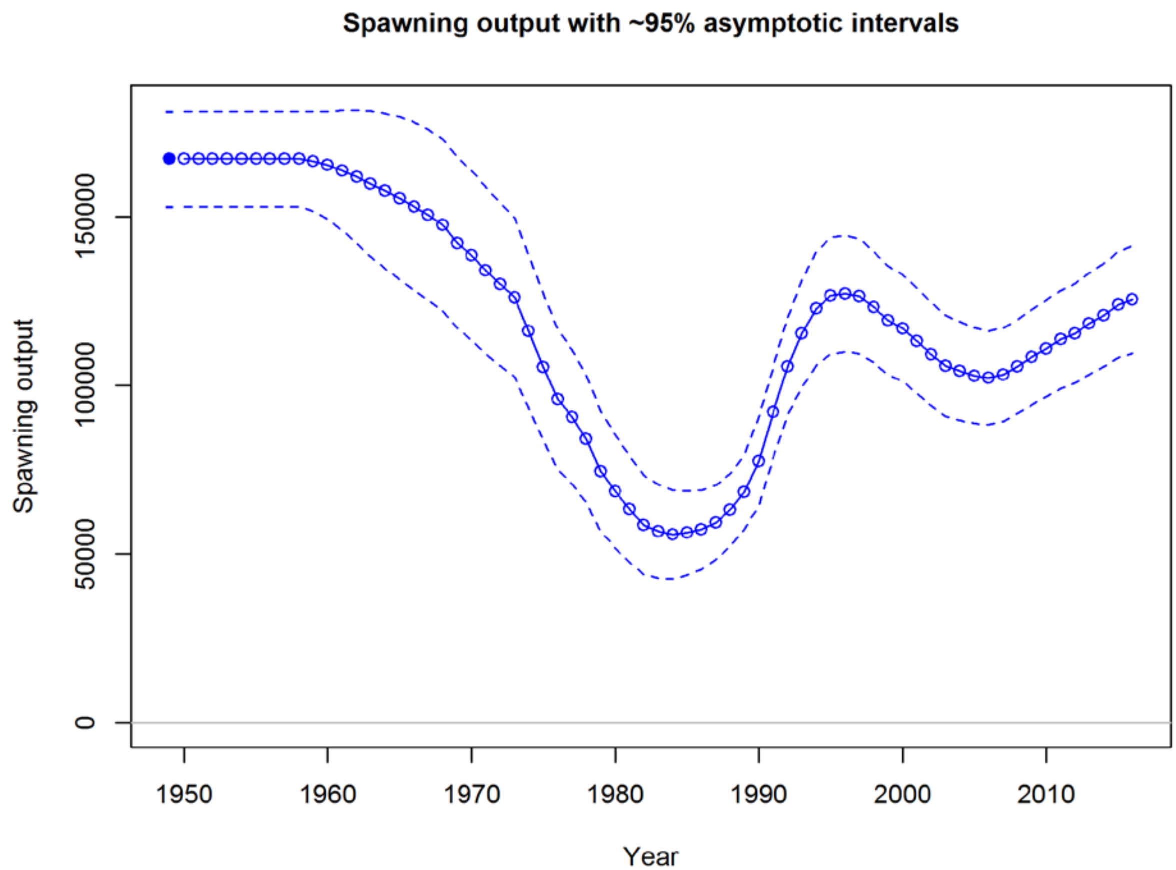


Figure 23. Model estimate of Alaska skate female spawning biomass. Dashed lines indicate 95% confidence interval.

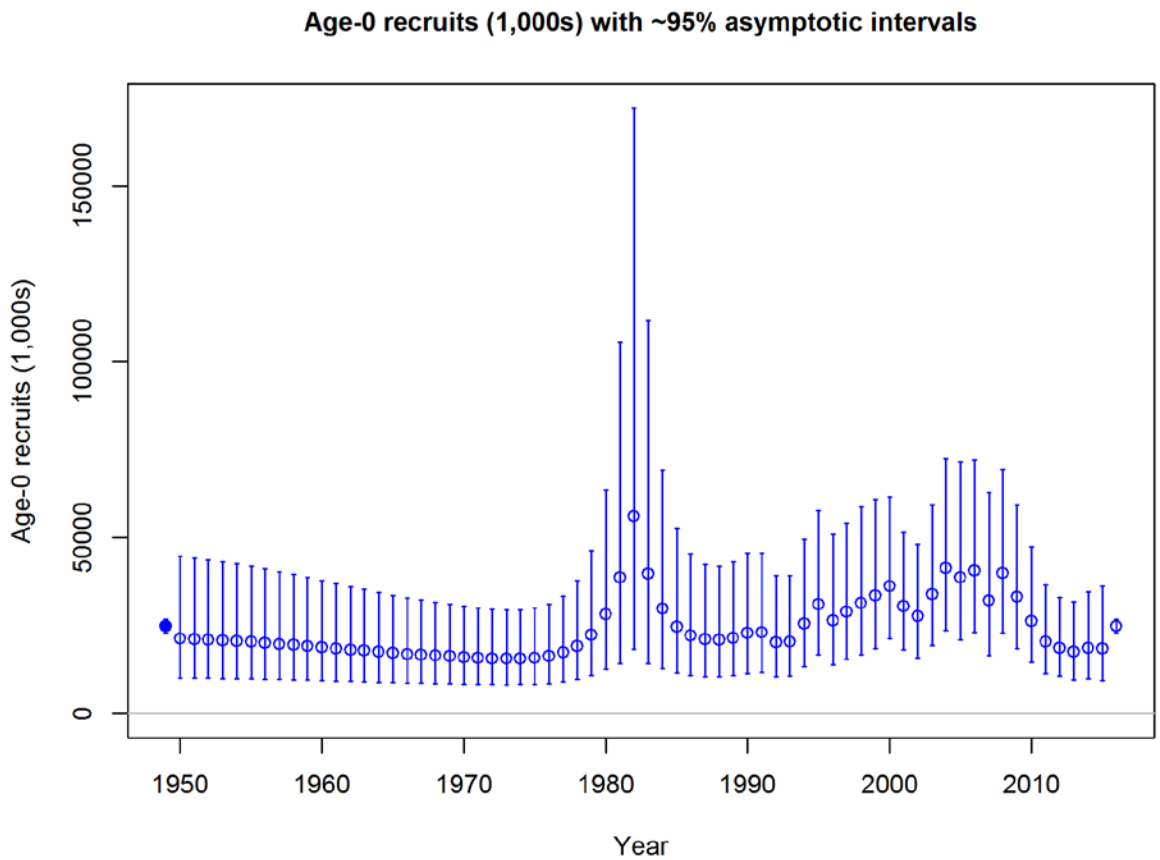


Figure 24. Model estimate of age-o recruitment of Alaska skates, with 95% confidence interval.

