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An exploration of GOA Pacific cod stock assessment models for 2015

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Introduction

This document represents an effort to respond to comments made the GOA Plan Team, the joint BSAI and GOA Plan Teams, and the SSC on the 2014 assessment of the Pacific cod (*Gadus macrocephalus*) stock in the Gulf of Alaska (A'mar et al., 2014). In order to allow for exploration of a wide variety of modeling assumptions, this preliminary overview focuses on model development rather than application of the same model(s) to multiple data sets. Specifically, the Stock Synthesis model configurations presented here are applied to the data used in the 2014 GOA Pacific cod stock assessment, with fishery and survey data updated through the end of 2014.

Comments from the Plan Teams and SSC

Joint Plan Team Comments from the May 2015 Minutes

JPT: "***For the GOA, the subcommittee recommended that the following models be developed for this year's preliminary assessment:***

- *Model 0: Final model from 2014*
- *Model 2: Final model from 2011*

For the GOA, the subcommittee recommended that the following non-model analyses be conducted for this year's preliminary assessment:

- *Analysis 1: Examine the longline survey RPN and length frequency data for use within the model*

For the GOA, the discretionary model was as follows:

- *Final model from 2014, but with an exploration of initial conditions*

For the GOA, there were no discretionary non-model analyses."

Response: Model 0 for 2015 will be the 2014 final model (model S1a) and Model 2 for 2015 will be the 2011 final model (model 3). Model 3 will be Model 0 with an exploration of initial conditions.

Steve Barbeaux has examined the NMFS longline survey data for GOA Pacific cod and found some inconsistencies. Analyses of these data are ongoing.

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Steve Barbeaux has also examined the ADF&G nearshore trawl survey data for GOA Pacific cod and found that many of the stations in the survey were not surveyed every year, so other methods, including GLMs, may be used to make use of the data from the consistently sampled stations.

SSC Comments from the June 2015 Minutes

SSC: "*Dr. Grant Thompson (AFSC) presented a report about the first of three stages of stock assessment of Pacific cod in the three areas eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA). In this stage, a committee reviews models used in the previous year, examines proposals for new models and analyses, and recommends a suite of models and analyses to be used. Gerry Merrigan (Freezer Longline Coalition) gave public testimony.* ***The SSC agreed that this suite of models was appropriate and practicable and had no suggestions for additional models and analyses.***"

Response: The above requests will be addressed.

Summary of the base model configuration

The software used to run all models was Stock Synthesis v3.24S as compiled on 15 July 2014 with ADMB v.11.1. All models used a σ_R value of 0.41.

Model evaluation

Model configurations for 2015

The following descriptions detail attributes of the requested models.

Model 0: the 2014 final model (2014 Model S1a)

This model includes:

- Three gear types (trawl, longline, and pot), 5 seasons (Jan-Feb, Mar-Apr, May-Aug, Sept-Oct, and Nov-Dec), and three fishery selectivity "seasons" (Jan-Apr, May-Aug, and Sept-Dec);
- Time-varying fishery selectivity-at-length for all gears and seasons (3 – 7 blocks);
- The bottom trawl survey is treated as one data source, not two, i.e., not split into sub-27 and 27-plus surveys;
- Two blocks for catchability for the survey, 1984 – 1993 and 1996 – 2013, with the catchability for the latter period fixed at 1.0;
- Two blocks for selectivity-at-age for the survey, 1984 – 1993 and 1996 – 2013;
- Conditional age-at-length survey data;
- Non-parametric survey selectivity curves; and
- The use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean

Model 2: the 2011 final model (2011 Model 3) with tail compression turned off

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This model includes:

- Three gear types (trawl, longline, and pot), 5 seasons (Jan-Feb, Mar-Apr, May-Aug, Sept-Oct, and Nov-Dec), and three fishery selectivity "seasons" (Jan-Apr, May-Aug, and Sept-Dec);
- Time-varying fishery selectivity-at-length for all gears and seasons (3 – 7 blocks);
- The bottom trawl survey is split into a sub-27 and 27-plus survey;
- Two blocks for catchability for the 27-plus survey, 1984 – 1993 and 1996 – 2013, with the catchability for the latter period set to 1.04;
- Time-varying catchability for the sub-27 survey;
- Time-varying survey selectivity-at-age for the 27-plus survey (12 blocks);
- Constant survey selectivity-at-age for the sub-27 survey; and
- Median recruitment before 1977 restricted to be less than the post-1976 median recruitment, as the pre-1977 recruitment deviation is restricted to be less than 0.0

<u>Model 3</u>: Model 0 with adjustments for initial conditions

This model includes:

- First age well-represented in the data changed from 1.33333 to 2.33333; and
- 16 early recruits estimated instead of 13

Other adjustments evaluated included recruitment autocorrelation and the number of early recruits estimated ranged from 14 to 18.

<u>Model 4</u>: Model 0 with adjustments

This model includes:

- Three gear types (trawl, longline, and pot), 5 seasons (Jan-Feb, Mar-Apr, May-Aug, Sept-Oct, and Nov-Dec), and three fishery selectivity "seasons" (Jan-Apr, May-Aug, and Sept-Dec);
- Time-varying fishery selectivity-at-length for all gears and seasons (3 – 7 blocks);
- The bottom trawl survey is treated as one data source, not two;
- Two blocks for catchability for the survey, 1984 – 1993 and 1996 – 2013, with the catchability for the latter period fixed at 1.0;
- Three or four blocks for selectivity-at-age for the survey, 1984 – 1987, 1990 – 1993 and 1996 – 2013 or 1984 – 1987, 1990 – 1993, 1996 – 2005, and 2007 – 2013;
- The omission of age-1 data from the survey indices and age composition and conditional age-at-length data for 1990 – 2013;
- Conditional age-at-length survey data for 1987 – 2013;
- Non-parametric or double normal survey selectivity curves;
- 16 years of early recruits instead of the 13 in previous models; and
- The use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean

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For the model configurations using the SS "multiplier" on σ_R: different values of the multiplier were evaluated in 2014, ranging from 1.0 to 5.0. The value of 4.0 was used for all model configurations based on the tradeoff between uncertainty in the 2011 – 2014 estimates and the 2015 forecast for age-0 recruits.

Parameters Estimated Outside the Assessment Model

Natural Mortality

In the 1993 BSAI Pacific cod assessment (Thompson and Methot 1993), the natural mortality rate *M* was estimated using SS1 at a value of 0.37. All subsequent assessments of the BSAI and GOA Pacific cod stocks (except the 1995 GOA assessment) have used this value for *M*, until the 2007 assessments, at which time the BSAI assessment adopted a value of 0.34 and the GOA assessment adopted a value of 0.38. Both of these were accepted by the respective Plan Teams and the SSC. In response to a request from the SSC, the 2008 BSAI assessment included further discussion and justification for these values.

For historical comparison, other published estimates of *M* for Pacific cod are shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

All of the models in this assessment set *M* independently at the SSC-approved value of 0.38.

Catchability

In the 2009 assessment (Thompson et al. 2009), catchability for the post-1993 27-plus trawl survey was estimated iteratively by matching the average (weighted by numbers at length) of the product of catchability and selectivity for the 60-81 cm size range equal to the point estimate of 0.92 obtained by Nichol et al. (2007). The resulting value of 1.04 was retained for several of the models in the present assessment; others set catchability equal to 1.00, per Plan Team request.

Variability in Estimated Age (ageing error)

Variability in estimated age in SS is based on the standard deviation of estimated age. Weighted least squares regression has been used in the past several assessments to estimate a linear relationship between standard deviation and age. The regression was recomputed in 2011, yielding an estimated intercept of 0.023 and an estimated slope of 0.072 (i.e, the standard deviation of estimated age was modeled as 0.023 + 0.072 × age), which gives a weighted R^2 of 0.88. This regression was used for all models in the present assessment.

