# BSAI Alaska skate – model revision 2012

NPFMC BSAI Groundfish Plan Team, September 2012

Olav Ormseth
NMFS Alaska Fisheries Science Center, Seattle, WA

## Executive Summary

This document contains a description of and results from a revised population model for the Alaska skate (*Bathyraja parmifera*), the most abundant skate species in the BSAI. The existing model was created in 2007 and has experienced only minor revision and data updates since then. The revision described here includes substantial changes to the modeling approach, but uses very similar data to that used in the 2011 run of the existing model.

### *Summary of Major Changes*

Changes in the input data:

- The data used in the revised model are identical to those in the existing model, except that only the most recent length-at-age dataset (2007) is used in the revised model (the existing model uses an additional two older datasets).

Changes in assessment methodology:

- The revised model was created using an updated version of the Stock Synthesis software (version 3.23), which has enhanced functionality relative to the software used to create the existing model.
- The 4-parameter Schnute growth function is used to model growth, instead of the von Bertalanffy growth function.
- Parameters of the growth model were estimated independently and fixed.
- Selectivity functions for both fisheries and the survey are dome-shaped rather than asymptotic.
- A "survivorship" function is used to model the stock-recruit relationship.
- The maximum age was raised from 25 to 30.

### *Summary of results*

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



*This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.*

| comparison of status determination criteria and other population characteristics between the existing and revised models | | |
|---|---|---|
| **quantity** | existing model values for 2012 | **revised model values for 2012** |
| *M* (natural mortality rate) | 0.13 | 0.13 |
| Tier | 3a | 3a |
| Projected total (age 0+) biomass (t) | 550,912 | **594,827** |
| Female spawning biomass (t) | | |
| Projected | 55,139 | **89,366** |
| $B_{100\%}$ | 92,117 | **116,911** |
| $B_{40\%}$ | 36,846 | **46,764** |
| $B_{35\%}$ | 32,241 | **40,919** |
| $F_{OFL}$ | 0.087 | **0.10** |
| max $F_{ABC}$ | 0.075 | **0.089** |
| $F_{ABC}$ | 0.075 | **0.089** |
| OFL (t) | 29,669 | **32,254** |
| max ABC (t) | 25,565 | **28,158** |
| ABC (t) | 25,565 | **28,158** |
| **Status** | | |
| Overfishing | No | **No** |
| Overfished | No | **No** |
| Approaching overfished | No | **No** |

# Overview

The first age-structured model for BSAI Alaska skates was created in 2007 and approved in 2008 for use in making harvest recommendations for 2009. Since 2008 the initial model (referred to here as the "existing model") has seen only minor revisions and updates with new data. During this time the modeling software (Stock Synthesis) has been upgraded extensively and the availability of data on Alaska skates has increased. Therefore, the stock assessment author felt it necessary to conduct a more thorough revision of the Alaska skate assessment model. This document presents the new model (referred to here as the "2012 revised model"), selected model results, and comparisons to the existing model.

The 2012 revised model begins in 1980, in contrast to the existing model that begins in 1992. The original rationale for a 1992 start year was the uncertainty in catch and survey data prior to 1992, as well as a short history of fishery length composition data. For these reasons, in the existing model the population was modeled during the "modern era" for skates in the BSAI, where the biomass has remained relatively stable and available data are substantially more complete and reliable. While this rationale still holds true, it was decided that the model would benefit from a short "burn-in period" that includes no survey data but does include a constant reduced level of estimated catch.

As in the existing model, the revised model includes some characteristics designed to accommodate life history features unique to skates. All skate species have an extended embryonic period during which they develop within protective eggcases on the seafloor. Alaska skates do not appear to form visible annual growth marks in their vertebrae during embryonic development. However, cohort analysis based on embryo lengths measured at an Alaska skate nursery site in the EBS suggested that the Alaska skate has an eggcase development time of approximately 3.6 years, possibly due to the cold ocean temperatures in the EBS (Hoff 2007; Fig. 1). Preliminary data from captive studies support these long development times (G. Hoff, AFSC, pers. comm.) and the field observations are consistent with development times observed in other skate species (Fig. 2; Hoff 2007). For example, thorny skate (*Raja radiata*) embryos spend approximately 2.5 years in the eggcase development stage at warmer temperatures than those found in the EBS (Berestovskii 1994 in Hoff 2007). Incorporating this information in the model is complicated by the possibility that embryo development times may be temperature-dependent, which is also supported by the preliminary captive-study data (G. Hoff, pers. comm.).

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

# Data

<u>General comment on data for the 2012 model update</u>

The 2012 model update relies on the same data used in the 2011 model run. The reason for this decision was mainly to allow direct comparison to the existing model, but also because new 2012 data (e.g. survey biomass estimates and length data) are not yet available. The data used in the 2012 update are identical to

the data from 2011 except that the 2012 update uses only the most recent set of length-at-age (LAA) data (from the 2007 EBS shelf bottom trawl survey) rather than the three LAA datasets in the existing model. A figure at the end of the data section summarizes the main data sources included in the model.

Survey biomass

Three bottom trawl surveys are conducted in the BSAI region: EBS shelf, EBS slope, and the Aleutian Islands. Because the Alaska skate population is concentrated on the EBS shelf, and the EBS shelf survey provides yearly estimates of biomass, we used biomass data from only the EBS shelf survey in this assessment. Recent (1999-2011) survey information on species composition was used to describe the relative proportion (0.95) of the Alaska skate to all other skate species ("Other Skates") within the EBS shelf area (Fig. 3). Biomass estimates from 1992 through 2010 were utilized in the Alaska skate model. For each survey prior to 1999, total skate biomass estimates were partitioned into Alaska skate and Other Skates based on the average proportion of each group in the 1999-2011 surveys (Table 1). The modeling software employs the coefficient of variation (CV) as the standard deviation (*s*) associated with each estimate. For the estimates prior to 1999, a value of *s* was chosen that was intermediate to recent values and a high *s* observed in 1999 (Table 1).

Survey length composition

Total length (TL) data from the EBS shelf survey were available from 2000-2011 (Table 2). The survey takes length measurements for every skate in each haul. Length data were aggregated into 4-cm bins and an N of 100 for each length composition was used in the model.

Total catch

Incidental catches of skates in the BSAI occur in several target fisheries but can be broken down into catches by two gear types: longline and trawl. These fisheries have different selectivities and the majority of catches occur in the longline fisheries. The revised model includes catch data from two distinct eras, 1980-1991 and 1992-2011. No catch data are available for the years 1980-1991, so catch in those years was set at 10,000 t for the longline fishery and 2,000 t for the trawl fishery. These values are identical to the initial equilibrium catch level used in the existing model.

For the 1992-2011 period, independent estimates of BSAI skate catch were made by the Blend system and AKRO CAS as described in the 2007 BSAI skate assessment. Catches were broken down by habitat area (EBS shelf, EBS slope, and AI) and by fishery gear type from 1992-2011 (Table 3). Total skate catch estimates for the EBS and AI are available since 1997; the average proportion of the skate catch in both of these areas (94% EBS and 6% AI) was assumed to remain constant prior to 1997 in order to reconstruct the area-specific catch. Catch is not estimated separately for the EBS shelf and EBS slope habitat areas by Blend or CAS; therefore a proxy based on fishery observer depth data was developed. The observed total skate catch from 2003-2011 in the EBS was partitioned by depth in order to approximate the proportion of the catch occurring in each of the two EBS habitat areas; catches less than 200 m were considered to occur on the EBS shelf (about 98%) and catches deeper than 200 m were considered to occur on the EBS slope (about 2%).

The average area-specific species compositions from the 1999-2011 bottom trawl surveys (Fig. 3) were utilized to further partition the catch into Alaska skates and Other Skates. The proportion of the catch by each fishery gear type differs by habitat area; for years without gear type data, the average proportion of each gear type from 2003 to 2005 was applied. The results were then totaled to obtain the total Alaska skate catch for each fishery across the entire BSAI management area, which was incorporated into the model (Table 3 and Fig. 4).

Catch length composition

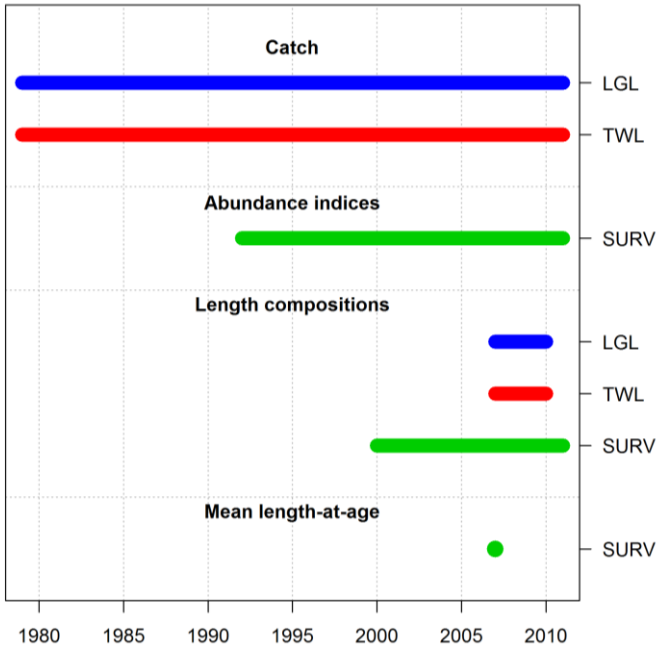
Length data for the Alaska skate were collected as a special project by fishery observers aboard trawl and longline vessels operating in the EBS in 2007. In 2008, the observer manual was changed to require collection of skate lengths on every haul where they were present in the target fisheries for Pacific cod and flatfishes. Fishery length composition varies by season, with larger skates caught later in the year (Figure 5). Fishery length data from 2007-2010 were included for both gear types. The number of hauls sampled for the fishery length data is much higher than in the survey because observers take a small number of length measurements from a large number of hauls, and an N of 100 (identical to the survey data) was applied to each fishery length composition. Length data were aggregated into 4-cm bins as for the survey data (Table 4).

Length at age

Mean LAA data were obtained from production ageing of skate vertebrae collected during the 2007 EBS shelf bottom trawl survey. Age was determined through examination of annual growth rings which begin to form in vertebral thin sections following hatching from the eggcase. Skate age determination is inherently difficult due to the typically faint appearance of growth zones, and CVs associated with many skate ageing studies tend to be high. However, Matta (2006) was able to corroborate ages generated from two different ageing structures in the Alaska skate, vertebrae and caudal thorns, as well as to verify the annual periodicity of vertebral growth ring formation through marginal increment analysis. In the existing model, three LAA datasets were used: one from the 2003 EBS shelf survey (n=182), one from the 2005 longline fishery (n=208), and one from the 2007 EBS shelf survey (n=243). For the updated model, the earliest 2 datasets were deemed redundant and the only the most recent dataset (2007) was used in the model update. This change simplified the model and also ensured that the model was working with the most recent LAA data.

Weight at length

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



Summary of data sources included in the revised model.

# Analytic Approach

Model structure

The 2012 revised model was created using the Stock Synthesis 3 (SS3) assessment program[1] (Methot 2005, 2007). The Stock Synthesis application allows the flexibility to incorporate both age- and size-structured information in an age-structured model. In the model described here, natural mortality is the only parameter that is explicitly age-based; selectivity, maturity, and mean body weight are length-based parameters. Length-at-age data and estimates of ageing error are used by SS3 to convert the size-based information into age-specific values that can be used to model the population through time.

Stock Synthesis 3 is comprised of three submodels. A population submodel captures the dynamics of an age-structured population and an observation model specifies likelihood components for comparing model predictions to observed data. A statistical model incorporates those components and others into an objective function that SS3 uses to maximize the overall likelihood by altering the parameters that govern the population dynamics model. SS3 also contains a forecasting routine that specifies fishery management targets and projects the population into the future, but we used an alternative projection model that was designed exclusively for use in Alaska fisheries by Jim Ianelli (AFSC, NMFS). The structure of SS3 is explained in detail elsewhere (Methot 1990, 2005, 2007), and we offer here only a limited explanation of the model structure.

The population dynamics model is depicted schematically in Fig. 7. Briefly, unfished recruitment and *M* determine the age structure of an unfished population. The unfished age structure is then modified by *M* and equilibrium catch to produce an initial age structure. For each subsequent year in the model, individuals are added through recruitment and subtracted through *M* and catch. The expected level of recruitment in each year results from estimates of spawning biomass in the previous year and the parameters of user-defined recruitment functions. Model estimates of recruitment deviate from the expected level according to the standard deviation of log recruitment ($\sigma_R$), which can be fixed or estimated within the model. In all cases, catch is modified by fishery age and length selectivity. For Alaska skates, the observation submodel includes three likelihood components based on model fits to observed data: EBS shelf survey biomass, length compositions from the shelf survey and each of the fisheries, and mean length at age. An additional likelihood component compares the deviations in recruitment to the value of $\sigma_R$. The objective function combines these four components to calculate overall likelihood. All likelihood components were weighted equally in the model.

The revised model continues a number of simplifications and assumptions used in the existing model. The entire BSAI was treated as one homogenous area. Because growth and maturity patterns are similar for males and females, we specified only one sex. Spawning was assumed to occur at the midpoint of the year. No informative priors were used. We also assumed that parameters did not vary with season or year and were not influenced by environmental conditions. All parameters used in the base model are listed in Table 5 and described in more detail below.

Modeling approach for the 2012 model revision

While the basic structure of the model remains the same in the 2012 revision, there have been some changes to the modeling approach that merit explicit attention. The conceptual approach differs slightly for the 2012 revision. Information considered to be of higher quality is given greater weight in the model: the model fit to the EBS shelf bottom trawl survey and the length-at-age data were considered especially important. Rather than having growth parameters estimated within the model (as in the existing model),

[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]

growth model parameters were estimated independently using reliable, recent data and fixed in the model. In contrast, features such as survey and fishery selectivity that are more uncertain were mainly estimated within the model. Specific changes to the analytical approach are described in the appropriate sections.