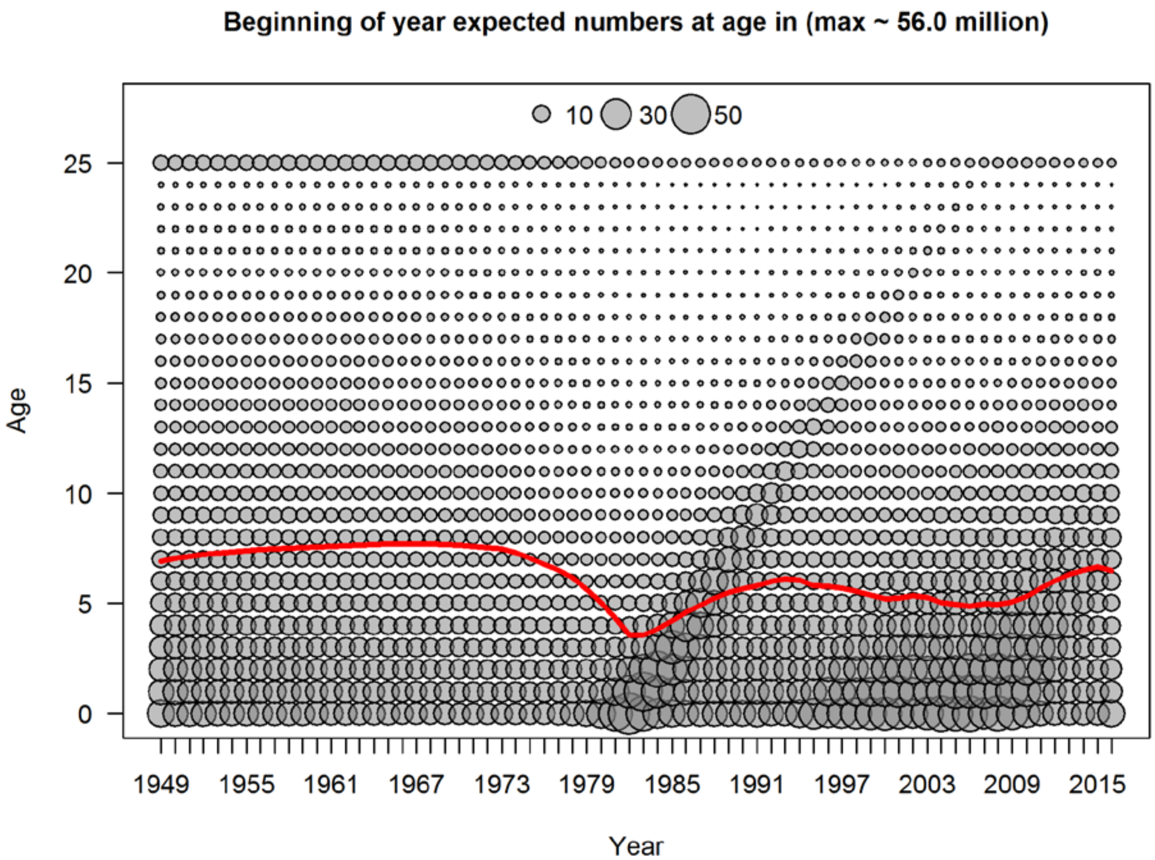


Figure 25. Estimated numbers at age from the preferred model, Model 14.2.

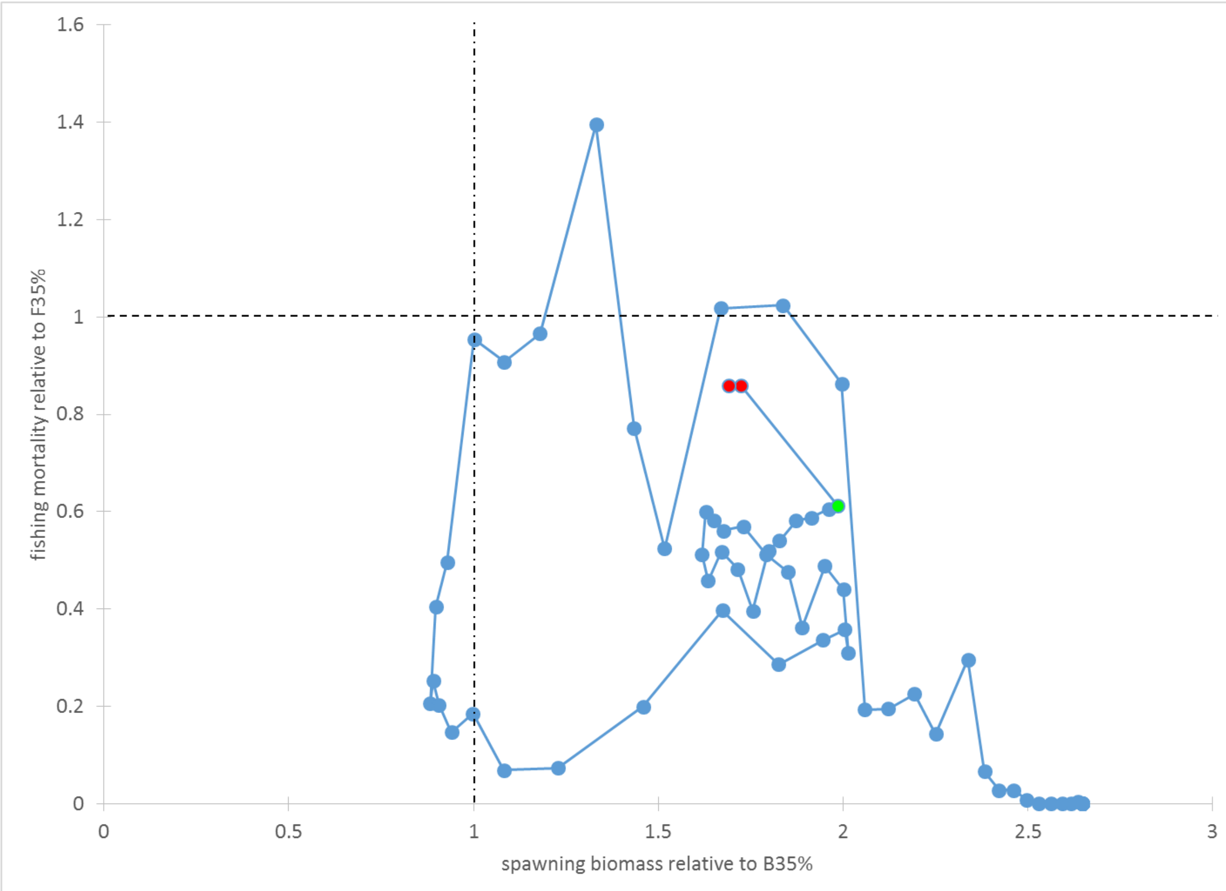


Figure 26. Trajectory of relative fishing mortality and relative spawning biomass as estimated by Model 14.2. Red circles indicate projected years 2017 & 2018; green circle indicates 2016. Vertical dashed line indicates B35%; horizontal dashed line indicates F35%.

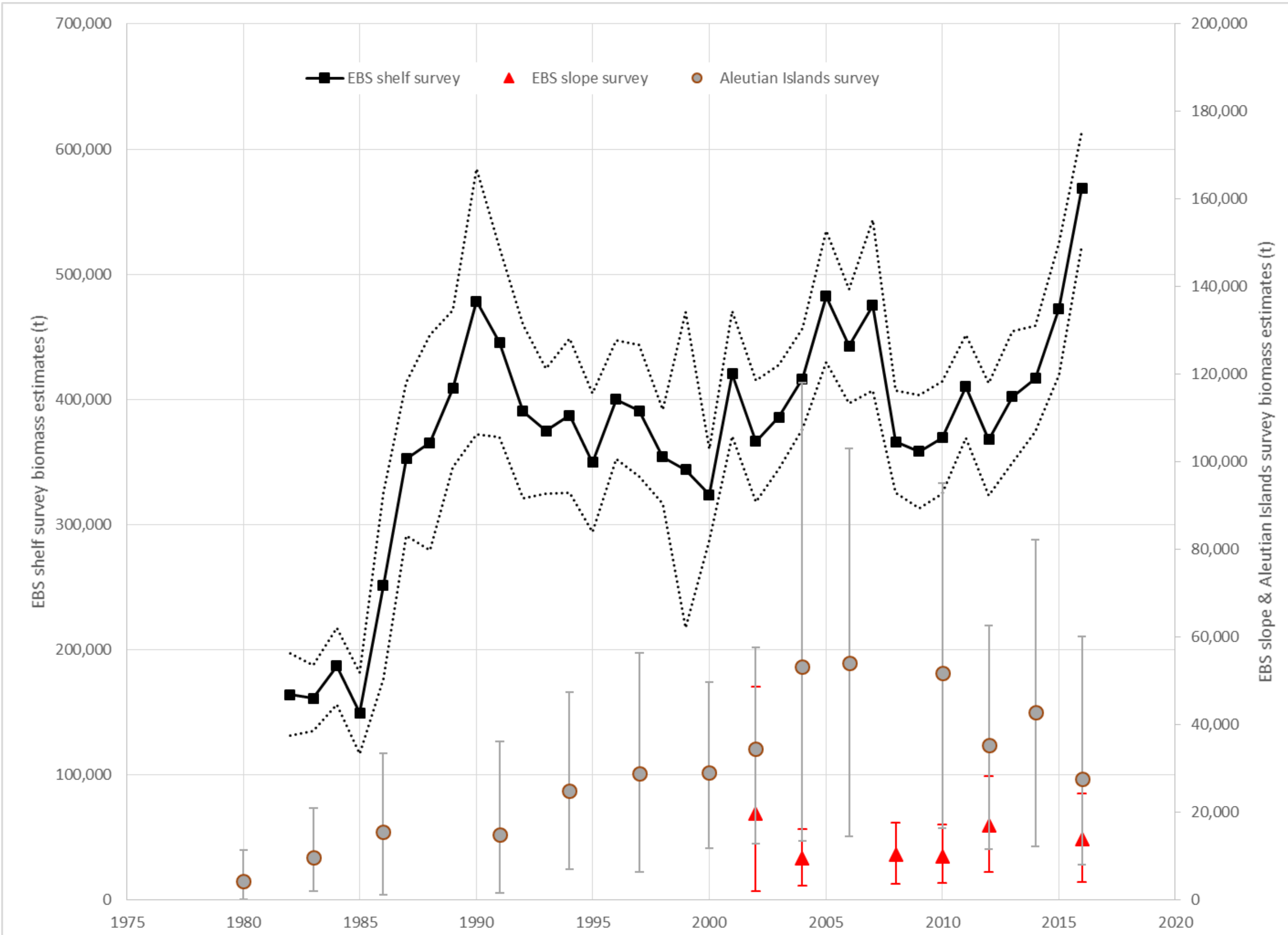


Figure 27. Aggregated skate biomass (t) and 95% confidence intervals estimated from RACE bottom trawl surveys in each of the three major habitat areas (1982 – 2016). Note that slope and AI estimates are much smaller and pertain to the secondary y-axis.