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Variability in Length at Age

The last few assessments have used a regression approach to estimate the parameters of the schedule of variability in length at age, based on the outside-the-model estimates of standard deviation of length at age and mean length at age from the survey age data (Thompson et al. 2009). The best fit was obtained by assuming that the standard deviation is a linear function of length at age. The regression was re-estimated in 2011 after updating with the most recent data, giving an intercept of 2.248 and a slope of 0.044. This regression was used for all models in the present assessment.

Use of this regression requires an iterative, "quasi-conditional" procedure for specifying the standard deviations of length at ages 0 and 20, because the regression is a function of length at age, and length at age is estimated conditionally (i.e., inside the model).

In the 2011 model, the age corresponding to the *L1* parameter in the length-at-age equation was increased from 0 to 1.3333 (to correspond to the age of a 1-year-old fish at the time of the survey, when the age data are collected). This made it necessary to re-do the iterative tuning process for this model.

Weight at Length

Season-specific parameters governing the weight-at-length schedule were estimated in the 2010 assessment (based on data through 2008), giving the following values:

Season:	Jan-Feb	Mar-Apr	May-Aug	Sep-Oct	Nov-Dec
α:	8.799×10^{-6}	8.013×10^{-6}	1.147×10^{-5}	1.791×10^{-5}	7.196×10^{-6}
β:	3.084	3.088	2.990	2.893	3.120
Samples:	36,566	29,753	6,950	9,352	2,957

The above parameters were retained for all models in the present assessment.

Maturity

A detailed history and evaluation of parameter values used to describe the maturity schedule for BSAI Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). A length-based maturity schedule was used for many years. The parameter values used for this schedule in the 2005 and 2006 assessments were set on the basis of a study by Stark (2007) at the following values: length at 50% maturity = 50 cm and slope of linearized logistic equation = –0.222. However, in 2007, changes in SS allowed for use of either a length-based or an age-based maturity schedule. Beginning with the 2007 assessment, the accepted model has used an age-based schedule with intercept = 4.3 years and slope = –1.963 (Stark 2007). The use of an age-based rather than a length-based schedule follows a recommendation from the maturity study's author (James Stark, Alaska Fisheries Science Center, personal communication). The age-based parameters were retained for all models in the present assessment.

Parameters Estimated Inside the Assessment Model

Parameters estimated conditionally (i.e., within individual SS runs, based on the data and the parameters estimated independently) in all models include the von Bertalanffy growth parameters, two ageing bias parameters, log mean recruitment before and since the 1976-1977 regime shift,

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annual recruitment deviations, initial fishing mortality, gear-season-and-block-specific fishery selectivity parameters, survey selectivity parameters, and pre-1996 catchability for the 27-plus survey. In addition, the 2011 models estimate annual deviations for catchability in the sub-27 survey. The same functional form (pattern 24 for length-based selectivity, pattern 20 for age-based selectivity) used to define the selectivity schedules in last year's assessments was used again this year. This functional form is constructed from two underlying and rescaled normal distributions, with a horizontal line segment joining the two peaks. This form uses the following six parameters (selectivity parameters are referenced by these numbers in several of the tables in this assessment):

1. Beginning of peak region (where the curve first reaches a value of 1.0)
2. Width of peak region (where the curve first departs from a value of 1.0)
3. Ascending "width" (equal to twice the variance of the underlying normal distribution)
4. Descending width
5. Initial selectivity (at minimum length/age)
6. Final selectivity (at maximum length/age)

All but the "beginning of peak region" parameter are transformed: The widths are log-transformed and the other parameters are logit-transformed.

Fishery selectivity curves are length-based and trawl survey selectivity curves are age-based in all models considered in this assessment.

Uniform prior distributions are used for all parameters, except that *dev* vectors are constrained by input standard deviations ("sigma"), which imply a type of joint prior distribution. These input standard deviations were determined iteratively in the 2009 assessment (Thompson et al. 2009) by matching the standard deviations of the estimated *dev*s. The same input standard deviation value of 0.41 was used in all models in the present assessment.

For all parameters estimated within individual SS runs, the estimator used is the mode of the logarithm of the joint posterior distribution, which is in turn calculated as the sum of the logarithms of the parameter-specific prior distributions and the logarithm of the likelihood function.

In addition to the above, the full set of year-, season-, and gear-specific fishing mortality rates are also estimated conditionally, but not in the same sense as the above parameters. The fishing mortality rates are determined exactly rather than estimated statistically because SS assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data.

Likelihood Components

All models included likelihood components for trawl survey relative abundance, fishery and survey size composition, survey age composition, survey mean size-at-age, recruitment, parameter deviations, and "soft bounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and initial (equilibrium) catch.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process.

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Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear, and season within the year. In the parameter estimation process, SS weights a given size composition observation (i.e., the size frequency distribution observed in a given year, gear, and season) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which SS was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. For many years, the Pacific cod assessments assumed a multinomial sample size equal to the square root of the true length sample size, rather than the true length sample size itself. Given the true length sample sizes observed in the GOA Pacific cod data, this procedure tended to give values somewhat below 400 while still providing SS with usable information regarding the appropriate effort to devote to fitting individual length samples.

Although the "square root rule" for specifying multinomial sample sizes gave reasonable values, the rule itself was largely *ad hoc*. In an attempt to move toward a more statistically based specification, the 2007 BSAI assessment (Thompson et al. 2007a) used the harmonic means from a bootstrap analysis of the available fishery length data from 1990-2006. The harmonic means were smaller than the actual sample sizes, but still ranged well into the thousands. A multinomial sample size in the thousands would likely overemphasize the size composition data. As a compromise, the harmonic means were rescaled proportionally in the 2007 BSAI assessment so that the average value (across all samples) was 300. However, the question then remained of what to do about years not covered by the bootstrap analysis (2007 and pre-1990) and what to do about the survey samples. The solution adopted in the 2007 BSAI assessment was based on the consistency of the ratios between the harmonic means (the raw harmonic means, not the rescaled harmonic means) and the actual sample sizes. For the years prior to 1999, the ratio was very consistently close to 0.16, and for the years after 1998, the ratio was very consistently close to 0.34.

This consistency was used to specify input sample sizes for size composition data in all GOA assessments since 2007 as follows: For fishery data, the sample sizes for length compositions from years prior to 1999 were tentatively set at 16% of the actual sample size, and the sample sizes for length compositions from 2007 were tentatively set at 34% of the actual sample size. For the trawl survey, sample sizes were tentatively set at 34% of the actual sample size. Then, all sample sizes were adjusted proportionally so that the average was 300. This method was used to adjust the samples sizes used for the size composition data for analyses performed through 2013.

For the models in this analysis, the number of hauls or trips was used as the sample size instead of the adjusted sample size. The sample sizes for the survey length composition data are the number of hauls in that survey year with cod present.

The fishery catch-at-length data did not have distinct haul or trip identifiers for all samples, so the adjusted sample size for each year, gear type, and season was the total number of samples multiplied by a scaling factor for each gear type and season. The scaling factor was calculated using the federal fishery observer catch-at-length data for 1987 – 2014. The scaling factor is the ratio of total

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number of hauls or trips to the total number of samples for each gear type and season. The average of the new sample sizes for the fishery catch-at-length data is 183.

Use of Age Composition Data in Parameter Estimation

Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular gear, year, and season within the year. Input sample sizes for the multinomial distributions were computed by scaling the actual number of otoliths read in each year proportionally such that the average of the input sample sizes was equal to 300. This scaling differs for models which do and do not include the sub-27 age comp data, as the sample sizes of all of the survey age comp data in each model were used in the averaging. This method was used to adjust the samples sizes used for the age composition data for analyses performed through 2013.