Parameters estimated independently:

*Natural mortality (M)*
In 2007, a conservative value of 0.13 was chosen from a set of *M* values estimated using different life history parameters (Matta 2006; Table 6): 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.

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

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

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

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

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

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 (Fig. 8). Maturity was estimated directly from paired length and maturity stage data; maturity stage was easily assessed through macroscopic examination of the reproductive organs.

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

*Survey catchability*
The approach to survey catchability remains unchanged from the existing model. Survey catchability was fixed at 1. The EBS shelf survey appears to sample Alaska skates very reliably, with CVs of approximately 0.05. In addition, we did not adjust catchability for the segments of the Alaska skate population (AI and EBS slope) that are not observed by the EBS shelf survey. Over 96% of the Alaska

skate population is on the shelf and surveys from the other areas are infrequent. It was considered a precautionary measure not to account for the small amount of Alaska skate biomass on the slope and in the AI.

*Age selectivity*
The uncertainty surrounding the embryonic development period for the Alaska skate poses some problems in the model, and age selectivity was used to partially offset these problems. The best estimate of embryo development times is approximately 3.6 years (Hoff 2007), and the majority of young skates appear to emerge during the winter. Therefore, it was assumed that no skates were available to either fisheries or the surveys before age 3.5, and were fully available (in terms of age) beyond age 3.5 (Fig. 9). Length-based selectivity was then used to model the selective behavior of the fleet and surveys for skate older than age 3.5.

<u>Parameters estimated conditionally:</u>

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

The changes described above required the abandonment of the logistic selectivity pattern for the EBS shelf survey. The existing model relies on an independent assessment of trawl survey capture probability using a logistic function (Kotwicki and Weinberg 2005). While this study provides valuable information regarding gear selectivity of the trawl gear, the assessment author felt this was likely to be an incomplete representation of survey selectivity. In the revised model, fishery and survey selectivity are modeled using a double-normal function that is the recommended function for use in SS3. The double-normal is defined by six parameters for each fishery or survey, where p1 is the peak or ascending inflection size, p2 is the width of the plateau, p3 is the ascending width, p4 is the descending width, p5 is the selectivity at the first length bin, and p6 is the selectivity at the last length bin. All selectivity parameters are internally estimated except p1. Selectivity parameters are summarized in Table 5. All bounds were the default values specified in the SS3 documentation.

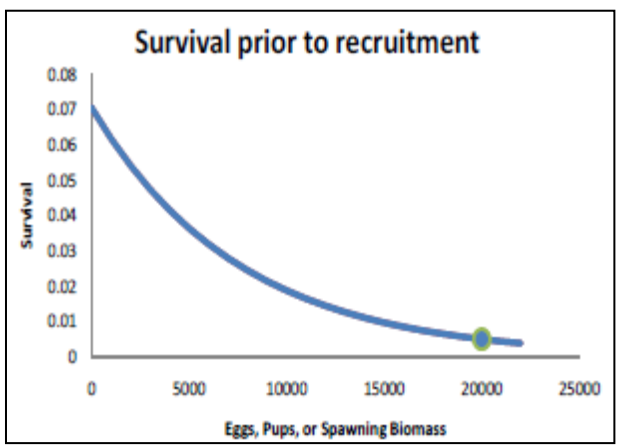
*Spawner-recruit parameters*
The existing model uses a Beverton-Holt function to describe the spawner-recruit relationship of the Alaska skate, with steepness fixed at 1.0 to create a mean level of recruitment . In the revised model, an SS3-specific "survivorship" function was instead used to model recruitment. The survivorship function was designed explicitly for use with low-fecundity species (Taylor et al. *in press*). The following excerpt from the SS3 user manual describes the survivorship function:

"This survival based spawner-recruitment function defines survival from the egg (e.g. hatched pups) to the recruits stage to be a declining function of the initial number of pups produced (Taylor et al. 2012).

- Start with the parameter, ln(R_0), which is the ln(mean number of recruits) that enter the population in unfished conditions.
- These recruits over their lifetime will produce some total number of eggs (pups), termed Pups_0, which can be calculated from natural mortality, which defines the numbers at age in the adult population, and fecundity at age.

- Because the unfished condition is considered to be a stable equilibrium, we can calculate PPR_0 = Pups_0/R_0 and its inverse which is survivorship, which we will define in logarithmic space. So, Z_0 = ln(R_0/Pups_0). Note that there is no explicit time over which this Z acts. Such an explicit time (e.g. the age ar recruitment) may be implemented in the future. For now, this means that the Z is really a Z*delta t.
- So, Z_0 is the survival when the population is at carrying capacity. On the other extreme, the maximum survival is 1.0, so the maximum Z is 0.0.
- The parameter, S_frac, defines the level of Z when the population approaches an abundance of 0.0. This has values bounded by 0.0 and 1.0 and creates a Z_max which is between Z_0 and 0.0.
- Z_max = Z_0 + S_frac*(0.0-Z_0)
- Then for the current level of pup production (e.g. total population fecundity, aka "spawning biomass"):
    - Zy=(1 - (Pupy/Pups_0)Beta)*(Z_max-Z_0)+Z_0
    - So Ry = Pupy * exp(-Zy)
    - Where beta is the third parameter and which logically has values between about 0.4 for a left-shifted spawner-recruitment curve, and 3.0 for a right-shifted curve.
- With the other spawner-recruitment relationships, the mean level of recruits, Ry , serves as the base against which environmental effects and annual lognormal deviations are applied. However, in a survival context, it is possible that a large positive deviation on recruitments could imply survival greater than 1.0, so an alternative approach is needed for this survival approach. Here, the lognormal deviations are applied to Z and the resultant S is constrained to not exceed 1.0.
- In SS, it is also necessary to be able to calculate the equilibrium level of spawning biomass (pup production) and recruitment for a given level of spawning biomass per recruit (pups per recruit), PPR.
    - Pups_equil = Pups_0 * (1 - (LN(1/PPR) - Z_0)/(Z_max - Z_0)) (1/Beta)
    - Then, R_equil = Pups_equil * exp(-(1 - (Pups_equil/Pups_0)Beta)*(Z_max-Z_0)+Z_0)"

Based on Taylor et al. (*in press*) and Gertseva and Taylor (2012), an S-frac of 0.5 and a beta of 1 was fixed in the model. The plot below shows the resulting survivorship curve:




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

# Results

## *Model Evaluation*

Model evaluation criteria

Likelihood values are given in Table 7. We evaluated the model based on the following criteria:

1) Likelihood gradient and sensitivity to starting values
2) Model fit to survey biomass estimates.
3) Model fit to length-at-age data.
4) Model fit to length compositions.
5) Reasonable estimates of fishery length selectivity parameters.
6) Reasonable estimates of unfished recruitment and recruitment variability.
7) Consistency with results from the existing and earlier models.

Evaluation of the model

1) The maximum gradient component of the likelihood was 7.76 X $10^{-5}$, indicating that the model had achieved a stable optimum. Sensitivity to starting values was tested by introducing varying levels of "jigger" in the starting values and re-running the model. The model presented here was perfectly stable at various levels of jiggering (i.e. it produced identical parameter values and overall likelihood).

2) The expected survey biomass produced by the model provided a good fit to the observed biomass (Fig. 10). Relative to the existing model, the revised model does a much better job of fitting annual variability in the biomass estimates (the existing model provided a very flat fit).

3) The model provides excellent fit to the length-at-age (LAA) data (Fig. 11), as should be expected since fitting the LAA data was a primary goal in the model construction. Because the existing model underestimates LAA, the improved fit results in larger and heavier skates in the model. Along with the change in the selectivity, this is likely the cause of the increased total and spawning biomass relative to the existing model.

4) The revised model provides good fits to the length composition data from the EBS shelf survey (Fig. 12), longline fishery (Fig. 14), and trawl fishery (Fig. 16). Analysis of Pearson residuals indicates that:
    a) In the survey (Fig. 13), the number of large skates is underestimated in earlier years (2000-2004), but that in recent years the model fit is fairly close for all size bins.
    b) In the longline fishery (Fig. 15) the model underestimates the amount of large skates in the catch, but that effect is smallest in the most recent data year (2010)
    c) In the trawl fishery (Fig. 17) the model underestimates small and large skates due to its dome-shaped fit to the data.

5) Estimates of selectivity parameters (Table 5) and selectivity at length (Figs. 18-20) for the fisheries and survey were reasonable. Longline fisheries (Fig. 18) displayed higher selectivity for larger skates, which is consistent with the length composition data. This selectivity may be due in part to the emergence of large skates from the nursery grounds during the third quarter of the year, when the longline catch of large skates is particularly high. It may also be a result of the nature of the longline fishery, where smaller skates are often removed from the groundline before being landed on the vessel. While fishery observers identify these dropped skates to genus and include them in counts, they are unable to take length measurements and it is likely that the longline length data are biased towards larger skates. The estimate of trawl selectivity (Fig. 19)

also seems reasonable, as the trawl fisheries occur in areas where small skates are more abundant and the observer measurements are less likely to have the length bias described earlier. Both fisheries and the survey (Fig. 20) have a descending limb that suggests the very oldest skates are relatively unavailable to the different gears. This is consistent with the hypothesis that mature skates spend a portion of the year (peaking in summer) engaging in spawning activities inside highly localized nursery areas on the upper continental slope, where they are not encountered by the EBS shelf survey and are less likely to encounter fisheries.

6) The base model estimate of unfished recruitment was consistent with the amount of spawning biomass and our limited knowledge of skate fecundity. Evaluating recruitment variability is difficult because little is known about recruitment of equilibrium strategists. The estimated levels of recruitment variability (Fig. 21) were higher than expected but still seem reasonable for this population.

7) An additional evaluation criterion and constraint on the model revision process was a desire to obtain results from the revised model that were reasonably consistent with the existing model- i.e. the new model should not produce dramatically different values for abundance estimates and biological reference points. The rationale for this desire has two parts: the existing model, while it underestimated LAA, provided a realistic description of the population that is consistent with survey data and previous harvest recommendations. In addition, the relationship between the model's total biomass estimate and the survey biomass estimate was reasonable- i.e. it is reasonable that the survey is missing some skates, so that the total biomass estimate should be higher, but it is not reasonable to expect that the survey is missing a huge proportion of the skate population. Thus model runs that produced biomass estimates in the millions of tons for skates were deemed unrealistic. The model presented here does have somewhat higher biomass estimates than the existing model, but this is entirely consistent with the improved fit to the length-at-age data and the change in the selectivity functions.

### *Time series results*

Results presented below are from the base model.

Definitions

Biomass is shown as total (age 0+) biomass (metric tons; t) of all Alaska skates in the population, and as female spawning biomass (t). Recruitment is reported as the number (in thousands) of Alaska skates at age 0. As described above, this corresponds to the number of viable embryos deposited in egg cases.

Biomass time series

Time series of total biomass and spawning biomass estimates from 1980-2011 are reported in Table 8 and in Fig. 22, respectively. These estimates indicate that biomass has fluctuated around values of approximately 600,000 t (total biomass) and 100,000 t (female spawning biomass).

Recruitment

Time series of age 0 recruitment are reported in Table 8 and Fig. 21. The model suggests that recruitment varies over time but that changes between adjacent years are small, as might be expected for an equilibrium strategist.

Exploitation rate

A time series of exploitation (catch/total biomass) is given in Table 9. The exploitation rates estimated in the 2011 assessment are similar to those of previous years.

# Literature Cited

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# Tables

Table 1. EBS shelf bottom trawl survey estimates of Alaska skate *Bathyraja parmifera* biomass (metric tons). Line indicates the first year (1992) that survey data are included in the model. Estimates and CVs in bold (1999-2011) 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 1999-2011.

| year | biomass | CV |
|---|---|---|
| 1982 | 167,826 | 0.10 |
| 1983 | 163,970 | 0.10 |
| 1984 | 190,037 | 0.10 |
| 1985 | | |
| 1986 | 255,409 | 0.10 |
| 1987 | 334,132 | 0.10 |
| 1988 | 392,645 | 0.10 |
| 1989 | 395,370 | 0.10 |
| 1990 | 513,751 | 0.10 |
| 1991 | 433,529 | 0.10 |
| 1992 | 379,682 | 0.10 |
| 1993 | 370,356 | 0.10 |
| 1994 | 412,663 | 0.10 |
| 1995 | 385,126 | 0.10 |
| 1996 | 426,649 | 0.10 |
| 1997 | 402,720 | 0.10 |
| 1998 | 352,101 | 0.10 |
| **1999** | **349,571** | **0.16** |
| **2000** | **311,970** | **0.06** |
| **2001** | **414,539** | **0.06** |
| **2002** | **410,016** | **0.06** |
| **2003** | **372,257** | **0.05** |
| **2004** | **433,660** | **0.05** |
| **2005** | **547,031** | **0.05** |
| **2006** | **437,737** | **0.05** |
| **2007** | **478,872** | **0.07** |
| **2008** | **361,298** | **0.06** |
| **2009** | **350,233** | **0.06** |
| **2010** | **366,116** | **0.06** |
| **2011** | **410,340** | **0.05** |

Table 2. Alaska skate EBS shelf survey length compositions, 2000-2011. Bin number is the lower limit of each 4 cm length bin; data are proportions of each bin. N = number of hauls.