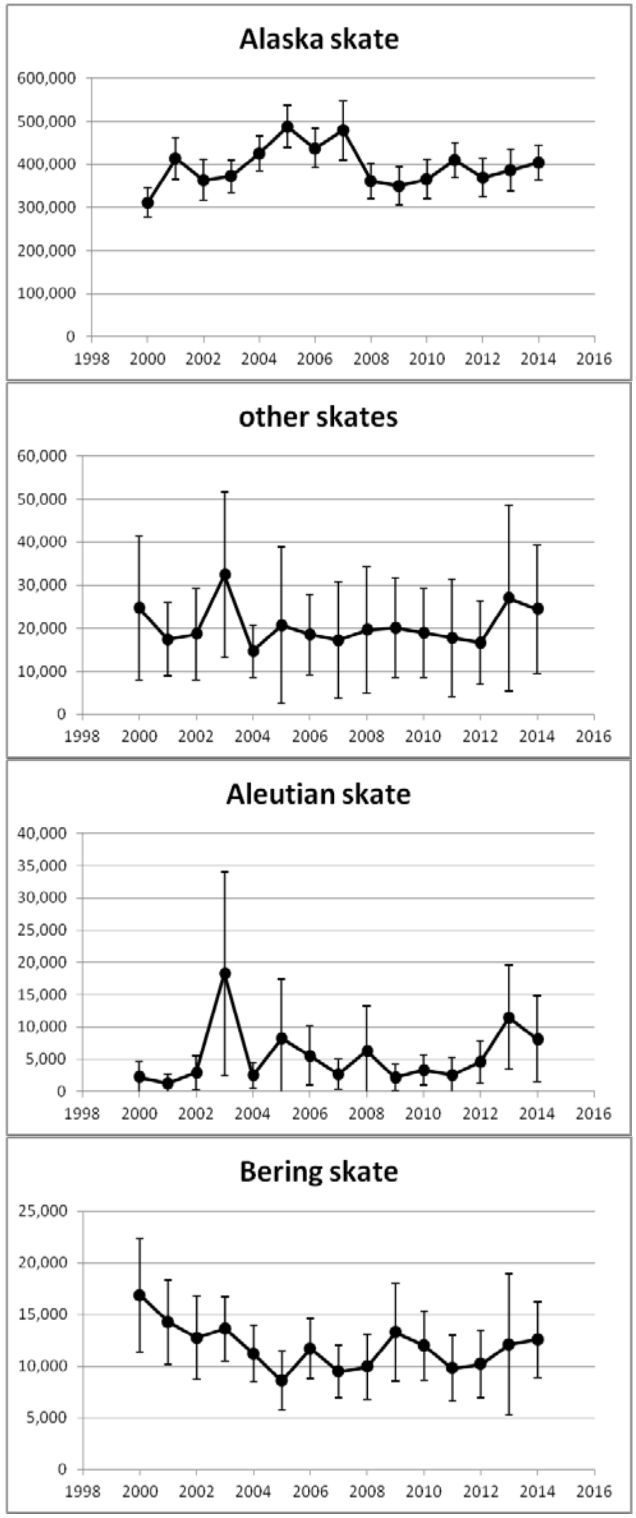


Figure 28. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS shelf. "Other skates" includes Aleutian and Bering skates and is included here to complement the skate management units. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, with greatest biomass at the top.

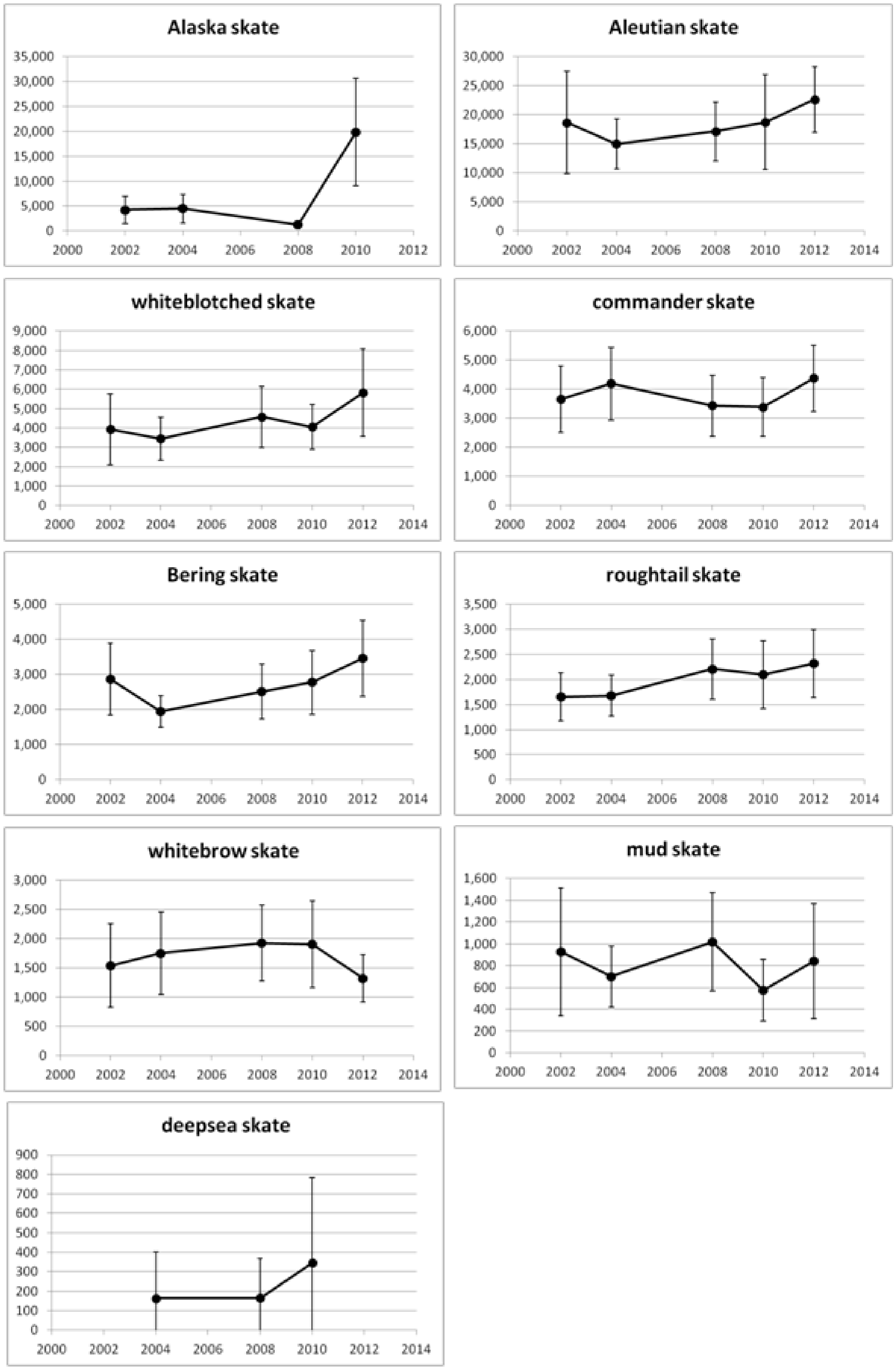


Figure 29. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS slope. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, from top left.