For the models in this analysis, the number of hauls was used as the sample size instead of the adjusted sample size. For the model configurations with survey age data used as conditional age-at-length data, the sample sizes for a given year sum to the number of hauls in that year.

To avoid double counting of the same data, all models ignore size composition data from each year in which survey age composition data are available for 1990 on.

Use of Fishery CPUE and Survey Relative Abundance Data in Parameter Estimation

Fishery CPUE data are included in the models for comparative purposes only. Their respective catchability values are estimated analytically, not statistically.

For the trawl surveys, each year's survey abundance datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey abundance in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey abundance datum's standard error to the survey abundance datum itself serves as the distribution's coefficient of variation, which is then transformed into the "sigma" parameter for the lognormal distribution.

Use of Recruitment Deviation "Data" in Parameter Estimation

The recruitment deviations likelihood component is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment deviation plays the role of the datum with mean zero and specified (or estimated) standard deviation; but, of course, the *dev*s are parameters, not data.

RESULTS

All model configurations were requested or suggested by the Plan Team. Model 3 and the 4 versions of Model 4 were the result of explorations with Model 0 to address the issues with age-1 data from the NMFS bottom trawl survey. The 4 versions of Model 4 omit all age-1 data in the survey abundance indices and age data for 1990 on.

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Model evaluation

Model 0 is the 2014 final model, Model 2 is the 2011 final model, and Model 3 is Model 0 with adjustments. There are 4 versions of Model 4, two configurations with 3 periods of non-parametric or double normal survey selectivity, and two configurations with 4 periods of non-parametric or double normal survey selectivity, labeled "Model 4 – non&3p", "Model 4 – dn&3p", "Model 4 – non&4p", and "Model 4 – dn&4p", respectively.

The model configurations were evaluated, differentiated by the data used in model fitting. The model evaluation criteria included the relative sizes of the likelihood components, and how well the model estimates fit to the total, 27-plus and sub-27, or no age-1 survey abundance indices and the survey age composition data; reasonable curves for fishery sand survey selectivity; and that the model estimated the variance-covariance matrix.

Comparing and Contrasting the Models

The number of parameters and likelihood components for each model configuration are in Table 1, and the growth parameters are in Table 2.

Table 1 – Negative log likelihood (NLL) components

	Model 0	Model 2	Model 3	Model 4 – non&3p	Model 4 – non&4p	Model 4 – dn&3p	Model 4 – dn&4p
Total NLL	2609.42	2841.10	2657.50	2566.73	2534.78	2591.00	2561.57
Parameters	229	260	232	230	240	210	215
Survey	-4.86	0.45	-5.85	-3.77	-8.27	-2.66	-6.37
Fsh len comp	2139.37	2197.71	2157.60	2172.10	2164.75	2170.75	2166.75
Srv len comp	10.32	41.02	13.85	7.30	7.27	11.00	8.86
Srv age comp	471.94	73.65	491.46	403.211	384.45	425.18	406.33
Srv size-at-age	–	540.89	–	–	–	–	–
Recr	-10.74	-12.69	-13.40	-14.79	-15.51	-15.51	-16.16

Table 2 – Growth parameter estimates

	Model 0	Model 2	Model 3	Model 4 - non 3p	Model 4 - non 4p	Model 4 - dn 3p	Model 4 - dn 4p
Amin	1	1	2	2	2	2	2
L at Amin	26.47	20.48	38.70	30.57	30.60	30.57	30.62
L_∞	93.75	97.11	94.31	94.16	94.60	94.32	94.39
k	0.188	0.197	0.183	0.193	0.189	0.194	0.192
CV for L at Amin	3.39	3.13	4.42	3.88	3.86	3.90	3.87
CV for L at A_∞	7.38	6.55	7.16	7.17	7.09	7.13	7.11

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Evaluation Criteria

The estimates of spawning biomass have a similar pattern across all model configurations, with a peak in the early 1980s and decreasing since then (Figs. 1 and 2); spawning biomass for the recent period is flat except for the models with 3 periods of survey selectivity, Model 4 – non&3p and Model 4 – dn&3p, which have a slight increase over the recent period. Spawning biomass estimates for Model 2 are significantly lower than those for all other model configurations.

The estimates of age-0 recruits have a similar pattern across all model configurations, with the highest value in 1977 (Figs. 3 and 4). Models 0, 2, and 3 have a peak in recent recruitment in 2012 and the 4 Model 4 configurations have a peak in 2011. Models 0 and 3 estimate the 1977 age-0 recruits to be about twice as large as the estimates from Model 0 and the 4 Model 4 configurations.

The patterns in the estimates of survey abundance vary across the model configurations, although all of the model configurations fit the 2009, 2011, and 2013 index values poorly. The estimates from Models 0 and 3 are very similar for all years, with Model 3 having a slightly better fit for the recent period (Fig 5). Model 2 has poor fits to the 27-plus survey abundance in most years (Fig. 6), while it has nearly exact fits to the sub-27 survey abundance in most years, due to estimating catchability for each survey year except the most recent year (Fig 7). The fits to the survey abundance for the 4 versions of Model 4 vary, with the model configurations with 4 periods of survey selectivity fitting better than the models with 3 periods (Fig. 8).

The estimates of survey selectivity vary considerably across the model configurations. Model 0 and Model 3 have virtually identical survey selectivity curves (Figs. 9 and 12, respectively); while Model 2 has a different selectivity curve for each survey year for the 27-plus survey (Fig. 10), and a constant selectivity curve for the sub-27 survey (Fig. 11). The 4 versions of Model 4 estimate similar curves for the early period, 1984 & 1987 (Figs. 13, 14, 15, and 16), with selectivity for age 7 and older around 0.1, as there are no survey age data for fish older than 6 for these years. All versions of Model 4 set selectivity to 0 for ages 0 and 1 for 1990 on. There are somewhat different curves for the two sets of models with non-parametric and double normal selectivity patterns for the 1990 & 1993 period. The survey selectivity curve for Model 4 – non&3p for 1996 – 2013 appears to cover the survey selectivity curves for Model 4 – non&4p for 1996 – 2005 and 2007 – 2013 (Figs. 13 and 14). Similarly, the survey selectivity curve for Model 4 – dn&3p for 1996 – 2013 appears to cover the survey selectivity curves for Model 4 – dn&4p for 1996 – 2005 and 2007 – 2013 (Figs. 15 and 16).

Summary

None of the model explorations were successful in addressing the high estimate of age-0 recruits for 1977, although the 4 versions of Model 4 had estimates lower than those for Models 0 and 3 and similar to the estimate from Model 2.

The performance of the 4 Model 4 configurations seems to be an improvement on previous model configurations, with the limitation that all age-1 data are omitted from the survey abundance indices and age data for 1990 on.