| | year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| bin | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| **4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.002 | 0 | 0 |
| **8** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **12** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 | 0 |
| **20** | 0.007 | 0.01 | 0.01 | 0.006 | 0.006 | 0.004 | 0.003 | 0.007 | 0.004 | 0.008 | 0.003 | 0.004 |
| **24** | 0.037 | 0.039 | 0.023 | 0.033 | 0.016 | 0.019 | 0.024 | 0.017 | 0.017 | 0.019 | 0.015 | 0.015 |
| **28** | 0.047 | 0.056 | 0.031 | 0.031 | 0.03 | 0.025 | 0.026 | 0.019 | 0.02 | 0.019 | 0.018 | 0.021 |
| **32** | 0.047 | 0.058 | 0.037 | 0.047 | 0.032 | 0.033 | 0.031 | 0.028 | 0.027 | 0.03 | 0.017 | 0.025 |
| **36** | 0.052 | 0.048 | 0.044 | 0.053 | 0.032 | 0.041 | 0.036 | 0.042 | 0.038 | 0.043 | 0.028 | 0.028 |
| **40** | 0.051 | 0.048 | 0.042 | 0.048 | 0.049 | 0.047 | 0.045 | 0.051 | 0.052 | 0.051 | 0.04 | 0.042 |
| **44** | 0.046 | 0.051 | 0.044 | 0.052 | 0.051 | 0.061 | 0.052 | 0.052 | 0.061 | 0.054 | 0.048 | 0.057 |
| **48** | 0.052 | 0.044 | 0.041 | 0.053 | 0.058 | 0.057 | 0.057 | 0.062 | 0.061 | 0.053 | 0.042 | 0.064 |
| **52** | 0.056 | 0.049 | 0.045 | 0.041 | 0.062 | 0.054 | 0.051 | 0.052 | 0.065 | 0.06 | 0.05 | 0.064 |
| **56** | 0.052 | 0.043 | 0.037 | 0.036 | 0.051 | 0.057 | 0.057 | 0.055 | 0.062 | 0.063 | 0.053 | 0.062 |
| **60** | 0.055 | 0.051 | 0.035 | 0.041 | 0.047 | 0.064 | 0.055 | 0.05 | 0.059 | 0.064 | 0.051 | 0.064 |
| **64** | 0.045 | 0.043 | 0.033 | 0.039 | 0.042 | 0.053 | 0.053 | 0.06 | 0.06 | 0.059 | 0.059 | 0.064 |
| **68** | 0.035 | 0.047 | 0.041 | 0.043 | 0.049 | 0.046 | 0.048 | 0.055 | 0.046 | 0.052 | 0.061 | 0.059 |
| **72** | 0.038 | 0.046 | 0.035 | 0.041 | 0.043 | 0.048 | 0.049 | 0.053 | 0.051 | 0.054 | 0.057 | 0.060 |
| **76** | 0.03 | 0.035 | 0.041 | 0.042 | 0.047 | 0.04 | 0.048 | 0.046 | 0.049 | 0.049 | 0.054 | 0.050 |
| **80** | 0.04 | 0.03 | 0.035 | 0.047 | 0.038 | 0.04 | 0.037 | 0.041 | 0.043 | 0.05 | 0.056 | 0.046 |
| **84** | 0.03 | 0.026 | 0.046 | 0.037 | 0.043 | 0.039 | 0.044 | 0.04 | 0.04 | 0.045 | 0.058 | 0.047 |
| **88** | 0.034 | 0.033 | 0.069 | 0.044 | 0.044 | 0.052 | 0.038 | 0.045 | 0.043 | 0.049 | 0.063 | 0.048 |
| **92** | 0.051 | 0.06 | 0.092 | 0.056 | 0.062 | 0.048 | 0.062 | 0.058 | 0.055 | 0.049 | 0.076 | 0.052 |
| **96** | 0.07 | 0.071 | 0.094 | 0.088 | 0.081 | 0.062 | 0.068 | 0.063 | 0.057 | 0.056 | 0.069 | 0.058 |
| **100** | 0.066 | 0.069 | 0.076 | 0.065 | 0.072 | 0.059 | 0.064 | 0.06 | 0.055 | 0.045 | 0.047 | 0.045 |
| **104** | 0.043 | 0.031 | 0.037 | 0.043 | 0.034 | 0.035 | 0.038 | 0.028 | 0.026 | 0.02 | 0.025 | 0.017 |
| **108** | 0.014 | 0.011 | 0.01 | 0.013 | 0.01 | 0.011 | 0.012 | 0.011 | 0.009 | 0.006 | 0.008 | 0.006 |
| **112** | 0.002 | 0.002 | 0.003 | 0.002 | 0.003 | 0.002 | 0.002 | 0.003 | 0.001 | 0 | 0.001 | 0.001 |
| **116** | 0 | 0 | 0 | 0 | 0 | 0.001 | 0 | 0.001 | 0 | 0 | 0 | 0 |
| **120** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **124** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **128** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **132** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N** | 316 | 354 | 333 | 332 | 380 | 370 | 352 | 362 | 346 | 363 | 361 | 361 |

Table 3. Partitioned Alaska skate catch estimates (metric tons) based on observed fishery catch data and survey species composition. Total BSAI catch estimates for each fishery (right-most column) were used in the "data-rich" portion of the model (i.e. 1992-2011).

| year | EBS shelf longline | EBS shelf trawl | EBS slope longline | EBS slope trawl | AI longline | AI trawl | BSAI longline | BSAI trawl |
|---|---|---|---|---|---|---|---|---|
| 1992 | 12,204 | 2,690 | 23 | 8 | 169 | 94 | 12,396 | 2,792 |
| 1993 | 8,797 | 1,939 | 16 | 6 | 122 | 68 | 8,935 | 2,013 |
| 1994 | 10,234 | 2,256 | 19 | 7 | 142 | 79 | 10,394 | 2,341 |
| 1995 | 10,715 | 2,362 | 20 | 7 | 148 | 83 | 10,883 | 2,451 |
| 1996 | 9,097 | 2,005 | 17 | 6 | 126 | 70 | 9,240 | 2,081 |
| 1997 | 12,885 | 2,840 | 24 | 8 | 150 | 84 | 13,059 | 2,932 |
| 1998 | 13,876 | 3,059 | 26 | 9 | 198 | 110 | 14,100 | 3,178 |
| 1999 | 10,129 | 2,233 | 19 | 7 | 141 | 78 | 10,288 | 2,318 |
| 2000 | 13,020 | 2,870 | 24 | 9 | 317 | 177 | 13,362 | 3,055 |
| 2001 | 13,778 | 3,037 | 26 | 9 | 440 | 245 | 14,244 | 3,291 |
| 2002 | 15,702 | 3,461 | 119 | 42 | 122 | 68 | 15,943 | 3,571 |
| 2003 | 13,944 | 3,271 | 30 | 7 | 115 | 64 | 14,088 | 3,342 |
| 2004 | 16,104 | 3,777 | 26 | 22 | 155 | 86 | 16,285 | 3,886 |
| 2005 | 17,498 | 3,333 | 40 | 4 | 122 | 68 | 17,660 | 3,405 |
| 2006 | 14,710 | 3,243 | 27 | 10 | 169 | 94 | 14,907 | 3,346 |
| 2007 | 13,432 | 2,961 | 25 | 9 | 177 | 98 | 13,634 | 3,068 |
| 2008 | 15,449 | 3,405 | 29 | 10 | 249 | 139 | 15,726 | 3,554 |
| 2009 | 14,796 | 3,262 | 28 | 10 | 211 | 118 | 15,035 | 3,389 |
| 2010 | 12,493 | 2,754 | 23 | 8 | 234 | 131 | 12,750 | 2,892 |
| 2011 | 14,857 | 3,275 | 28 | 10 | 127 | 70 | 15,012 | 3,355 |

Table 4. Alaska skate length compositions from the BSAI longline and trawl fisheries, 2007-2010. Bin number is the lower limit of each 4 cm length interval.

| | 2007 | | 2008 | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|---|---|
| **bin** | **longline** | **trawl** | **longline** | **trawl** | **longline** | **trawl** | **longline** | **trawl** |
| **4** | 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 |
| **12** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| **16** | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.002 |
| **20** | 0.000 | 0.008 | 0.000 | 0.004 | 0.000 | 0.003 | 0.000 | 0.003 |
| **24** | 0.000 | 0.017 | 0.000 | 0.022 | 0.000 | 0.011 | 0.000 | 0.010 |
| **28** | 0.000 | 0.013 | 0.000 | 0.035 | 0.000 | 0.024 | 0.000 | 0.018 |
| **32** | 0.000 | 0.023 | 0.000 | 0.043 | 0.001 | 0.035 | 0.001 | 0.031 |
| **36** | 0.000 | 0.030 | 0.001 | 0.062 | 0.001 | 0.053 | 0.001 | 0.037 |
| **40** | 0.002 | 0.040 | 0.002 | 0.056 | 0.002 | 0.065 | 0.002 | 0.054 |
| **44** | 0.005 | 0.054 | 0.004 | 0.047 | 0.005 | 0.066 | 0.006 | 0.055 |
| **48** | 0.006 | 0.061 | 0.014 | 0.049 | 0.009 | 0.056 | 0.014 | 0.051 |
| **52** | 0.016 | 0.053 | 0.020 | 0.046 | 0.017 | 0.051 | 0.024 | 0.042 |
| **56** | 0.027 | 0.046 | 0.027 | 0.037 | 0.023 | 0.044 | 0.032 | 0.041 |
| **60** | 0.046 | 0.061 | 0.030 | 0.039 | 0.032 | 0.041 | 0.045 | 0.043 |
| **64** | 0.062 | 0.067 | 0.053 | 0.037 | 0.043 | 0.048 | 0.056 | 0.048 |
| **68** | 0.054 | 0.049 | 0.074 | 0.038 | 0.058 | 0.048 | 0.068 | 0.057 |
| **72** | 0.072 | 0.053 | 0.062 | 0.039 | 0.063 | 0.048 | 0.070 | 0.054 |
| **76** | 0.055 | 0.059 | 0.072 | 0.037 | 0.069 | 0.040 | 0.062 | 0.050 |
| **80** | 0.059 | 0.045 | 0.072 | 0.041 | 0.069 | 0.054 | 0.071 | 0.054 |
| **84** | 0.060 | 0.048 | 0.073 | 0.044 | 0.069 | 0.045 | 0.067 | 0.054 |
| **88** | 0.065 | 0.059 | 0.078 | 0.052 | 0.083 | 0.061 | 0.072 | 0.055 |
| **92** | 0.089 | 0.052 | 0.082 | 0.056 | 0.098 | 0.061 | 0.091 | 0.069 |
| **96** | 0.117 | 0.060 | 0.110 | 0.075 | 0.129 | 0.058 | 0.103 | 0.068 |
| **100** | 0.137 | 0.051 | 0.132 | 0.075 | 0.124 | 0.050 | 0.104 | 0.054 |
| **104** | 0.080 | 0.025 | 0.063 | 0.040 | 0.068 | 0.027 | 0.057 | 0.028 |
| **108** | 0.031 | 0.013 | 0.029 | 0.014 | 0.028 | 0.007 | 0.028 | 0.012 |
| **112** | 0.010 | 0.008 | 0.001 | 0.006 | 0.006 | 0.002 | 0.013 | 0.004 |
| **116** | 0.006 | 0.004 | 0.001 | 0.002 | 0.002 | 0.000 | 0.006 | 0.003 |
| **120** | 0.002 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.004 | 0.001 |
| **124** | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 |
| **128** | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| **132** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **N** | 2,911 | 858 | 1,369 | 2,930 | 18,081 | 8,174 | 17,168 | 9,545 |

Table 5. Final parameter values of the revised model. Where parameters were estimated freely within the model, minimum and maximum bounds are shown.

| parameter | | value | min | max | fix? |
|---|---|---|---|---|---|
| **growth and natural mortality** | natural mortality (M) | 0.13 | | | X |
| | length at A1 (L1) | 23 | | | X |
| | length at A2 (L2) | 115 | | | X |
| | von Bertalanffy coefficient (κ) | 0.15 | | | X |
| | Richards coefficient (γ) | 0.1 | | | X |
| | CV of L1 | 0.180 | 0.05 | 0.25 | |
| | CV of L2 | 0.05 | 0.05 | 0.25 | |
| **length-weight relationship** | coefficient (a) | $2.44 \times 10^{-6}$ | | | X |
| | exponent (b) | 3.35 | | | X |
| **length at maturity** | length at 50% maturity (a) | 93.28 | | | X |
| | slope (b) | -0.548 | | | X |
| **length-fecundity relationship** | intercept | -14.7 | | | X |
| | slope | 0.214 | | | X |
| **survivorship function (recruitment)** | ln virgin recruitment level (R0) | 10.32 | 5 | 15 | |
| | survivorship S fraction | 0.5 | | | X |
| | survivorship beta parameter | 1 | | | X |
| | SD of R0 (σR) | 0.4 | | | X |
| **EBS shelf survey catchability** | ln catchability (Q) | 0 | | | X |
| **longline length selectivity** | peak (p1) | 90 | | | X |
| | top (p2) | -0.709132 | -6 | 4 | |
| | ascending width (p3) | 6.46015 | -1 | 9 | |
| | descending width (p4) | 3.70571 | -1 | 9 | |
| | selectivity at first size bin (p5) | -4.99918 | -5 | 9 | |
| | selectivity at last size bin (p6) | -2.78652 | -5 | 9 | |
| **trawl length selectivity** | peak (p1) | 49 | | | X |
| | top (p2) | 0.703218 | -6 | 4 | |
| | ascending width (p3) | 5.19082 | -1 | 9 | |
| | descending width (p4) | 3.87284 | -1 | 9 | |
| | selectivity at first size bin (p5) | -0.759541 | -5 | 9 | |
| | selectivity at last size bin (p6) | -2.69474 | -5 | 9 | |
| **survey length selectivity** | peak (p1) | 49 | | | X |
| | top (p2) | 1.09405 | -6 | 4 | |
| | ascending width (p3) | 3.35676 | -1 | 9 | |
| | descending width (p4) | -0.192972 | -1 | 9 | |
| | selectivity at first size bin (p5) | 0.5 | | | X |
| | selectivity at last size bin (p6) | -3.70268 | -5 | 9 | |
| **age selectivity (logistic) for all fisheries and survey** | (p1) | 3.5 | | | X |
| | (p2) | 0.1 | | | X |
| **initial fishing mortality** | longline fishery F | 0.030 | 0 | 1 | |
| | trawl fishery F | 0.005 | 0 | 1 | |

Table 6. Estimates of M based on Alaska skate life history parameters from Matta (2006). "Age mature" ($T_{mat}$) was given a range to estimate M by the Rikhter and Efanov method to account for uncertainty in this parameter.