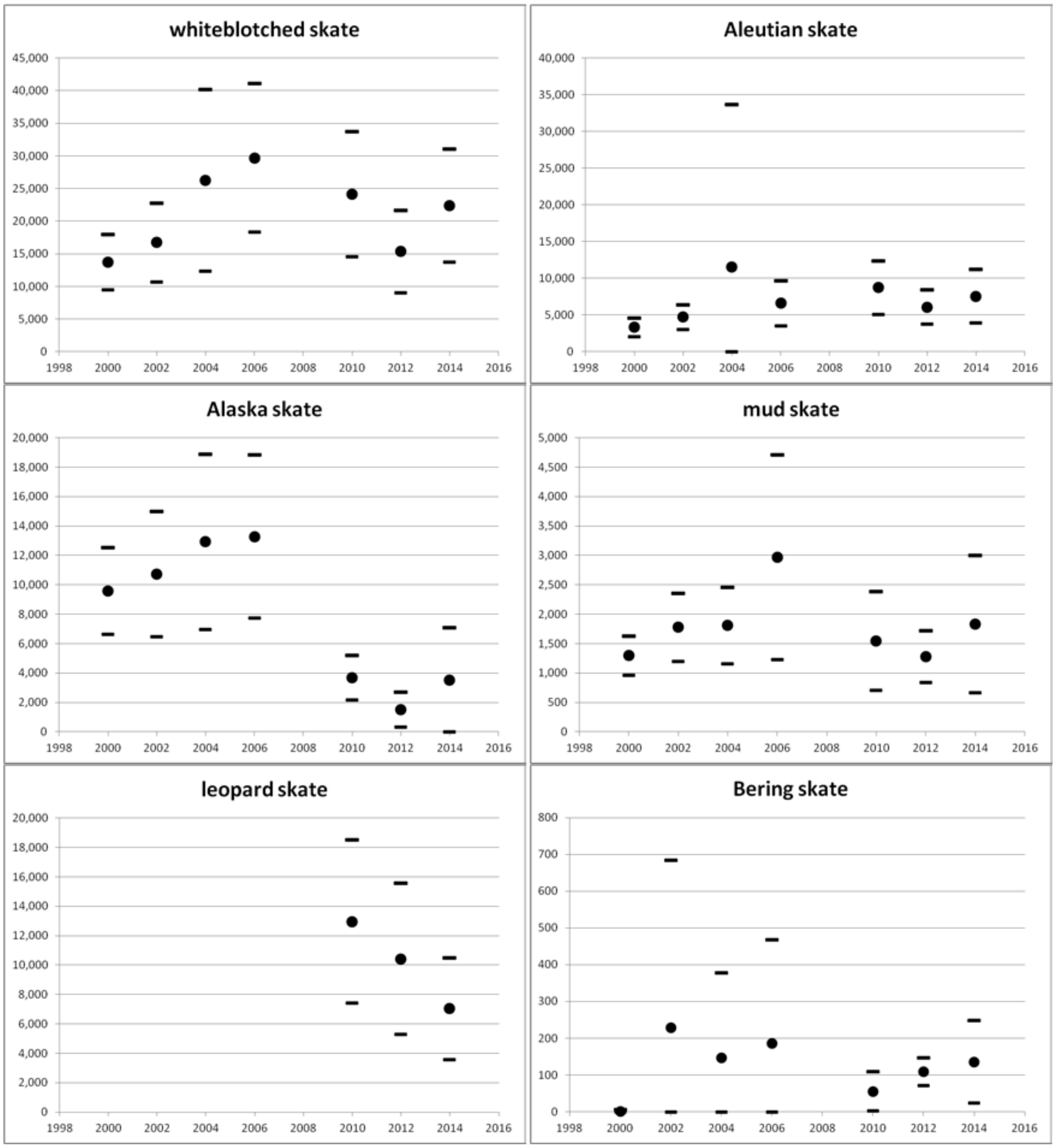


Figure 30. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates in the Aleutian Islands. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, from top left.

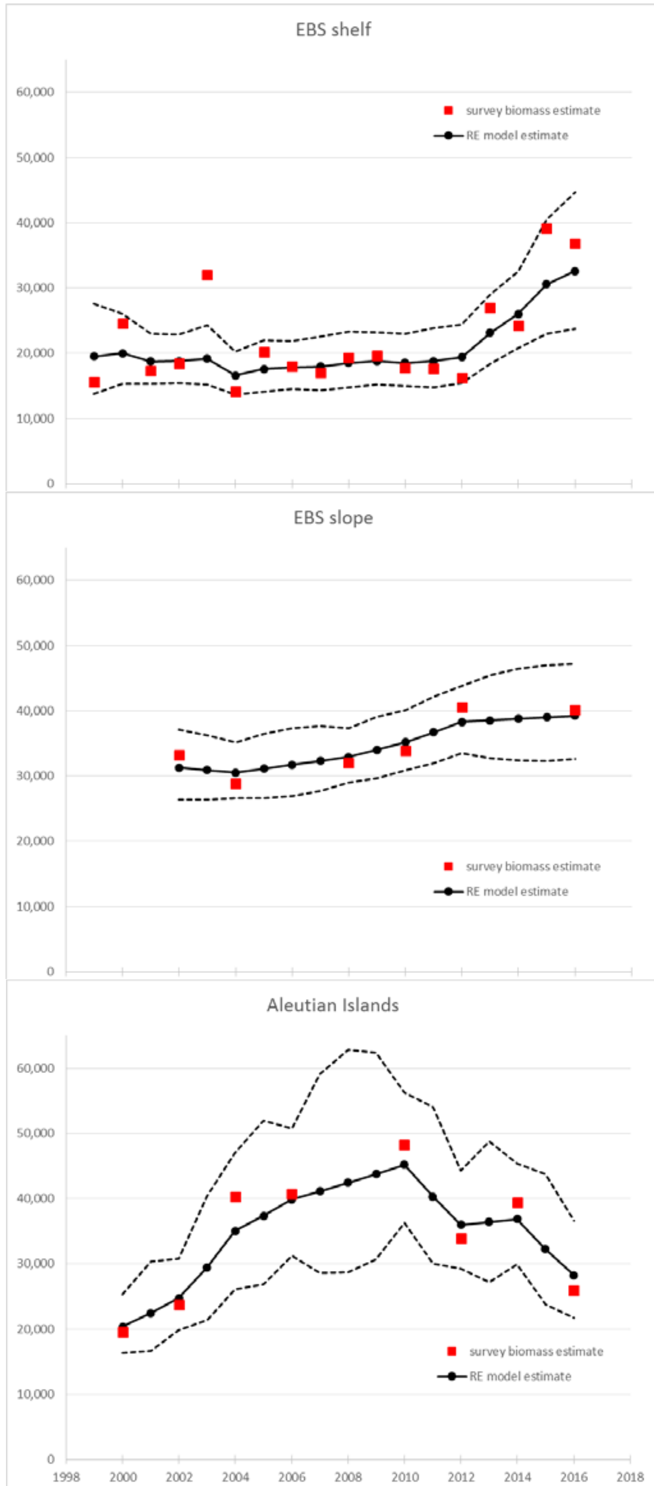


Figure 31. Estimates of “other skate” biomass from each of the 3 bottom trawl surveys conducted in the BSAI region (EBS shelf, top; EBS slope, middle; Aleutian Islands, bottom) and the corresponding predictions from the random effects (RE) model. Dashed black lines indicate 95% confidence interval for the RE estimate.