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Figures

Figure 1 – Estimates of spawning biomass for Models 0, 2, 3, and the 4 versions of Model 4

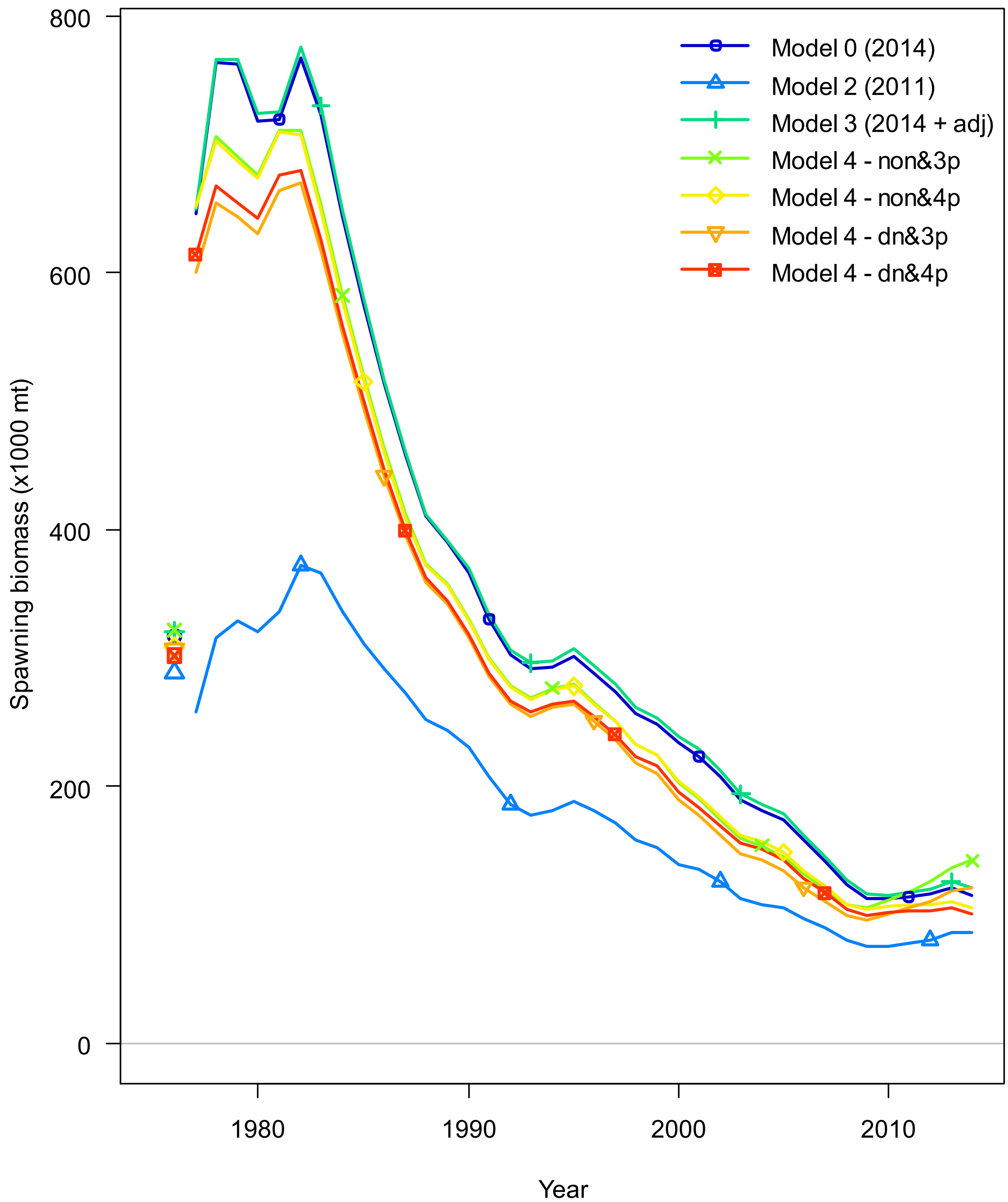

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Figure 2 – Estimates of spawning biomass with uncertainty intervals for Models 0, 2, 3, and the 4 versions of Model 4

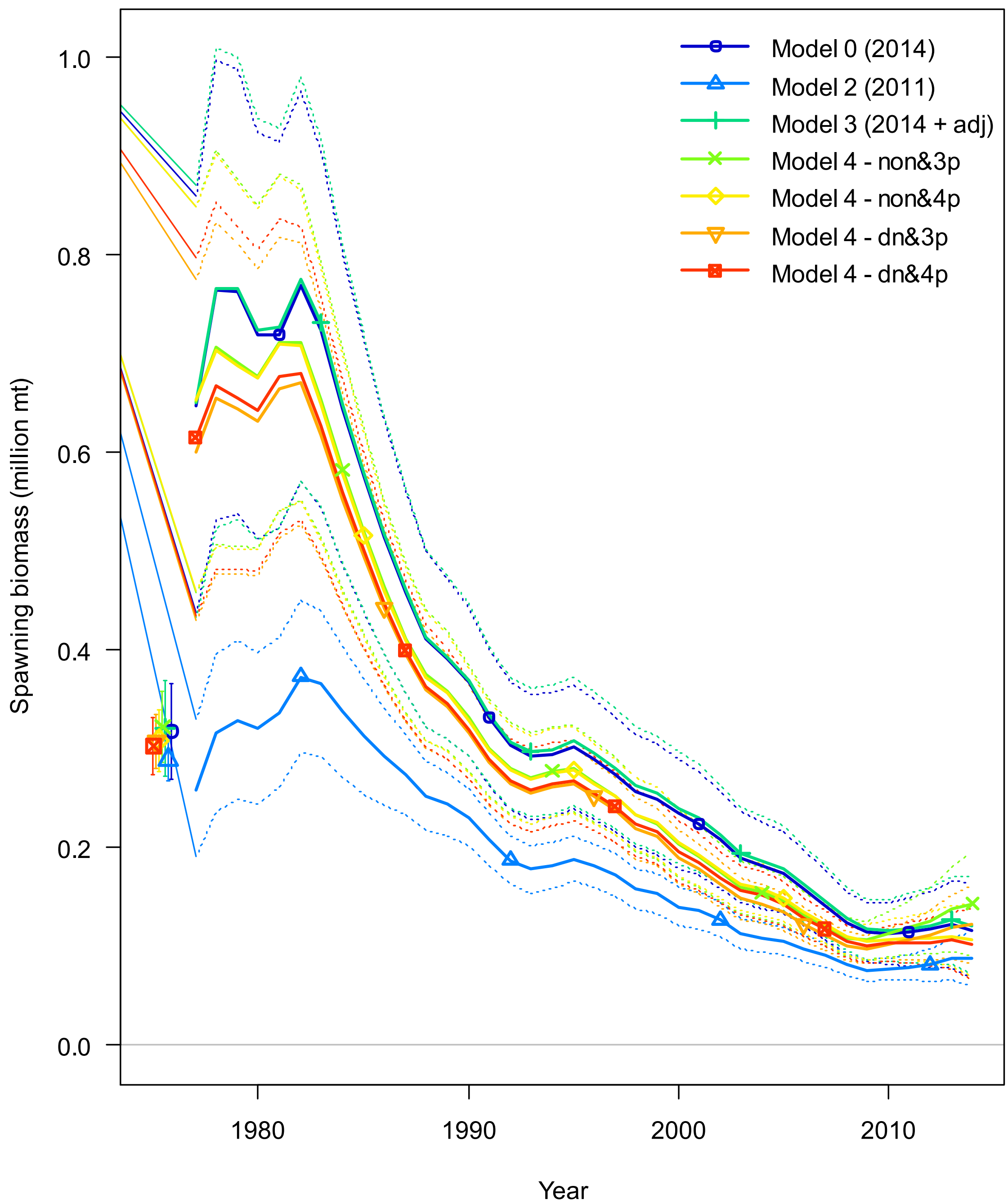

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Figure 3 – Estimates of age-0 recruits for Models 0, 2, 3, and the 4 versions of Model 4