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

Table 7. Overall and component likelihoods.

| **overall likelihood** | **101.2** |
|---|---|
| survey | -11.87 |
| length compositions | 98.20 |
| length at age | 33.78 |
| recruitment | -19.66 |
| forecast recruitment | -0.7540 |

Table 8. Time series of total (age 0+) biomass, spawning biomass and the number of age 0 recruits predicted by the revised model.

| | total biomass (t) | female spawning biomass (t) | recruits (1000s) |
|---|---|---|---|
| 1980 | 621,143 | 99,816 | 21,337 |
| 1981 | 621,101 | 99,816 | 20,665 |
| 1982 | 620,935 | 99,816 | 20,661 |
| 1983 | 620,517 | 99,816 | 21,537 |
| 1984 | 619,658 | 99,816 | 23,809 |
| 1985 | 618,066 | 99,816 | 26,950 |
| 1986 | 615,466 | 99,814 | 31,845 |
| 1987 | 611,671 | 99,809 | 36,103 |
| 1988 | 606,660 | 99,796 | 42,178 |
| 1989 | 600,646 | 99,768 | 38,907 |
| 1990 | 594,084 | 99,716 | 37,975 |
| 1991 | 587,627 | 99,624 | 43,683 |
| 1992 | 582,065 | 99,258 | 41,833 |
| 1993 | 574,945 | 97,918 | 34,350 |
| 1994 | 574,514 | 96,682 | 33,119 |
| 1995 | 575,008 | 94,601 | 28,649 |
| 1996 | 577,753 | 92,090 | 31,012 |
| 1997 | 585,198 | 89,923 | 37,268 |
| 1998 | 590,045 | 87,505 | 27,296 |
| 1999 | 594,962 | 85,678 | 28,067 |
| 2000 | 605,162 | 85,545 | 24,074 |
| 2001 | 611,437 | 86,014 | 24,636 |
| 2002 | 615,777 | 87,237 | 20,742 |
| 2003 | 616,749 | 88,883 | 20,646 |
| 2004 | 618,023 | 91,187 | 20,713 |
| 2005 | 614,471 | 93,124 | 15,787 |
| 2006 | 607,747 | 94,589 | 14,053 |
| 2007 | 601,460 | 95,833 | 16,942 |
| 2008 | 594,328 | 96,604 | 28,115 |
| 2009 | 582,186 | 96,410 | 28,478 |
| 2010 | 568,636 | 95,786 | 28,815 |
| 2011 | 556,023 | 95,260 | 29,162 |

Table 9. Time series of exploitation rates (catch/total biomass) as estimated by the model.

| | longline | trawl | total F |
|---|---|---|---|
| 1980 | 0.030 | 0.005 | 0.035 |
| 1981 | 0.030 | 0.005 | 0.035 |
| 1982 | 0.030 | 0.005 | 0.035 |
| 1983 | 0.030 | 0.005 | 0.035 |
| 1984 | 0.030 | 0.005 | 0.035 |
| 1985 | 0.030 | 0.005 | 0.035 |
| 1986 | 0.030 | 0.005 | 0.035 |
| 1987 | 0.030 | 0.005 | 0.035 |
| 1988 | 0.030 | 0.005 | 0.035 |
| 1989 | 0.030 | 0.005 | 0.036 |
| 1990 | 0.031 | 0.005 | 0.036 |
| 1991 | 0.032 | 0.005 | 0.037 |
| 1992 | 0.041 | 0.008 | 0.048 |
| 1993 | 0.030 | 0.006 | 0.036 |
| 1994 | 0.036 | 0.007 | 0.043 |
| 1995 | 0.038 | 0.007 | 0.045 |
| 1996 | 0.032 | 0.006 | 0.038 |
| 1997 | 0.045 | 0.008 | 0.053 |
| 1998 | 0.047 | 0.008 | 0.056 |
| 1999 | 0.033 | 0.006 | 0.039 |
| 2000 | 0.041 | 0.007 | 0.049 |
| 2001 | 0.042 | 0.008 | 0.050 |
| 2002 | 0.046 | 0.008 | 0.054 |
| 2003 | 0.040 | 0.008 | 0.047 |
| 2004 | 0.045 | 0.009 | 0.054 |
| 2005 | 0.049 | 0.008 | 0.057 |
| 2006 | 0.042 | 0.008 | 0.050 |
| 2007 | 0.039 | 0.007 | 0.047 |
| 2008 | 0.046 | 0.009 | 0.055 |
| 2009 | 0.046 | 0.009 | 0.054 |
| 2010 | 0.040 | 0.008 | 0.048 |
| 2011 | 0.049 | 0.010 | 0.059 |

## Figures

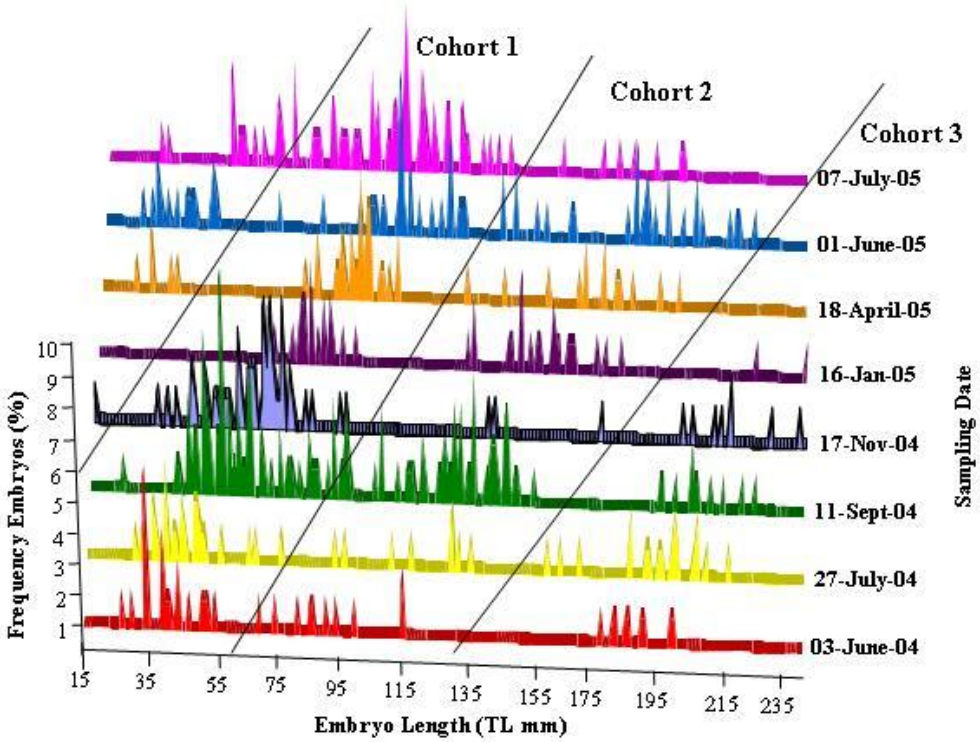



Figure 1. Embryo length composition data used in a cohort analysis of embryo development time. Figure is from G. Hoff (pers. comm.).

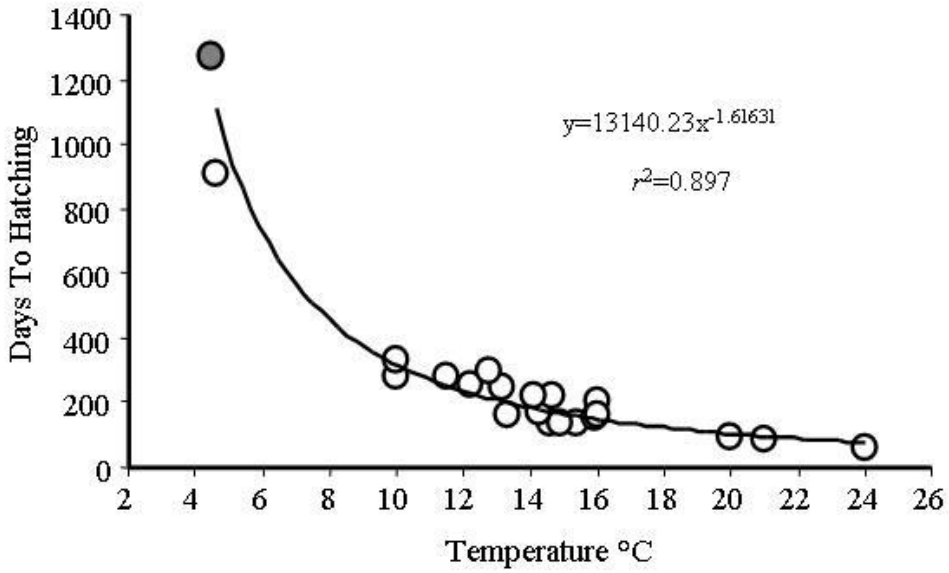



Figure 2. Ocean temperature versus embryo development time for 21 skate species. Dark grey circle is the Alaska skate. Equation and $R^2$ are the values of the fitted relationship. Figure is from G. Hoff, AFSC, pers. comm.

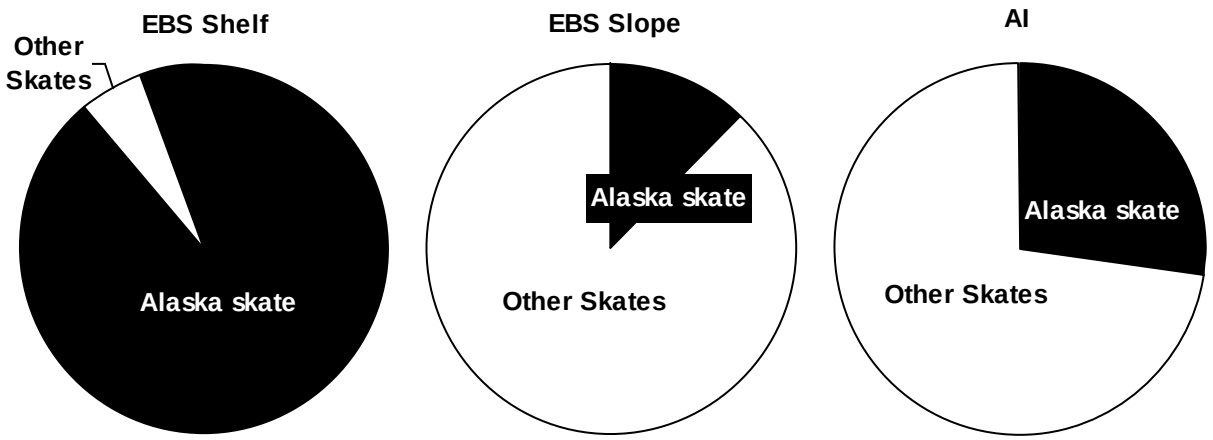



Figure 3. Relative proportion of Alaska skates and Other Skates in each habitat area. Graphs represent weighted averages from 1999-2011 trawl survey biomass estimates. These data were used to reconstruct catch data for the Alaska skate for use in the assessment model.

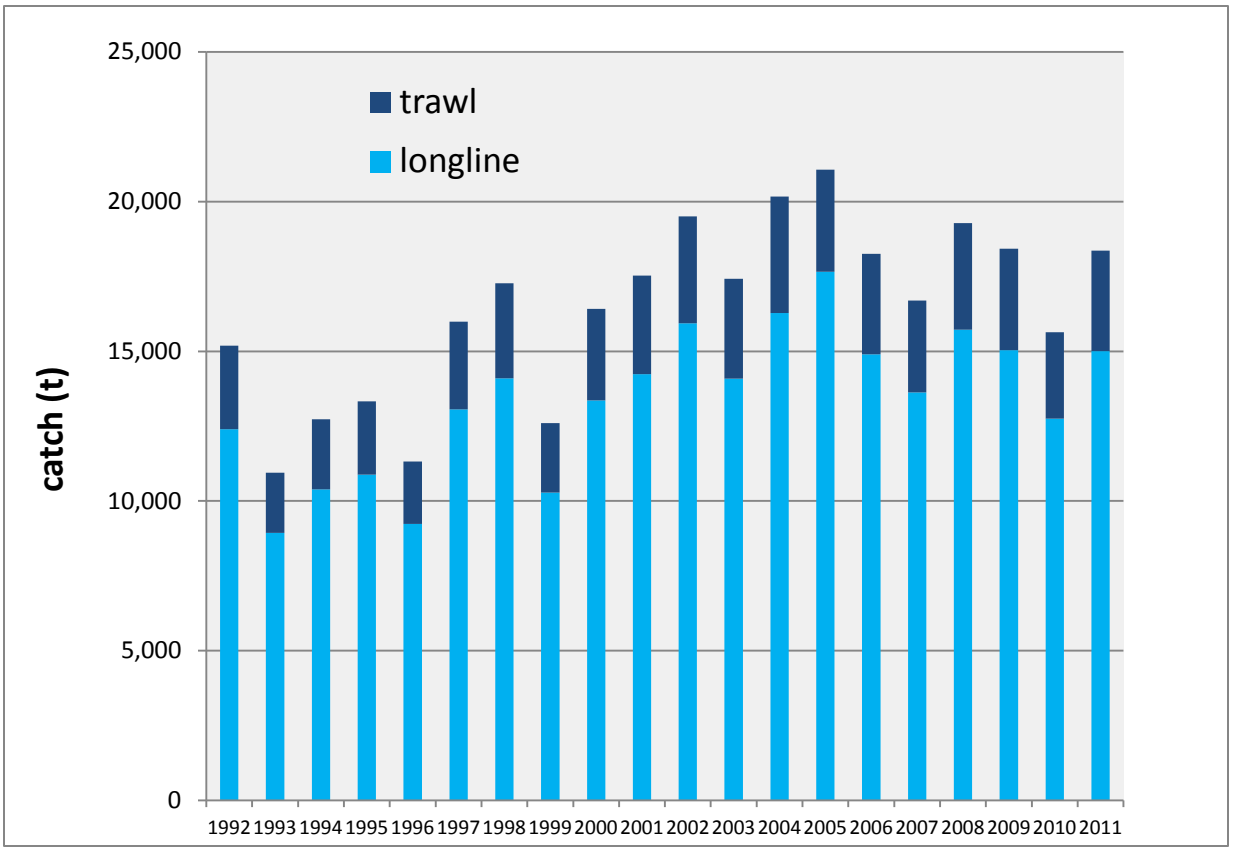
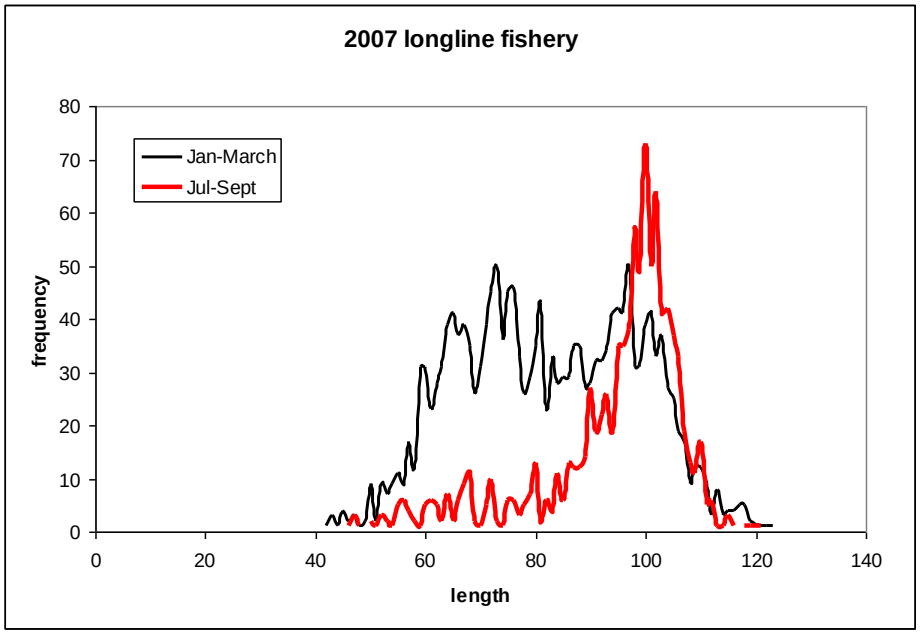