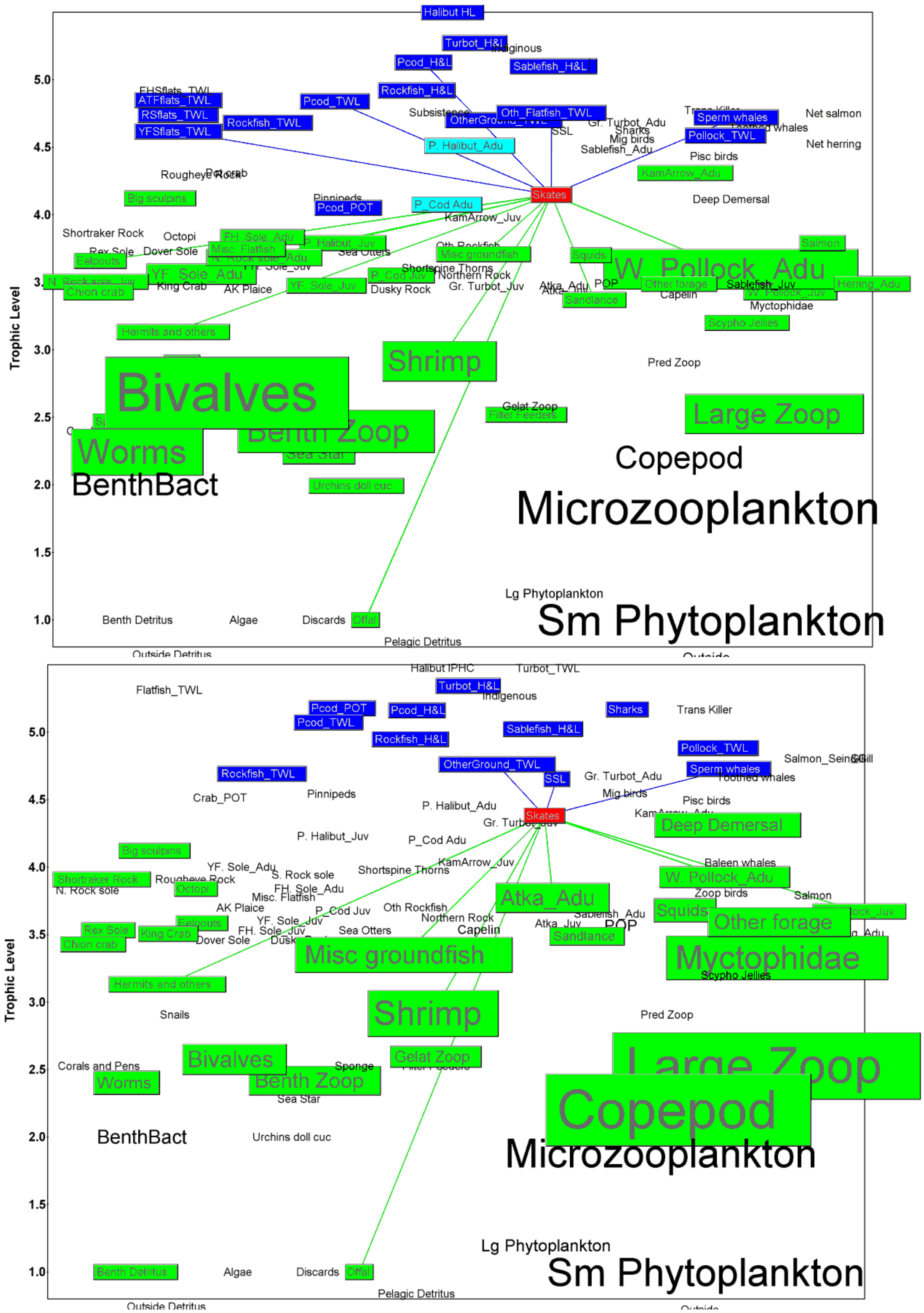


Figure 32. EBS (upper panel) and AI (lower panel) skate food webs derived from mass balance ecosystem models, with skate species aggregated in each area. Source: K. Aydin, AFSC, code available upon request.

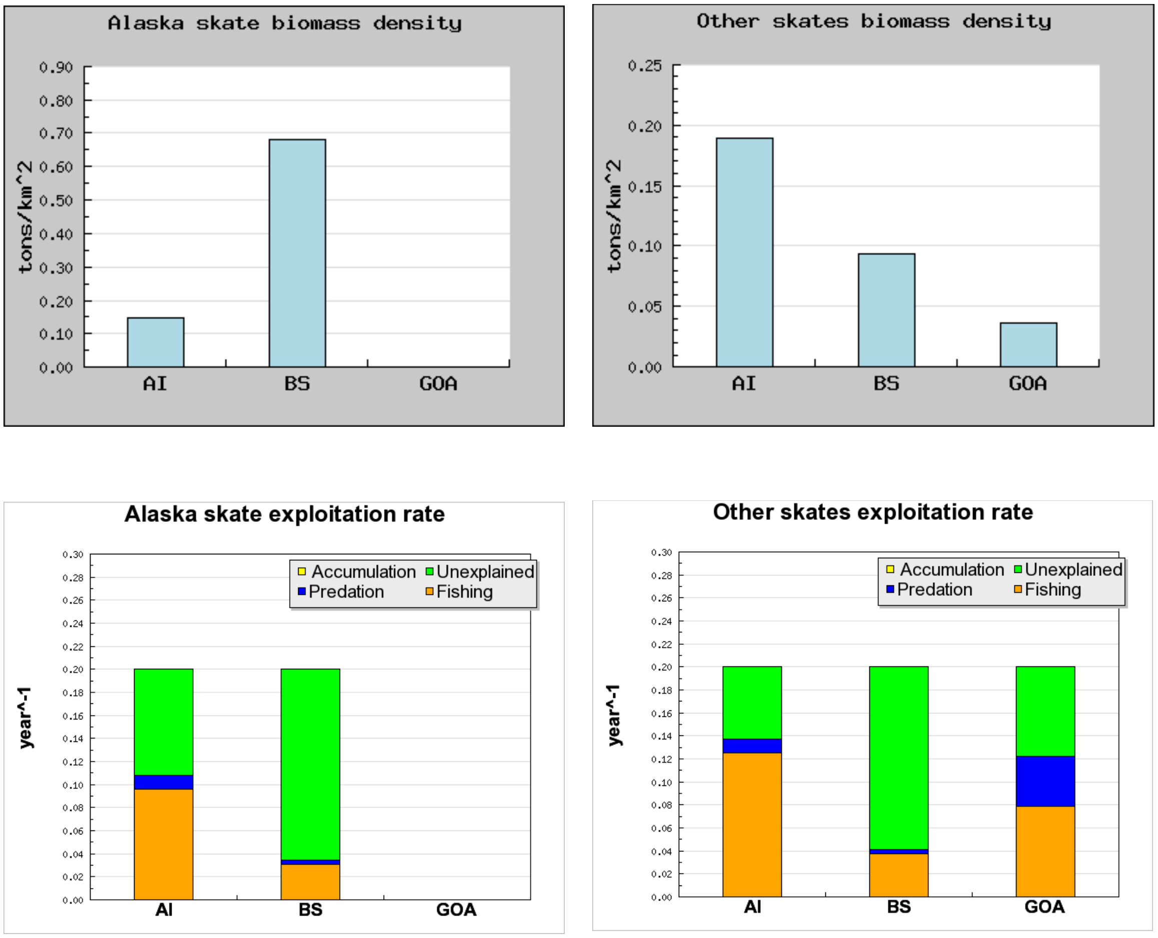


Figure 33. Comparative density (upper panels) and exploitation rate (lower panels) of Alaska (left panels) and all other *Bathyraja* (right panels) skates in the AI, EBS, and GOA (early 1990s, before fishery in GOA). (Alaska skates are a very small component of skate biomass in the GOA, and are therefore 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).