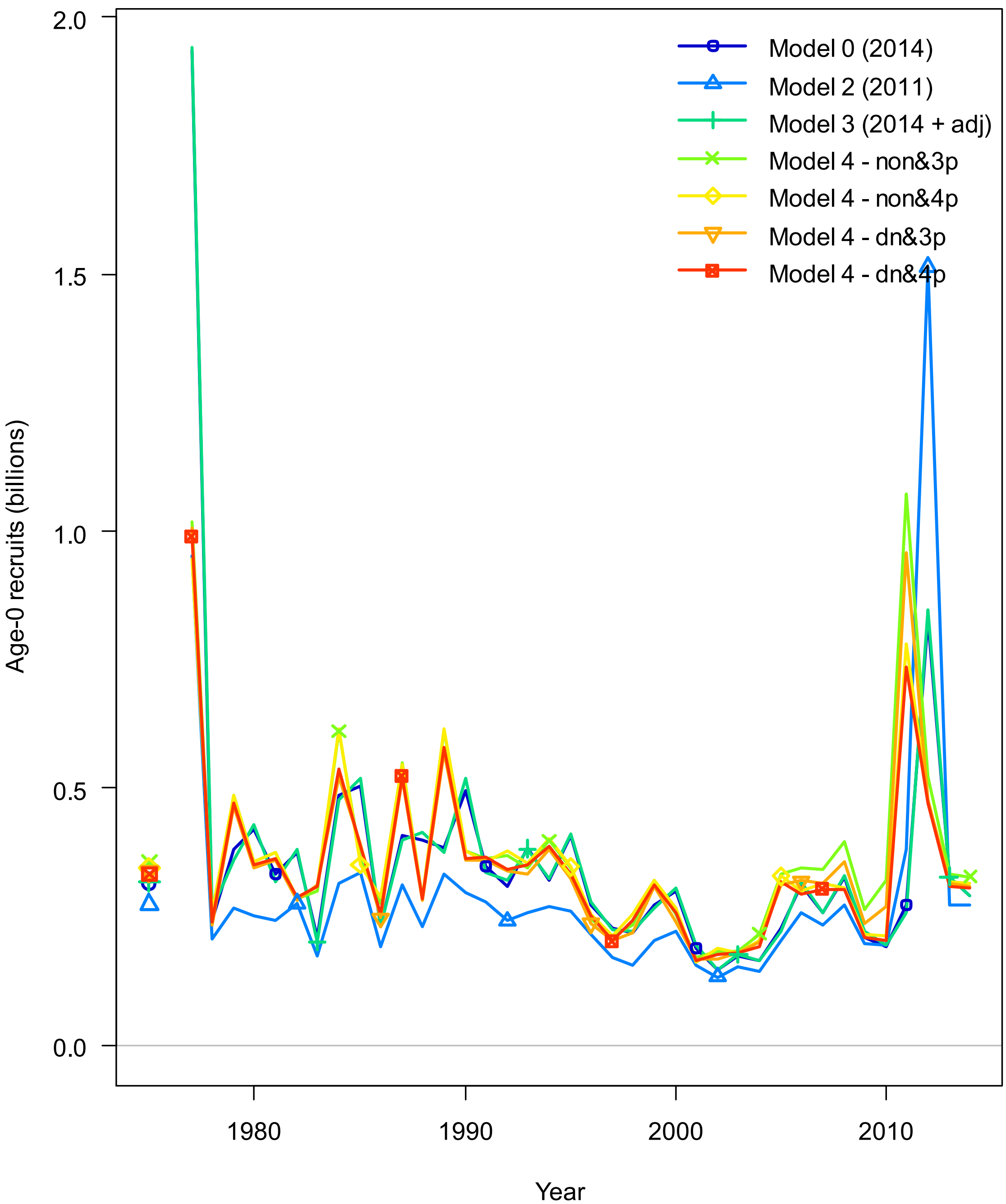

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Figure 4 – Estimates of age-0 recruits with uncertainty intervals for Models 0, 2, 3, and the 4 versions of Model 4

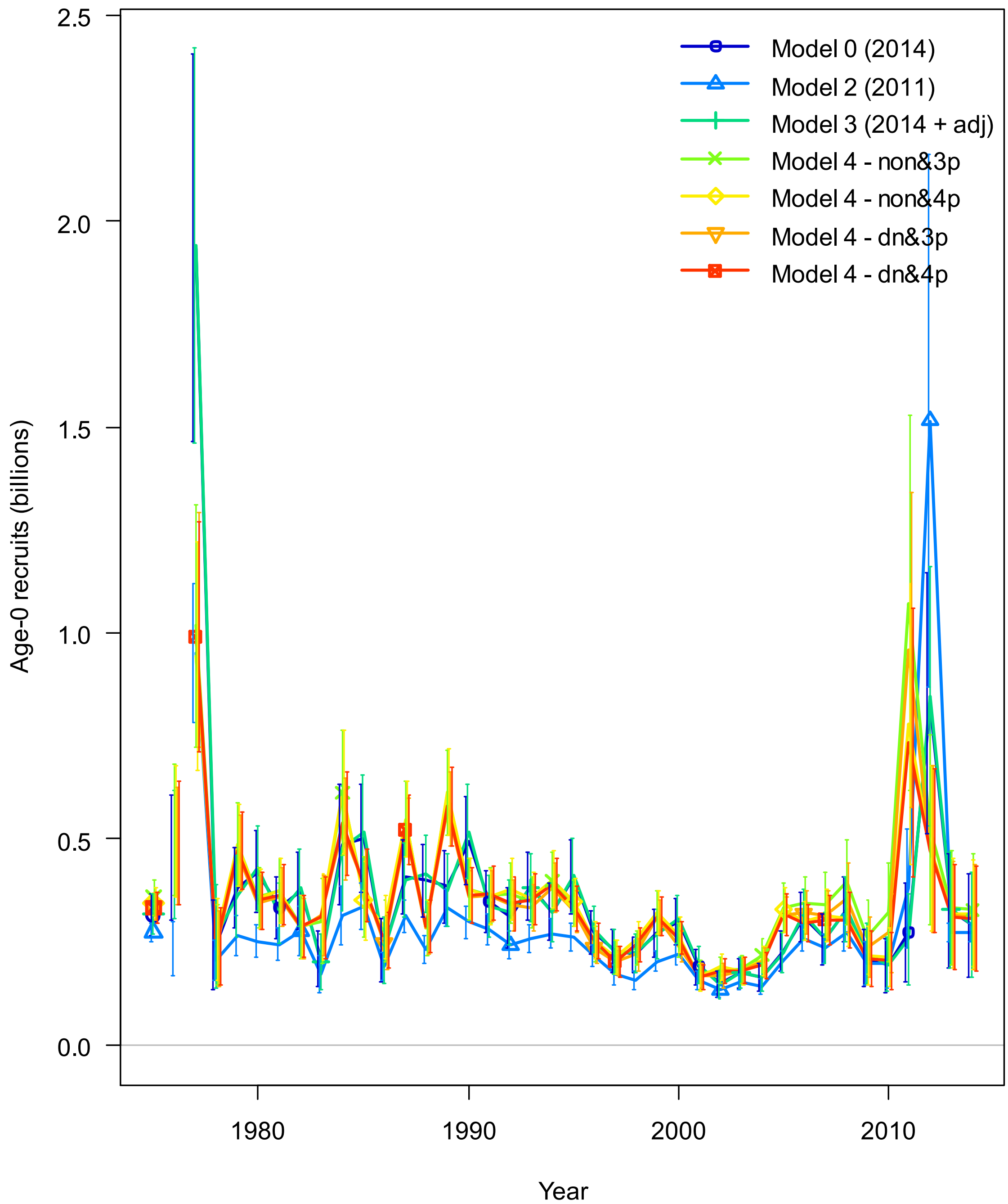

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Figure 5 – Estimates of log survey abundance for Models 0 and 3