Figure 4. Estimated catch of Alaska skates (t) in the BSAI used in the "data-rich" period of the model, 1992 to 2011. Data were obtained from the Blend system and AKRO CAS. 2011 catch is as reported through November 3, 2011.



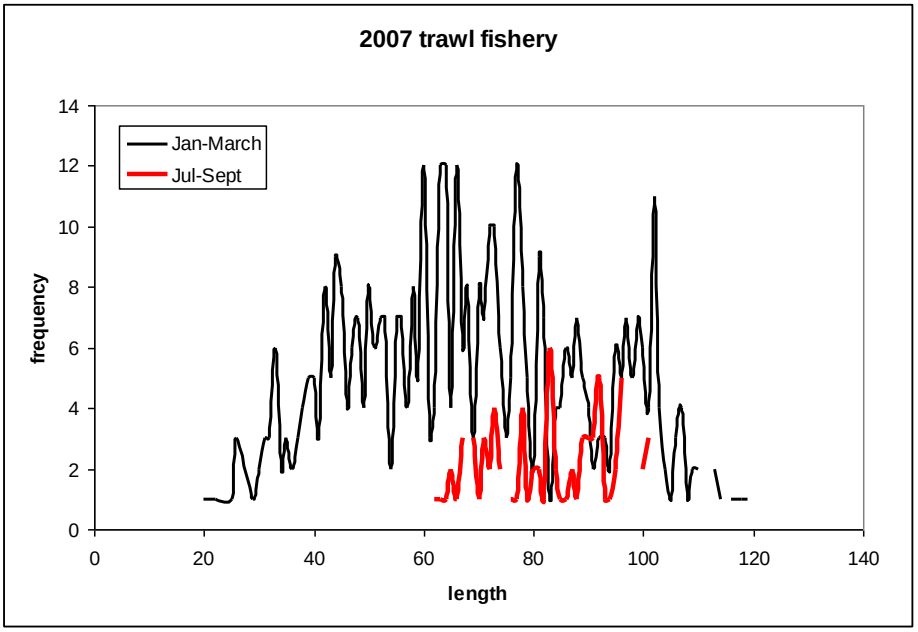




Fig. 5. Fishery length compositions by quarter (unbinned data) for Alaska skates during 2007.

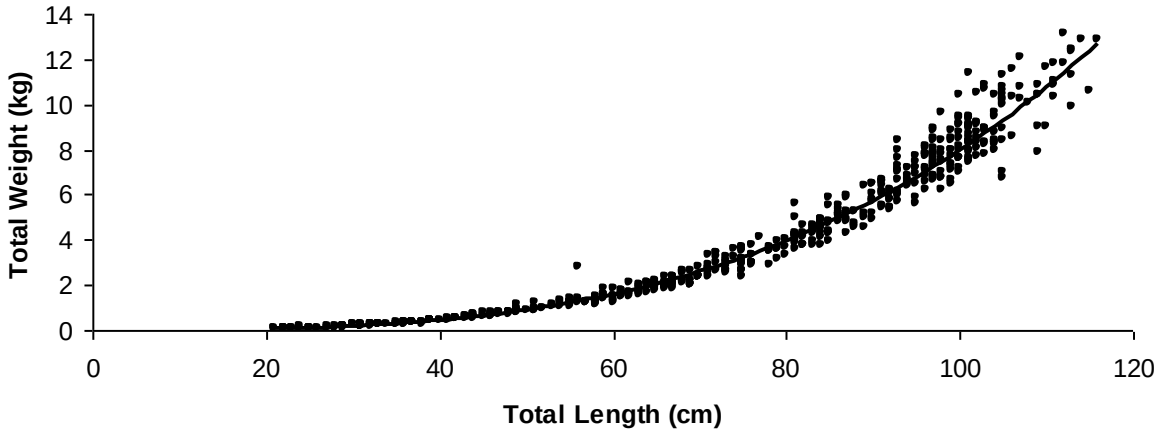



Figure 6. The relationship between total length (TL) and total body weight (W) for the Alaska skate, both sexes combined (n=526).

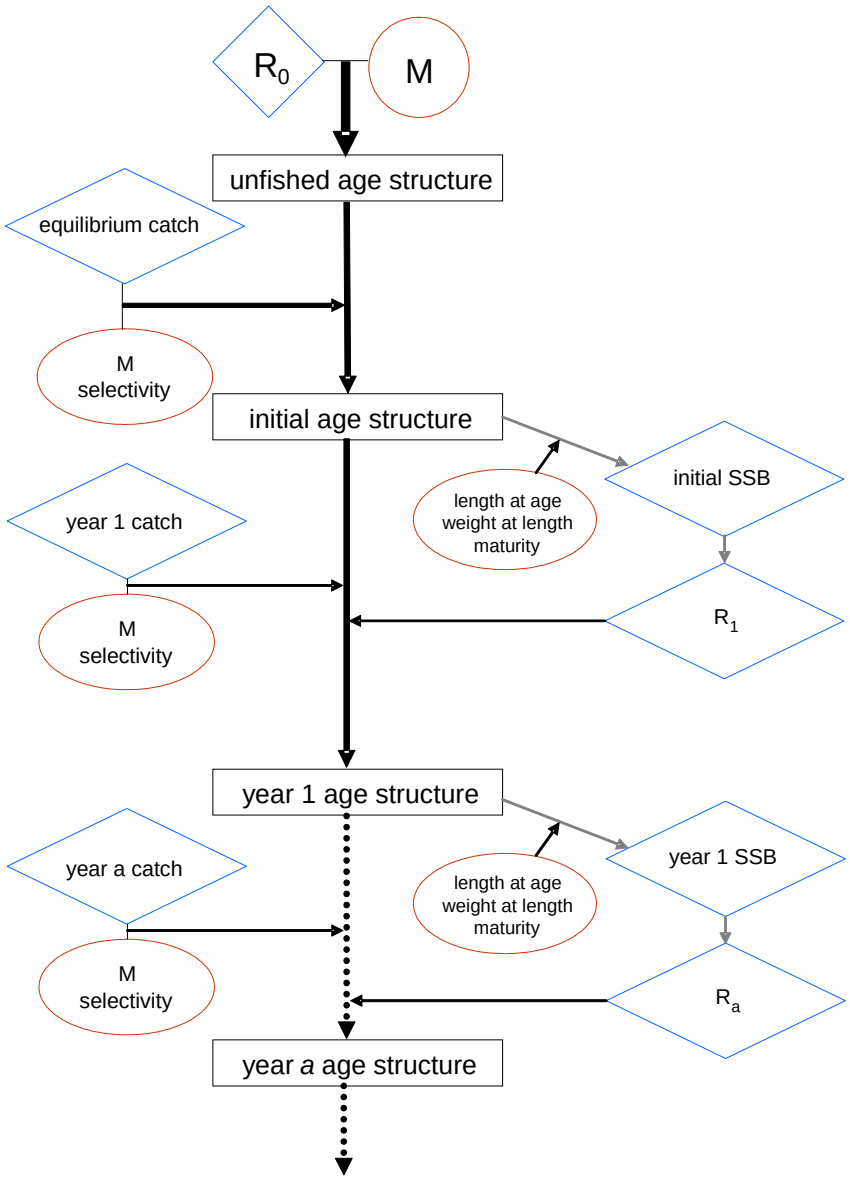



Figure 7. Simplified schematic depiction of population dynamics model used in the Alaska skate assessment. Blue diamonds indicate physical quantities, red circles indicate rates. $R_a$ = recruitment in year a, M = natural mortality, SSB = spawning biomass.

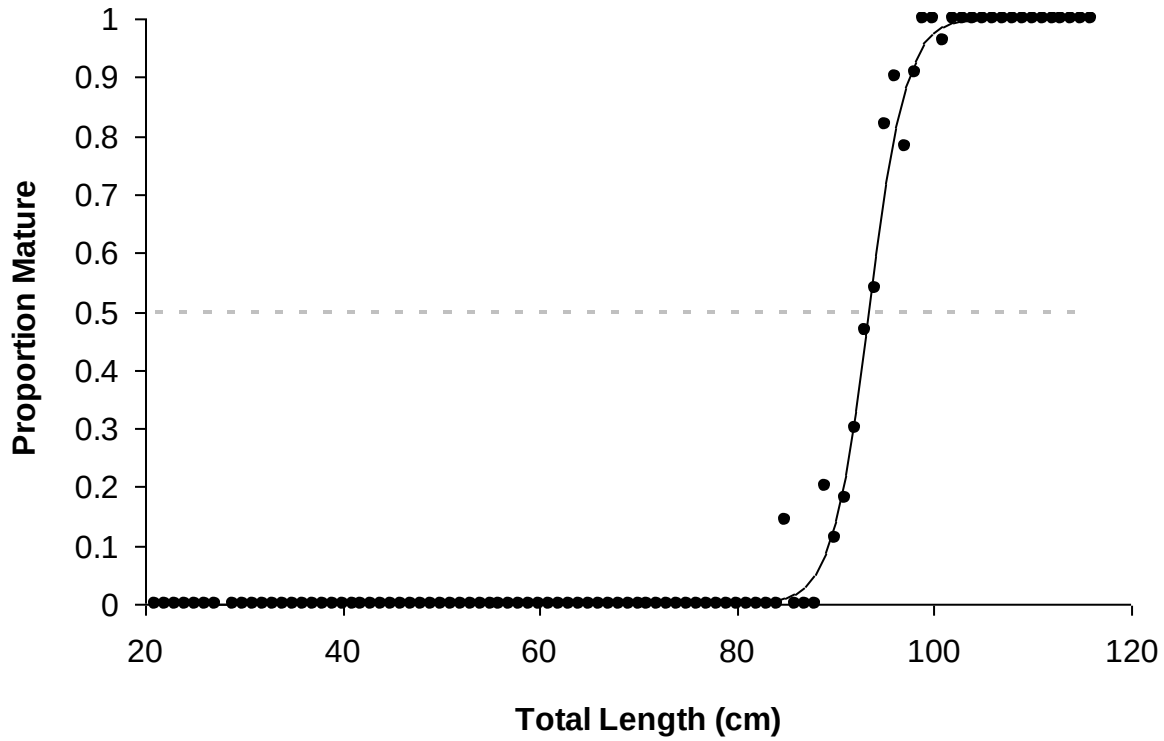



Figure 8. Female Alaska skate maturity-at-length data shown with fitted logistic curve from Matta (2006) (n=642).