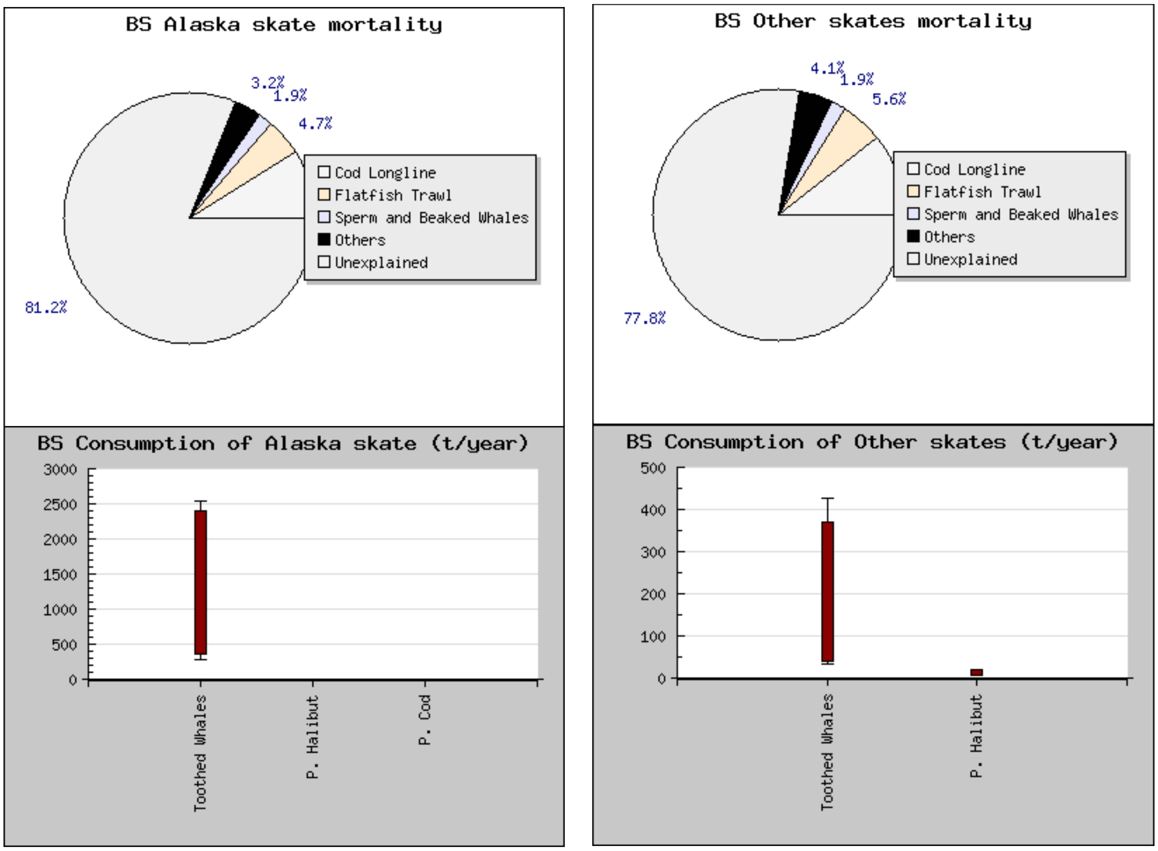


Figure 34. Mortality sources and consumption of skates in the EBS—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for EBS Alaska skates (left panels) and all other EBS skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

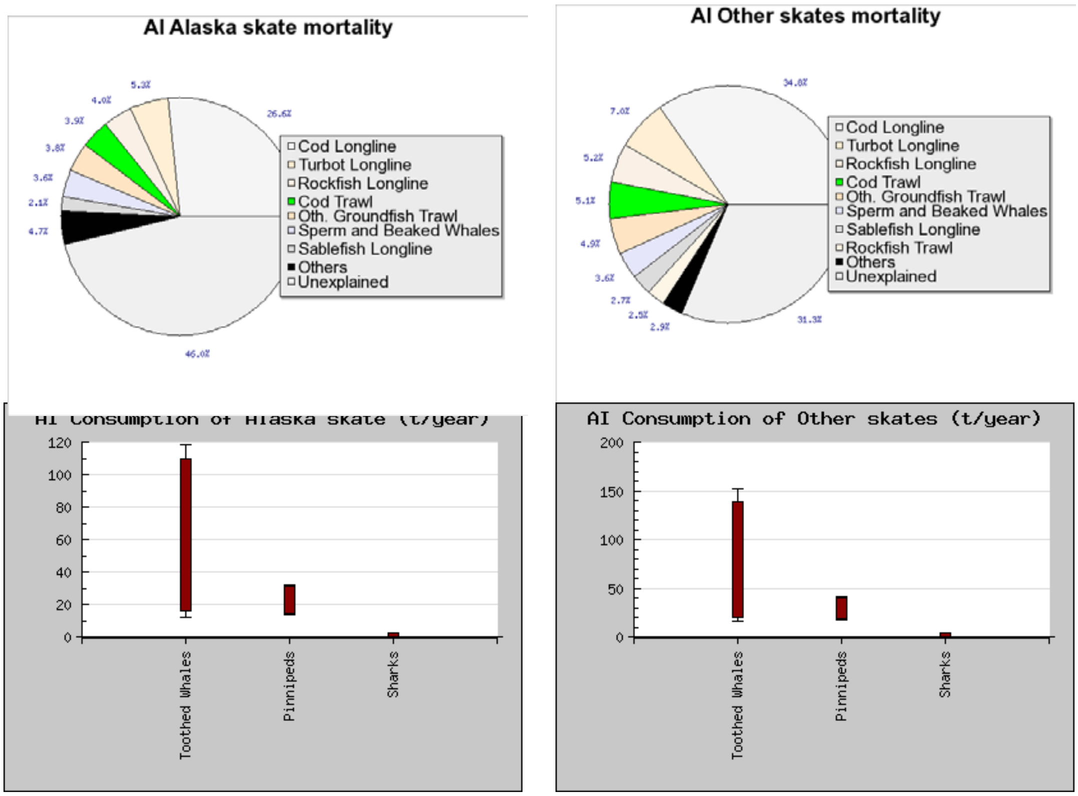


Figure 35. Mortality sources and consumption of skates in the AI—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for AI (former) Alaska skate (left panels) and AI Other Skates (right panels). Model outputs were derived from diet compositions, production rates,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

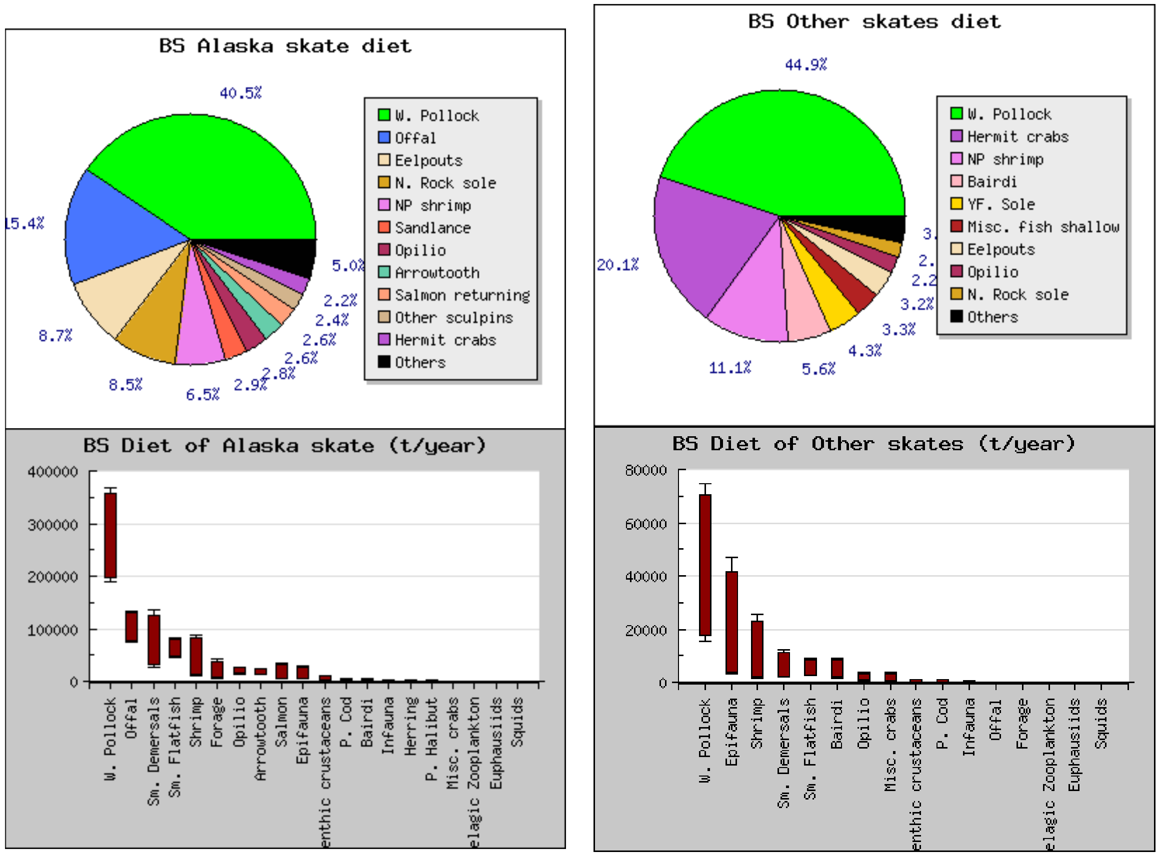


Figure 36. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for EBS Alaska skates (left panels) and Other Skates (right panels). Results were generated from stomach content collections occurring during RACE trawl surveys.