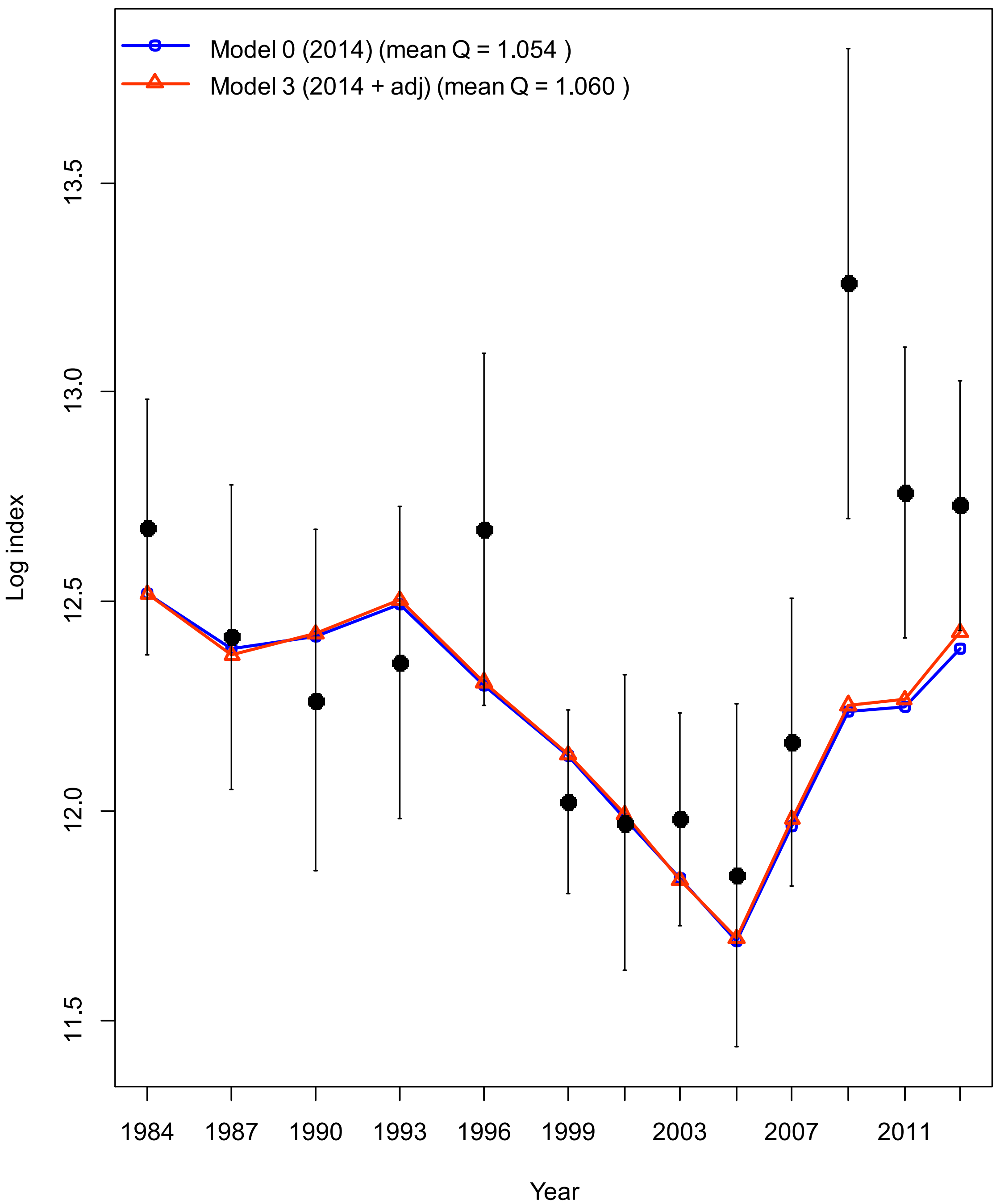

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Figure 6 – Estimates of log survey abundance for the 27-plus survey for Model 2

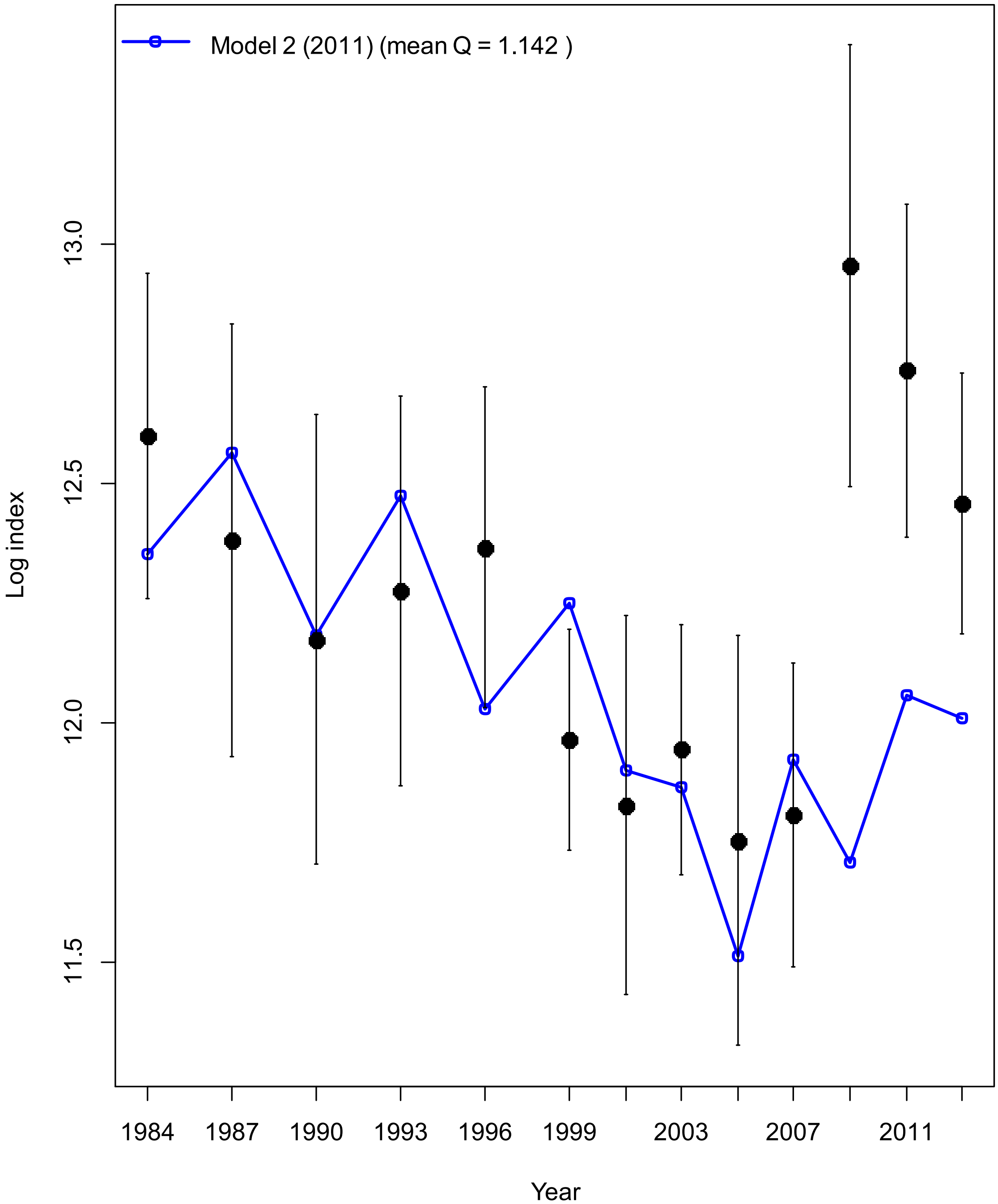

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Figure 7 – Estimates of log survey abundance for the sub-27 survey for Model 2