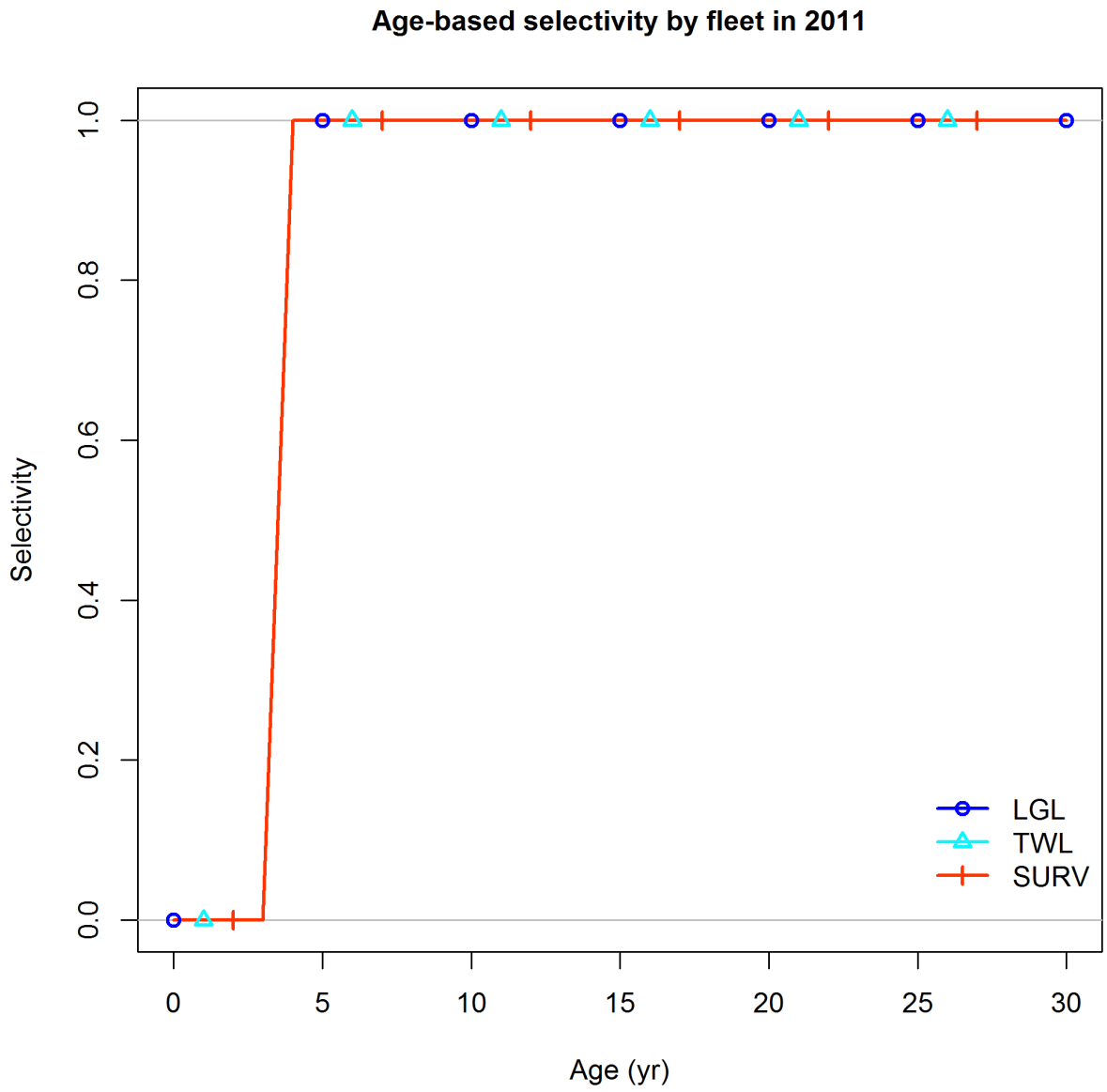



Figure 9. Age-based selectivity for the fisheries and the survey (all are identical).

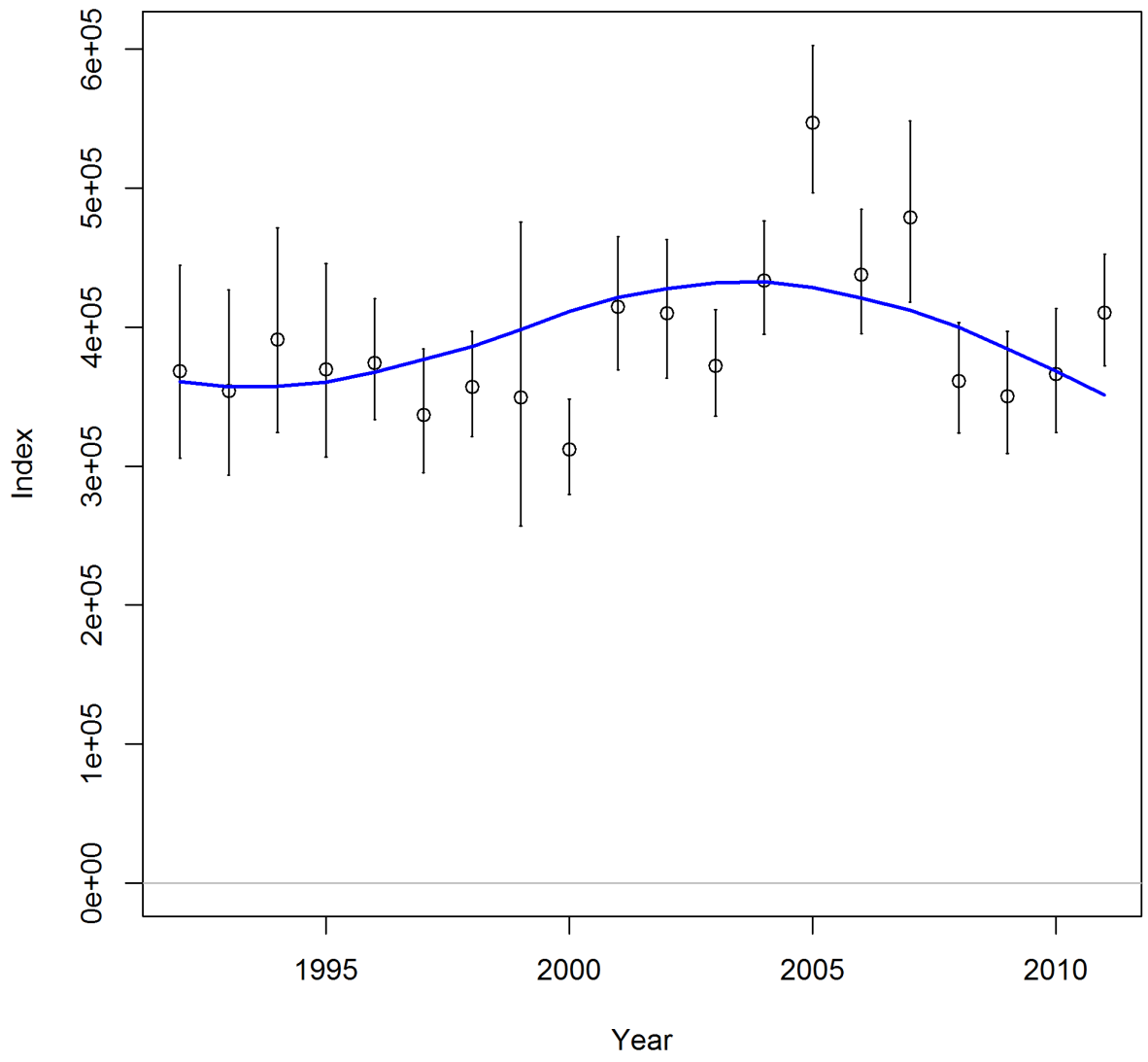



Figure 10. Observed biomass (circles) from EBS shelf surveys 1992-2011, with approximate confidence intervals (± 2 SE), and predicted survey biomass from the model (blue line).

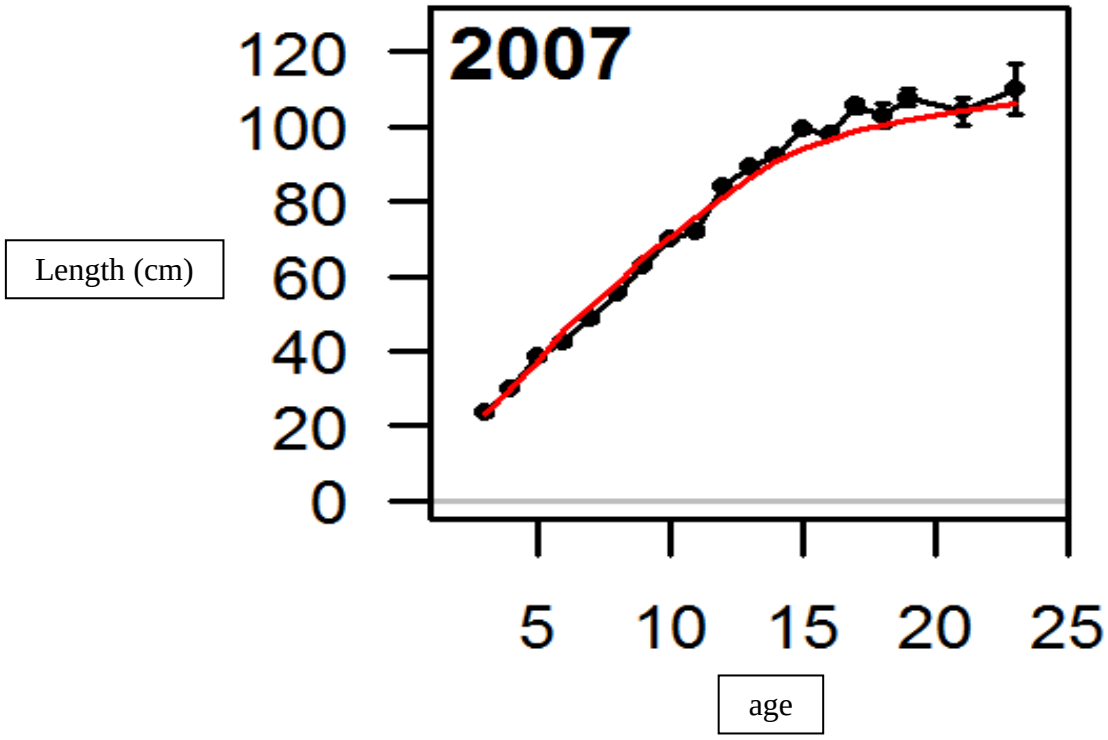



Figure 11. Observed (black circles) and model-predicted (red line) length-at-age from samples taken during the 2007 EBS shelf survey.

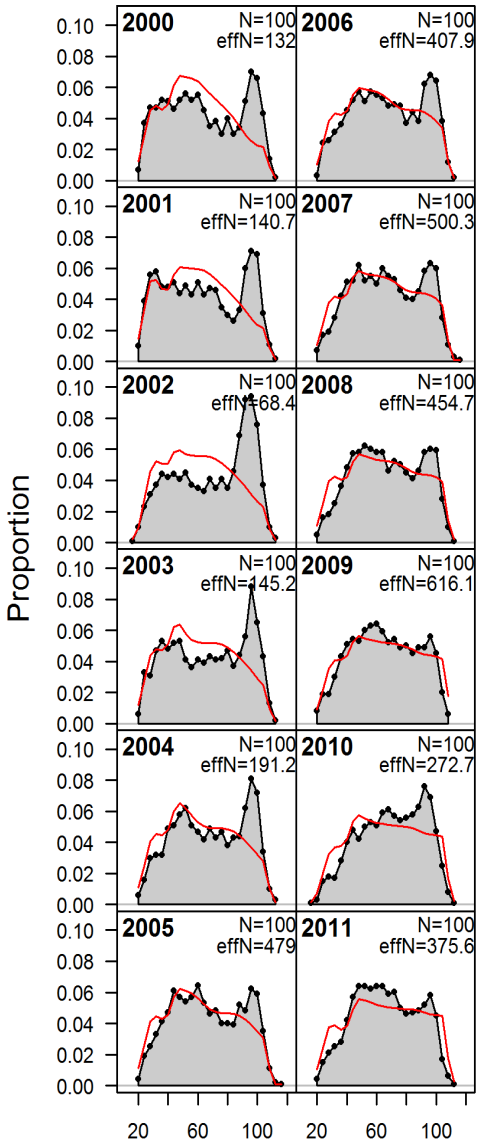



Figure 12. EBS shelf survey length compositions from 2000-2011. Grey shading = observed proportions; red line = model predictions. X-axis values are lengths in cm.

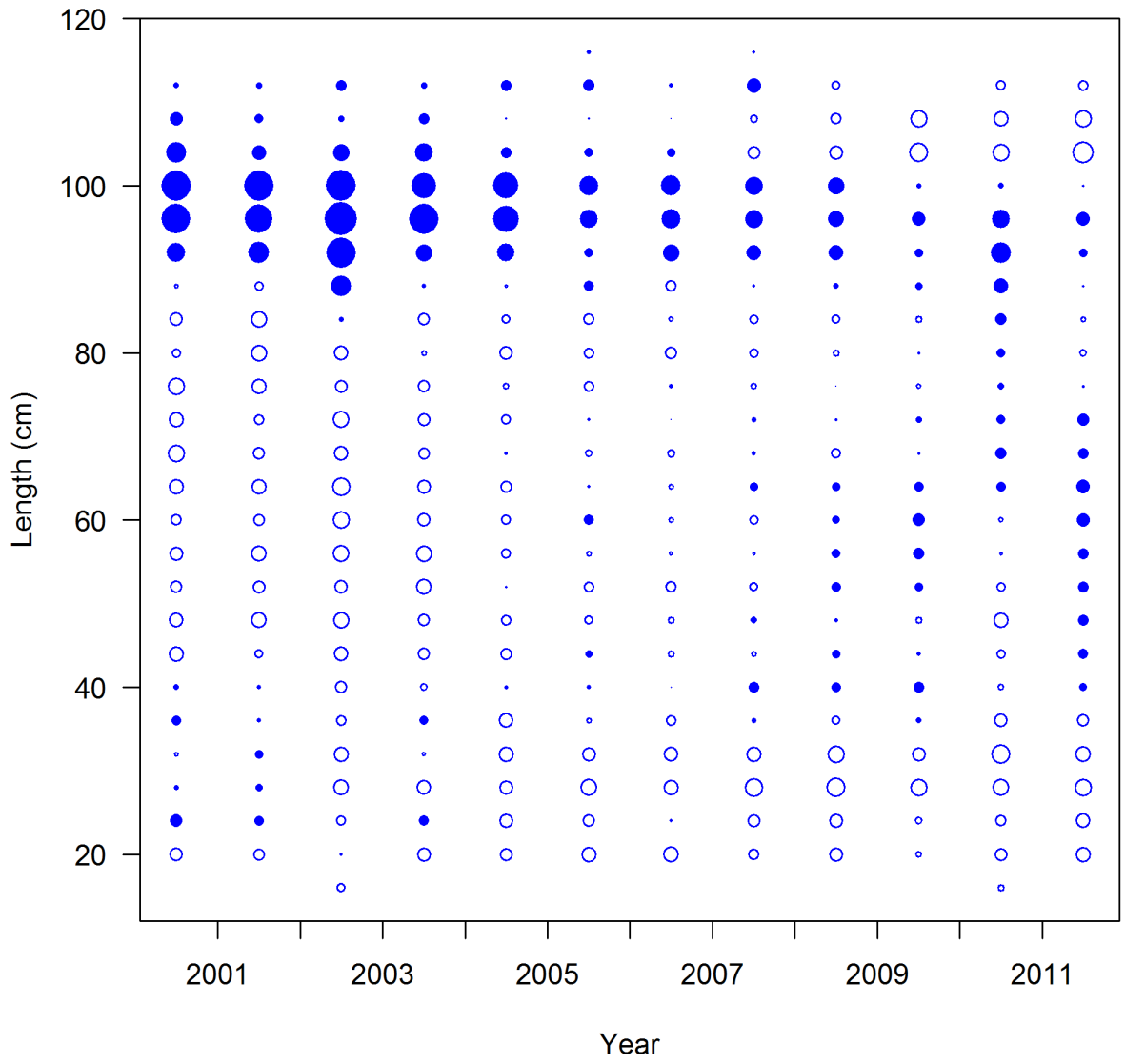



Figure 13. Pearson residuals for model fit to survey length composition data. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 3.62. Solid circles indicate positive residuals, open circles indicate negative residuals.