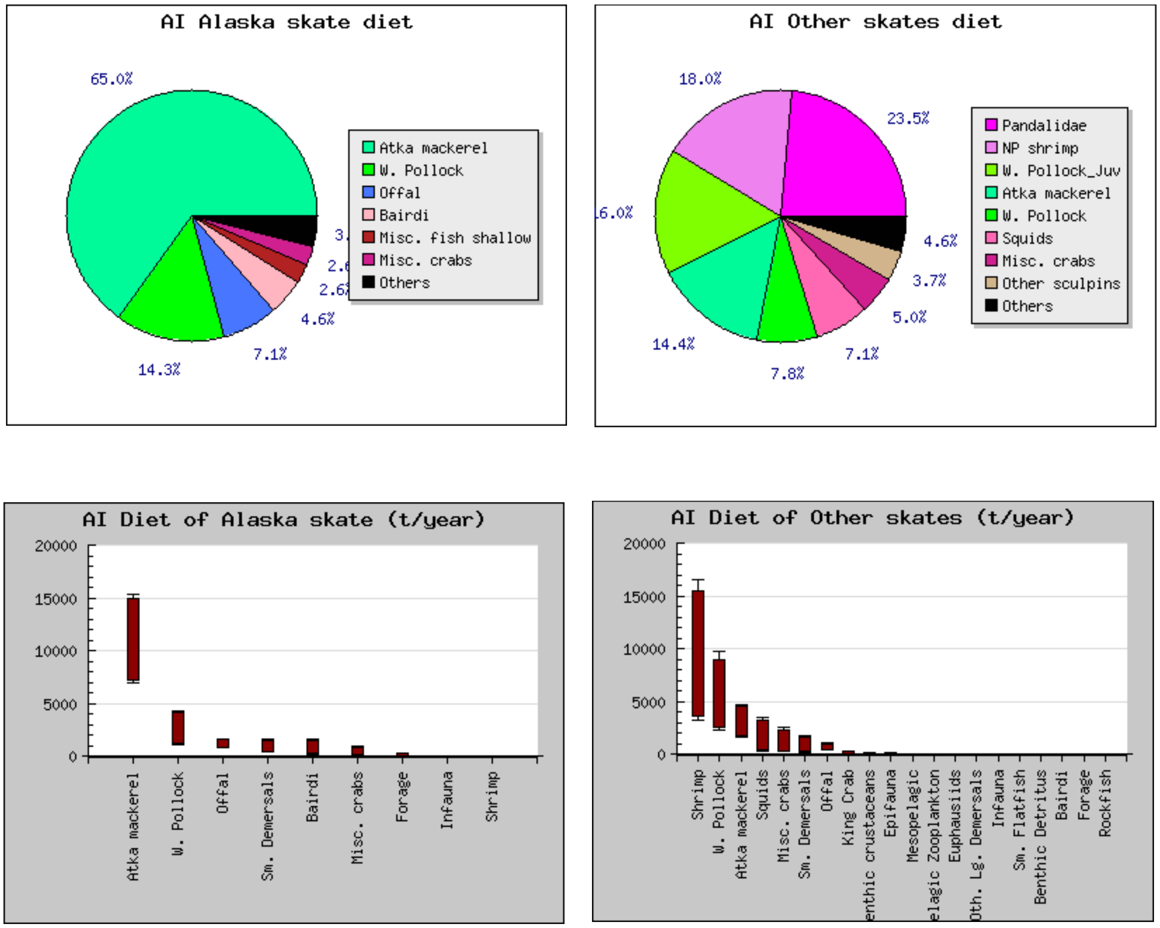
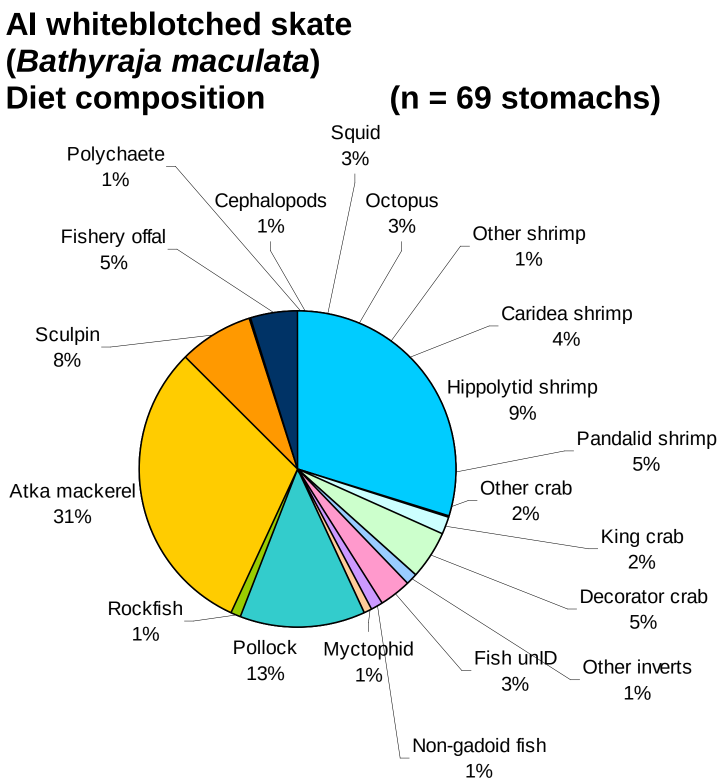


Figure 37. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for AI Alaska skates (left panels) and Other Skates (right panels). Consumption rates were estimated using published diet data from the Kuril Islands (Orlov 1998, 1999) and estimated prey densities.



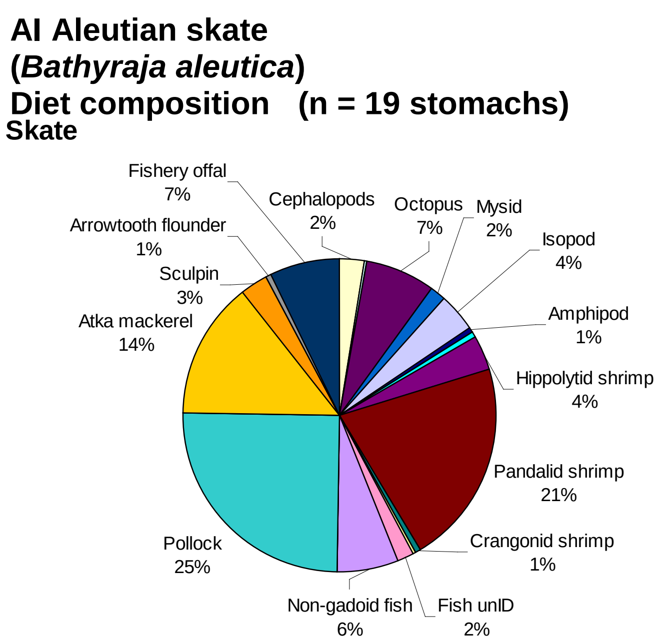


Figure 38. Diet composition (by weight) for the other two biomass-dominant skate species in the Aleutian Islands (AI,which are included in the “Other Skates” group in the previous figure): whiteblotched skate (top) and Aleutian skate (bottom). Results were generated from stomach content collections occurring during trawl surveys, and are described in more detail in Yang (2007).

Appendix 1: 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.

	ADF&G				IPHC	NMFS											
	ADFG Golden King Crab Pot Survey	ADFG Large-Mesh Trawl Survey	ADFG Pribilof Islands Crab Survey	ADFG St. Mathews Crab Survey	IPHC Annual Longline Survey	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	Gulf of Alaska Bottom Trawl Survey	Northern Bering Sea Bottom Trawl Survey	Pollock EFP 11-01	Summer EBS Survey with Russia	**total (kg)**
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		232		568	41,976	7,675		6,093		31,118	9,567			4,929			**102,157**
2011		215	2		25,617			5,393	19,786			34,540	25		1,451		**87,029**
2012	23	139			27,786	4,889		7,459			17,593	29,330			1,080,877	70	**1,168,167**
2013		138			42,782			7,980				28,925	211				**80,036**
2014		119			55,220	6,166		11,698				29,396					**102,599**
2015		117			42,530			5,836				33,217					**81,701**

Appendix 2: Changes in exploitation rate between Alaska skate models 14.1 and 14.2

The major revision of the Alaska skate model in 2014 produced an unexpected result: while spawning biomass and the fishing mortality rate associated with the overfishing level (F_{OFL}) declined, the overfishing level itself increased. At the time the assessment did not include a sufficient explanation for this change. In this appendix the differences in age-specific exploitation rate are briefly explored to illustrate how the changes in the model produced this result.