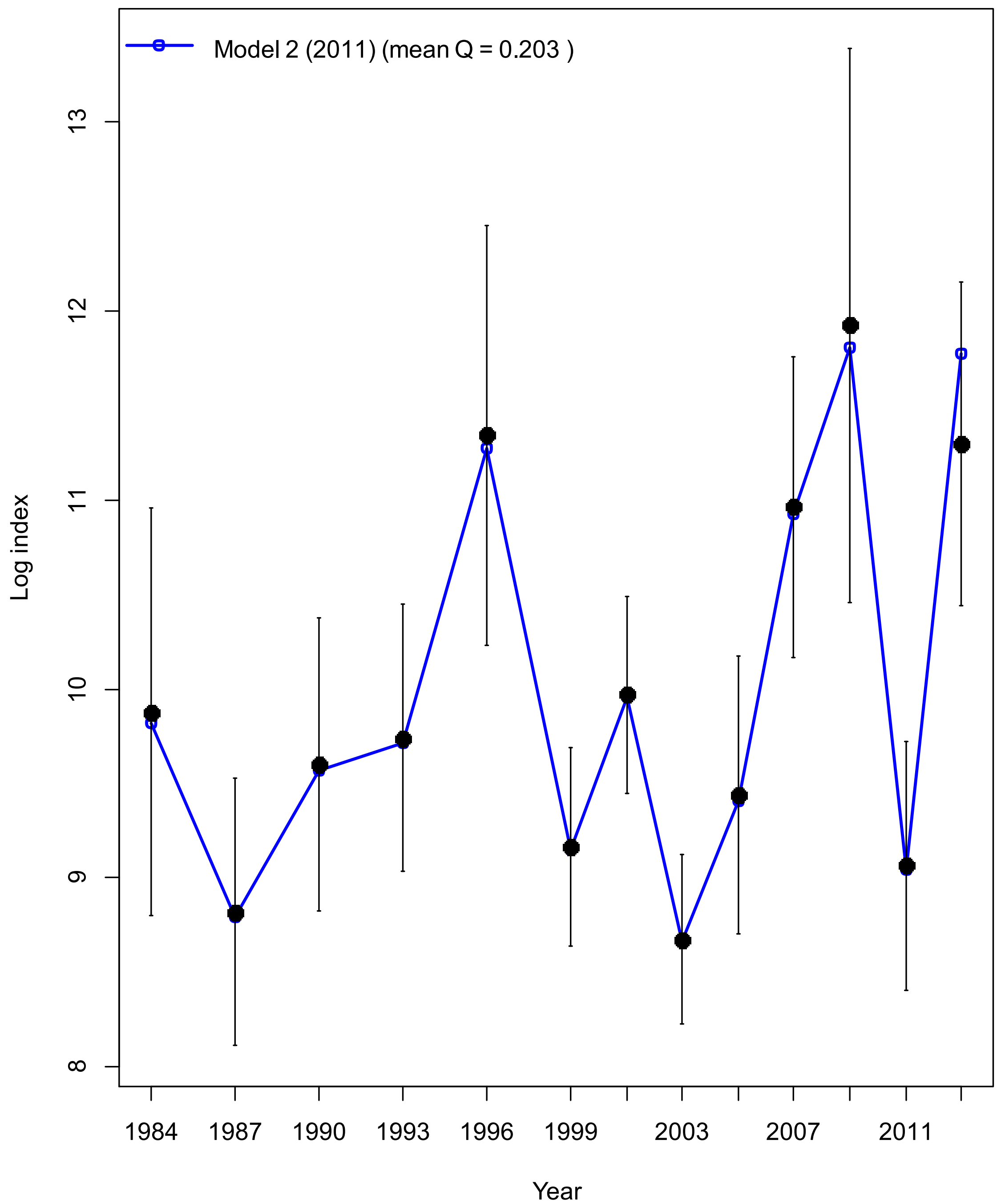

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Figure 8 – Estimates of log survey abundance for the 4 versions of Model 4

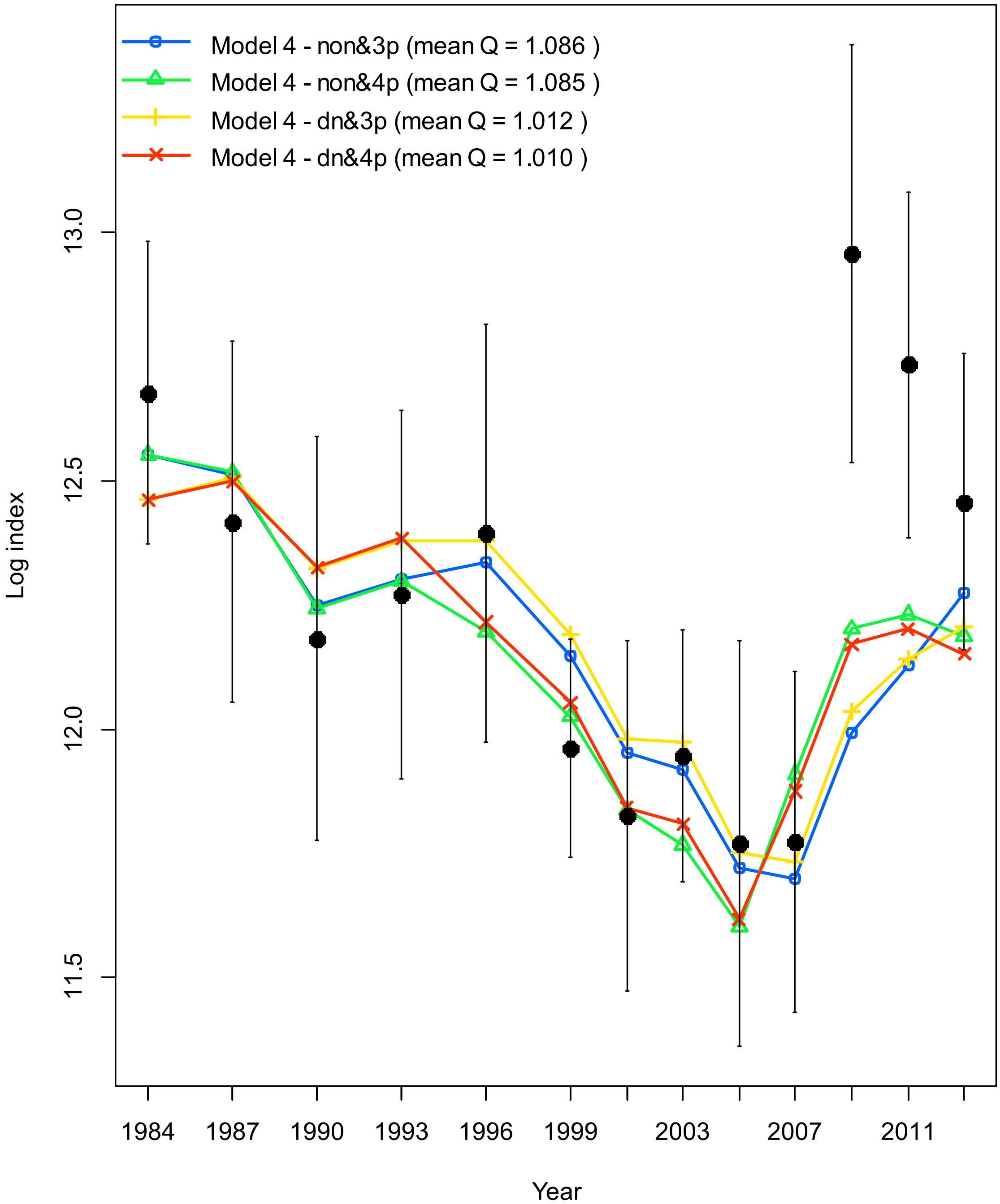

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Figure 9 – Survey selectivity-at-age for the trawl survey for Model 0