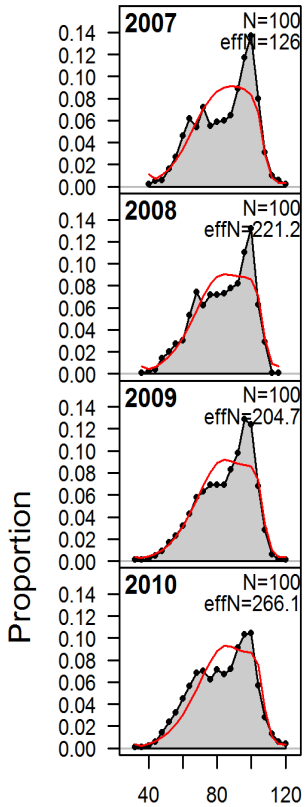



Figure 14. Observed and model-predicted length compositions from the 2007-2010 longline fisheries, with model predictions. Blue bars = observed values, orange line with circles = predicted values

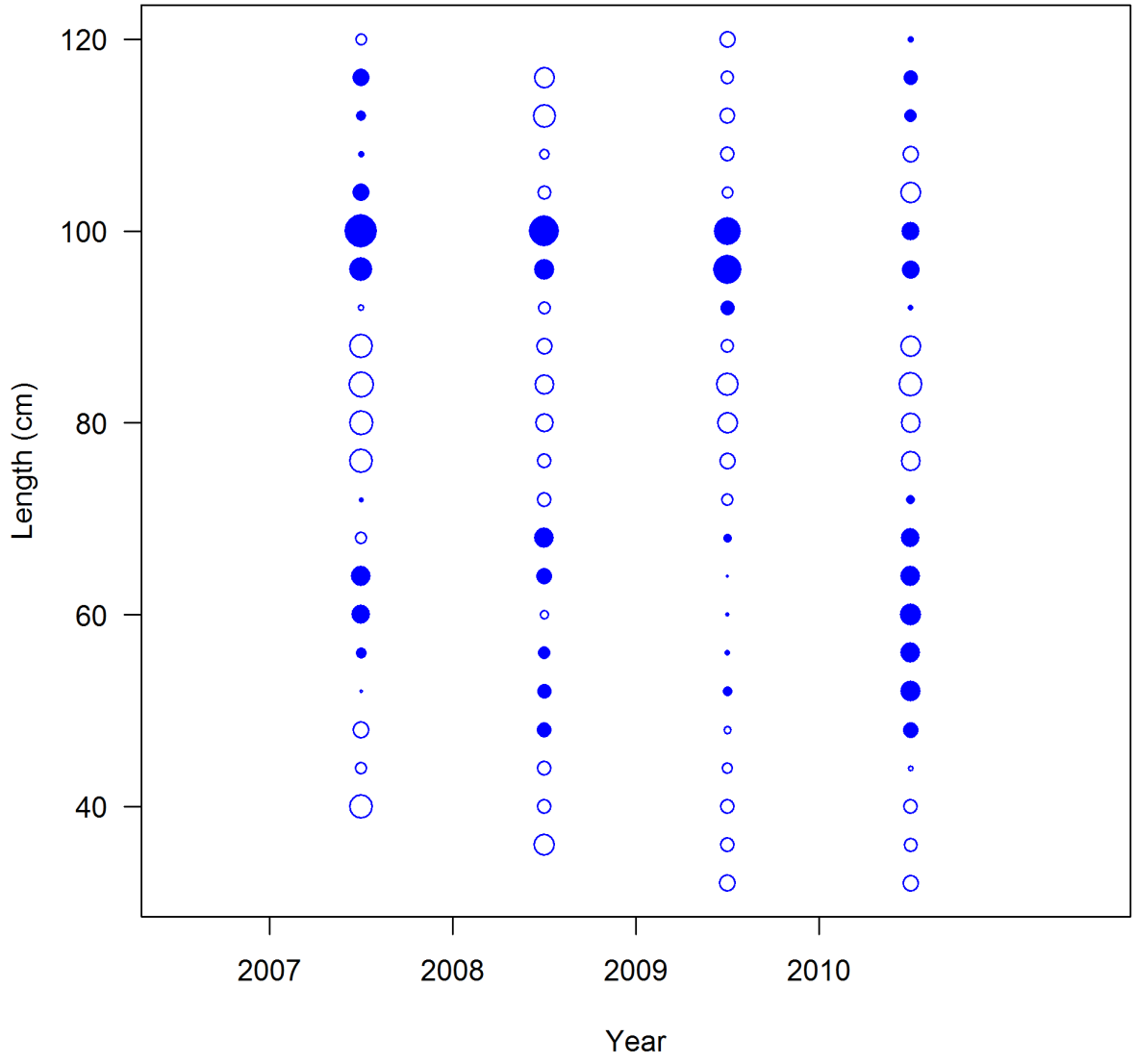



Figure 15. Pearson residuals for model fit to longline fishery length composition data. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 1.93. Solid circles indicate positive residuals, open circles indicate negative residuals.

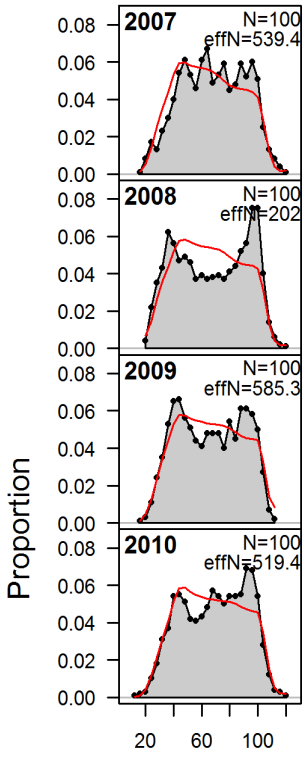



Figure 16. Observed and model-predicted length compositions from the 2007-2009 trawl fisheries, with model predictions. . Blue bars = observed values, orange line with circles = predicted values.

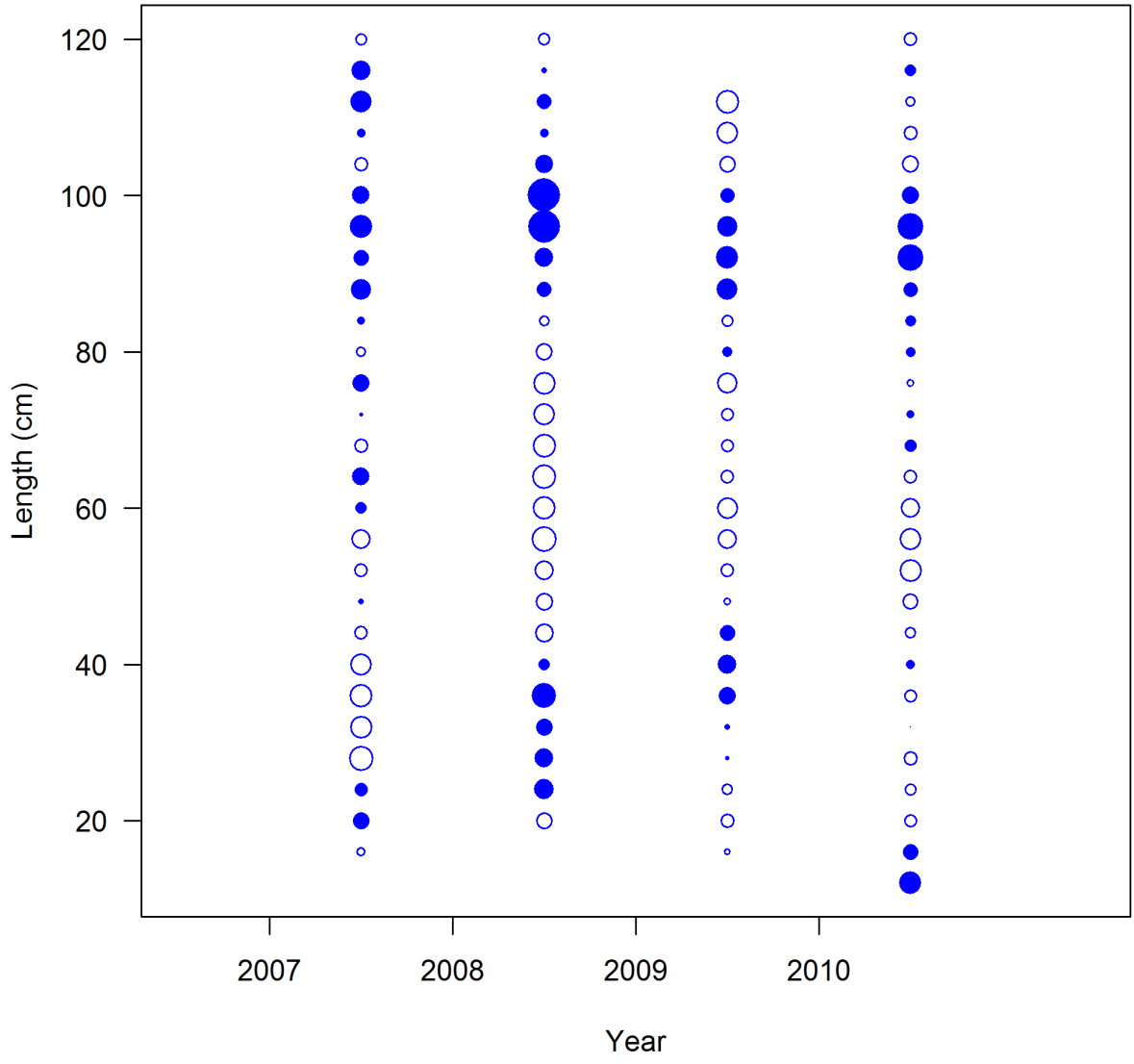



Figure 17. Pearson residuals for model fit to longline fishery length composition data. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 1.6. Solid circles indicate positive residuals, open circles indicate negative residuals.

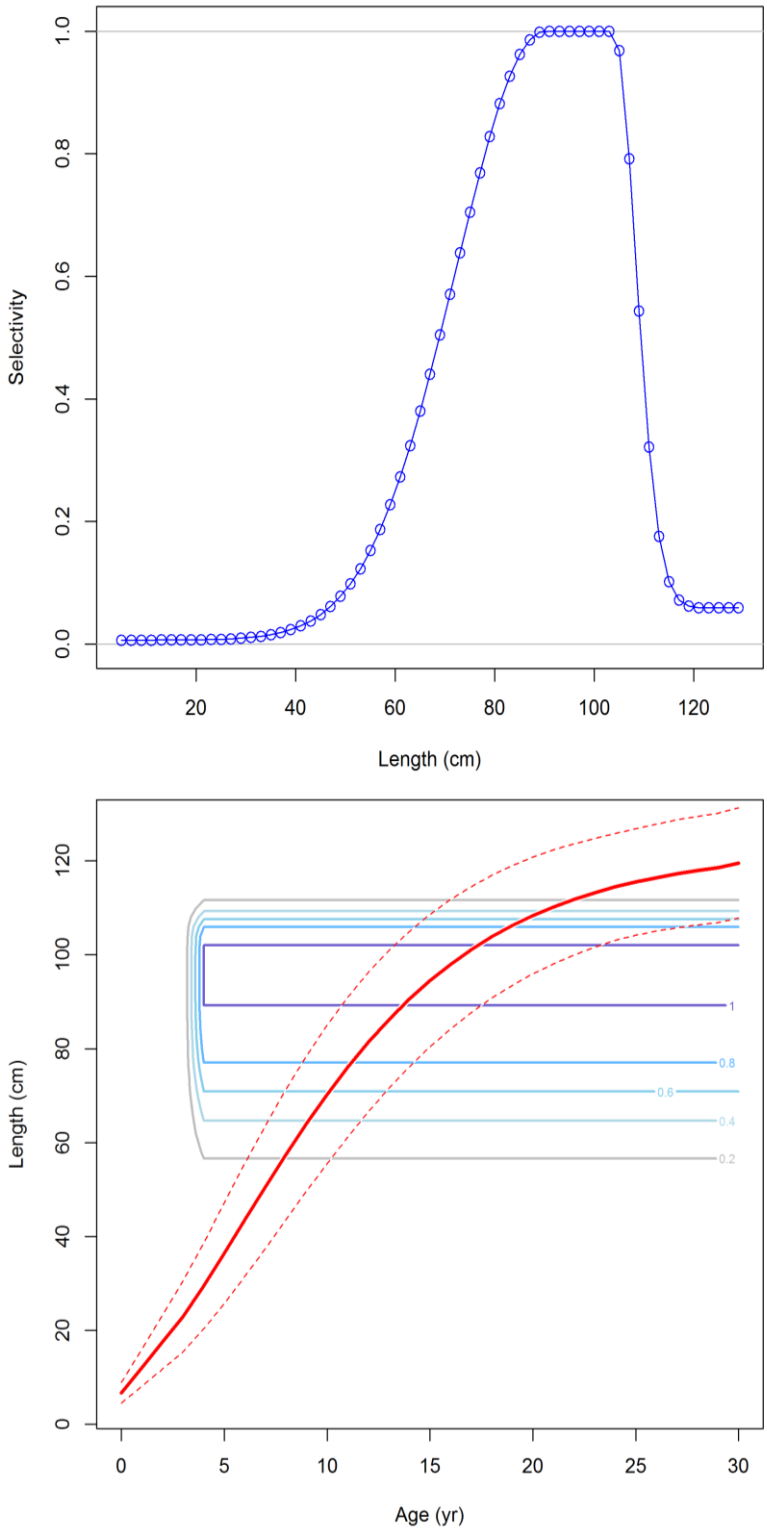



Figure 18. Length-based selectivity for the longline fishery. Upper plot shows selectivity at length; lower plot shows the selection surface imposed on the function for length at age.