Methods:
Age-specific data was used in the following equations to produce estimates of catch at age for each model when fishing at F_{OFL}:

$$C_{A,LL} = p_{LL} * F_{OFL} * N_A * S * W_A * sel_{A,LL}$$

$$C_{A,TWL} = p_{TWL} * F_{OFL} * N_A * S * W_A * sel_{A,TWL}$$

$$C_A = C_{A,LL} + C_{A,TWL}$$

$$\text{Exploitation rate at age} = C_A / B_A$$

where

- C_A, $C_{A,LL}$, $C_{A,TWL}$ are total catch at age and catch at age in the longline and trawl fisheries, respectively
- p_{LL} and p_{TWL} are the proportion of the catch taken by the longline and trawl fisheries
- N_A is numbers at age
- S is survival (not age-dependent, equal to 1- M)
- W_A is weight at age
- $sel_{A,LL}$ and $sel_{A,TWL}$ are age-specific selectivity in the longline and trawl fisheries
- BA is the total biomass of all individuals at each age

Results and discussion:
Model 14.2 estimates a much higher catch at age for younger skates and for the plus group (Figure 1). In addition, the weight at age was misspecified in model 14.1 resulting in older skates having excessive body weight. As a result, the exploitation rate at age in model 14.2 is much higher than it is in model 14.1 at most ages and particularly for younger skates (Figure 2). The higher exploitation rate at most ages results in a higher OFL even though F_{OFL} in model 14.2 is lower.

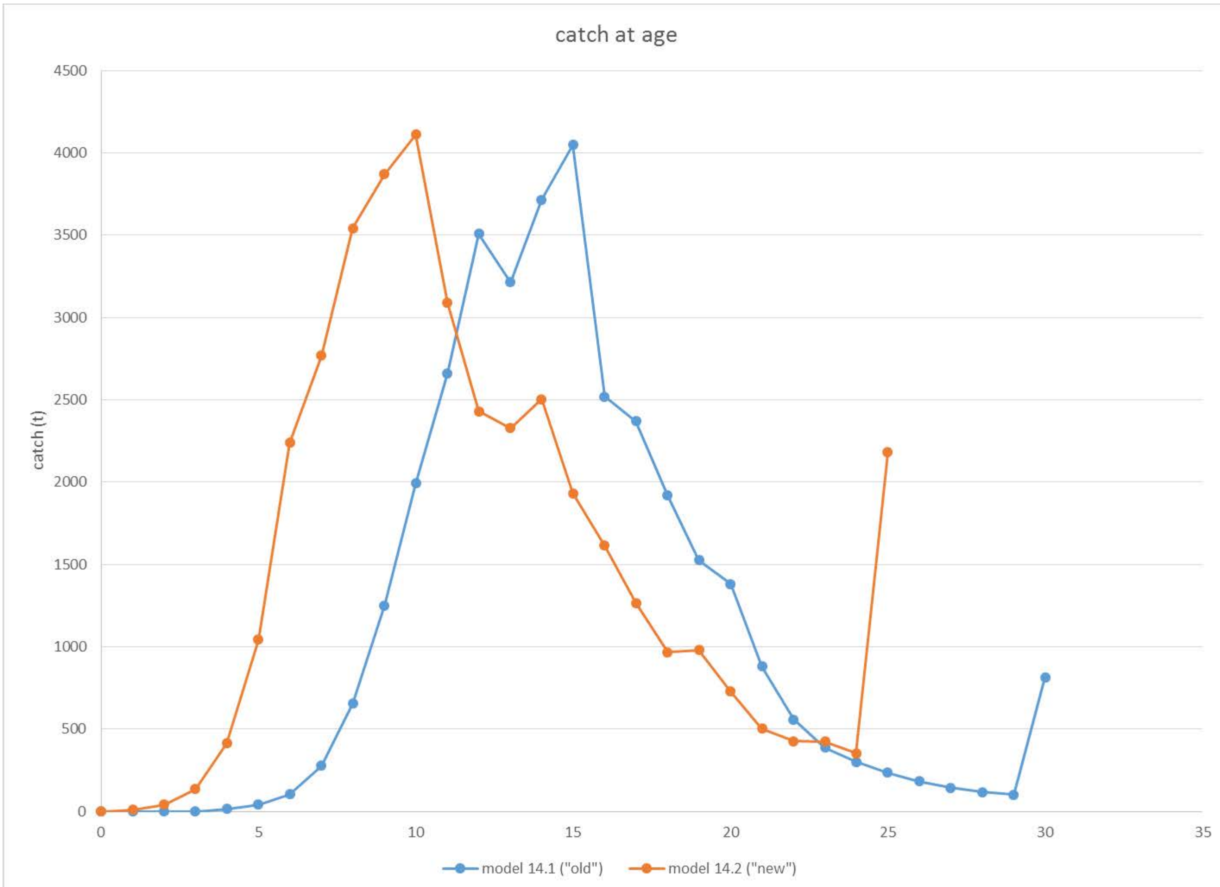


Figure 1. Estimated catch at age for the two models in this analysis.

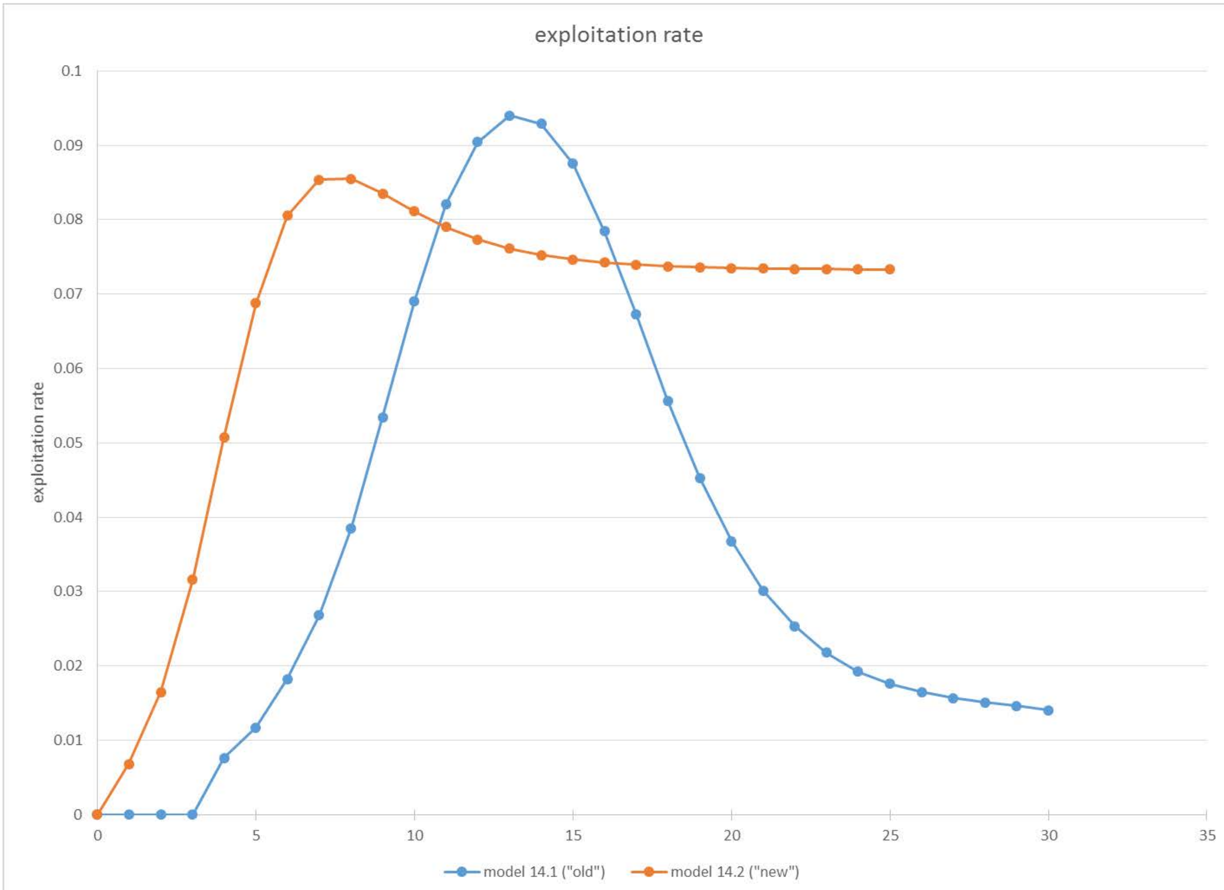


Figure 2. Estimated exploitation rate at age for the two models in this analysis.

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