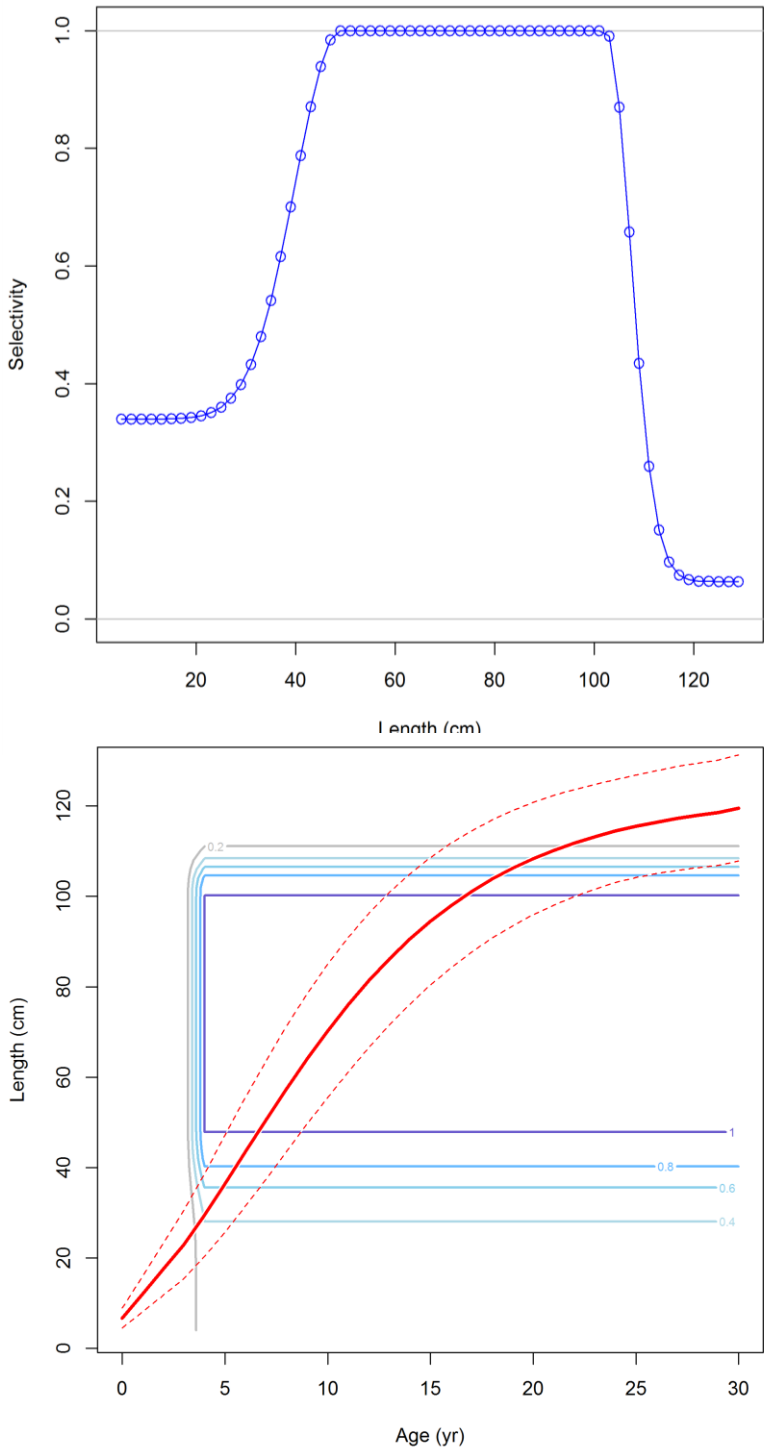



Figure 19. Length-based selectivity for the trawl fishery. Upper plot shows selectivity at length; lower plot shows the selection surface imposed on the function for length at age.

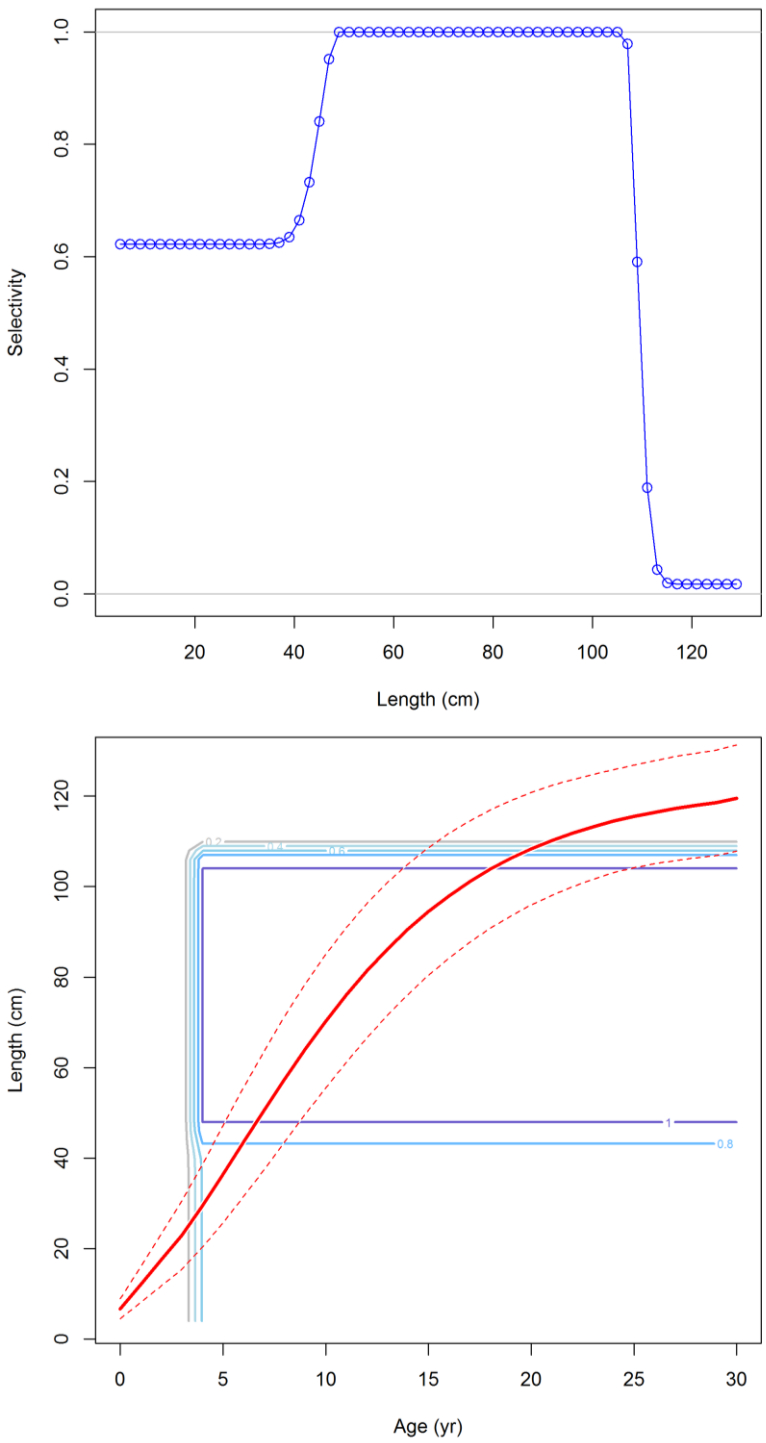



Figure 20. Length-based selectivity for the EBS bottom trawl survey. Upper plot shows selectivity at length; lower plot shows the selection surface imposed on the function for length at age.

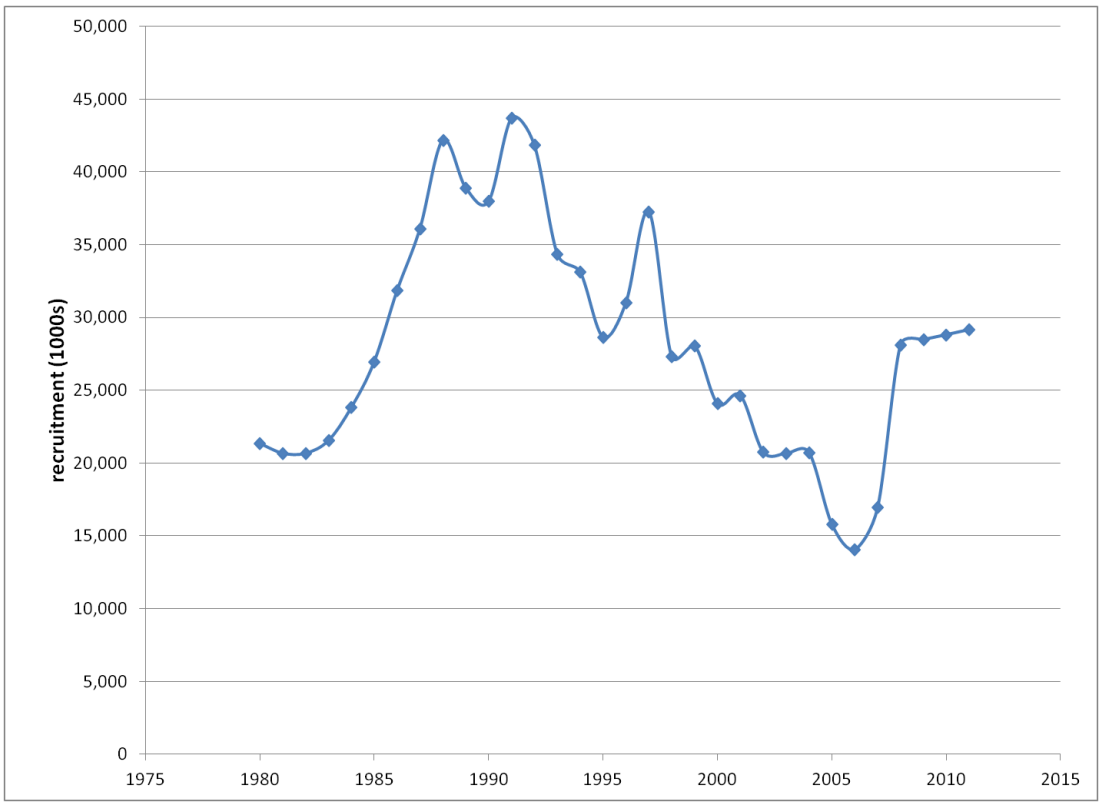



Figure 21. Time series of expected recruitment (in thousands of age 0 skates) estimated by the model.

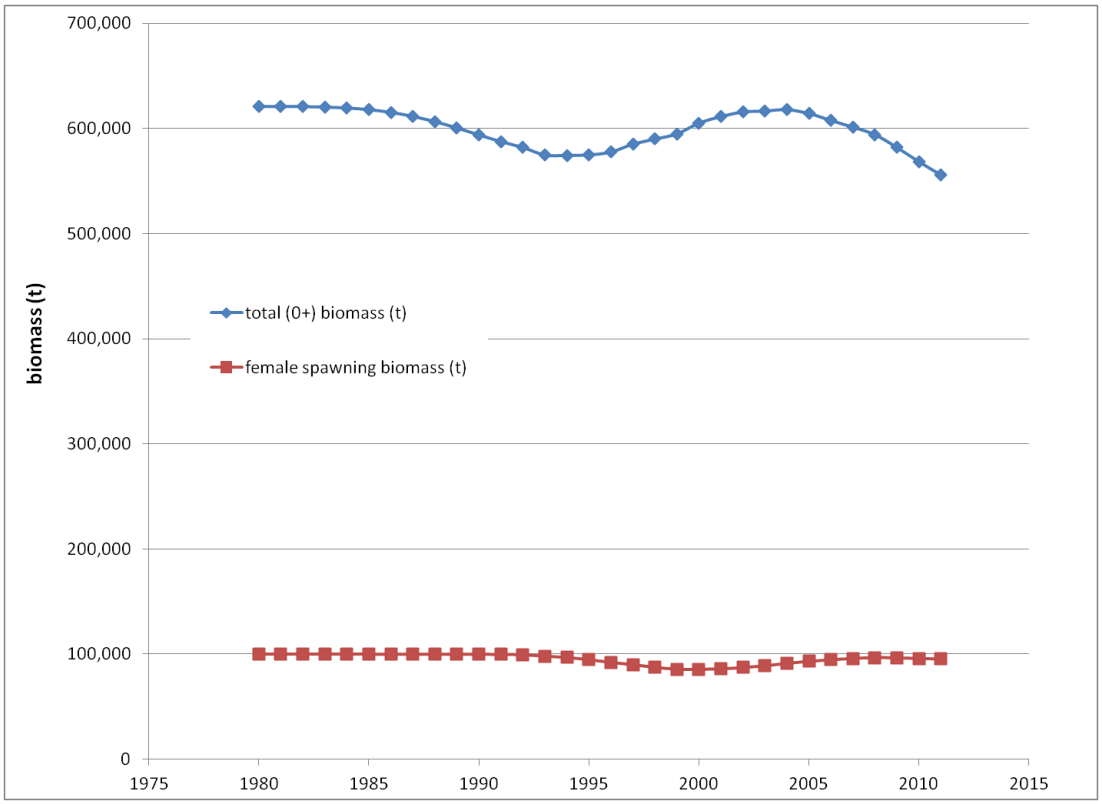



Figure 22. Time series of model estimates for total and female spawning biomass.