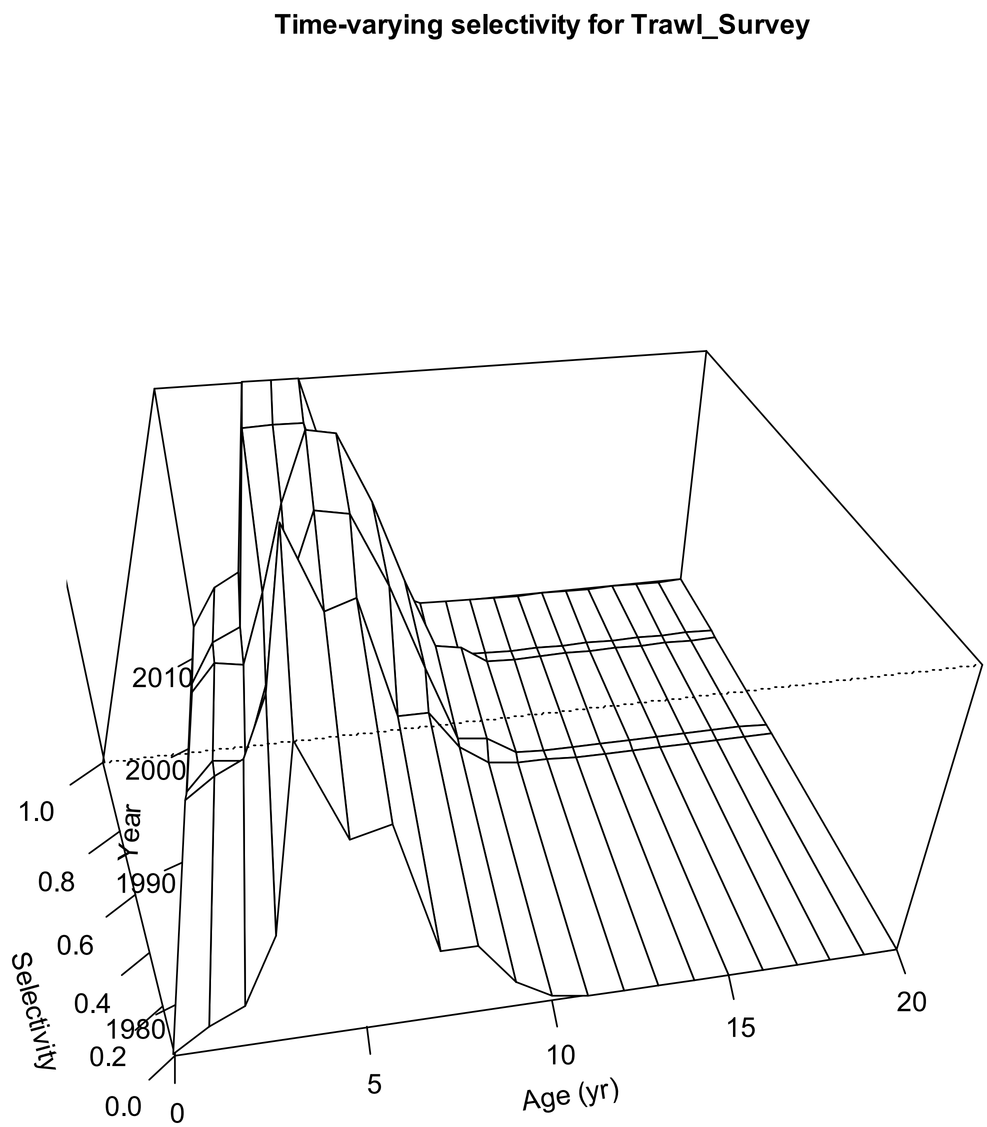

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Figure 10 – Survey selectivity-at-age for the 27-plus survey for Model 2

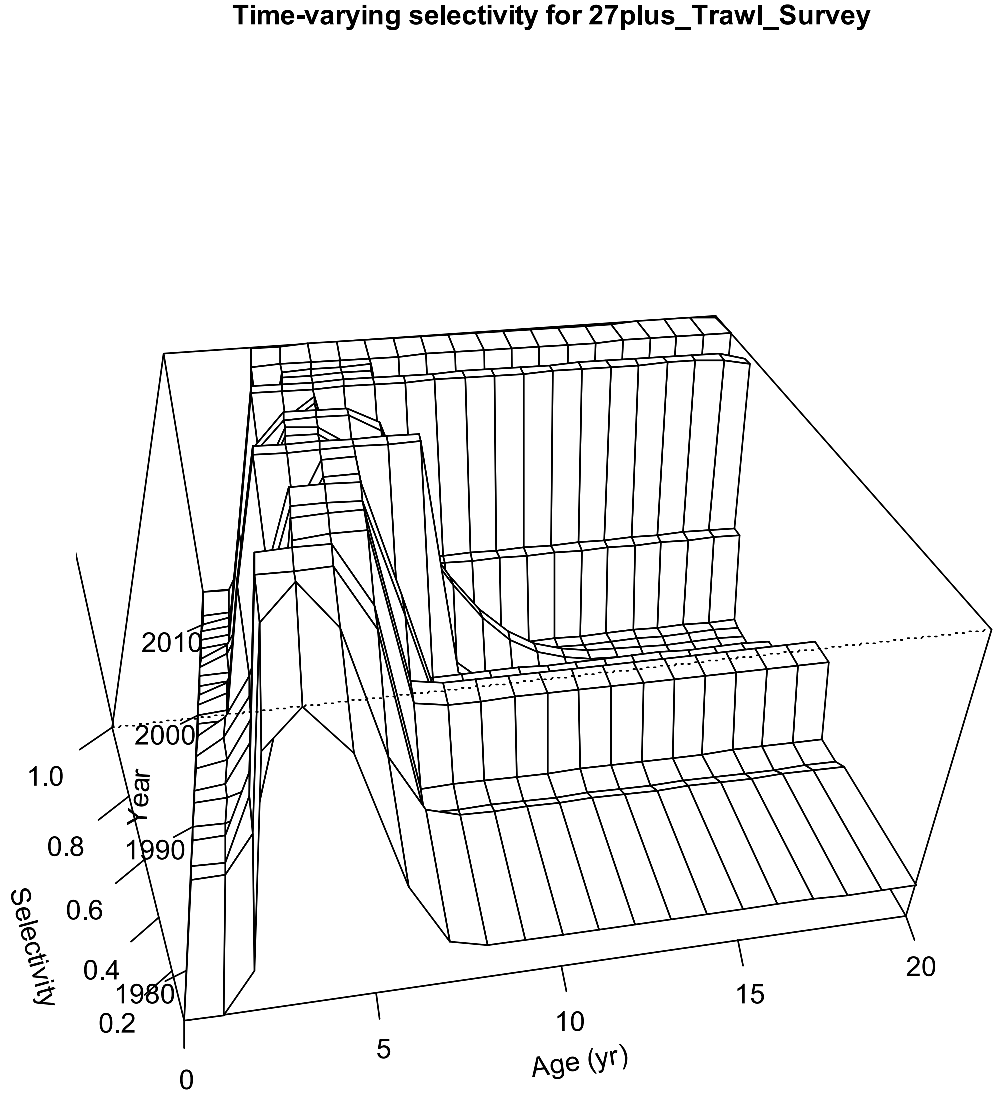

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Figure 11 – Survey selectivity-at-age for the sub-27 survey for Model 2

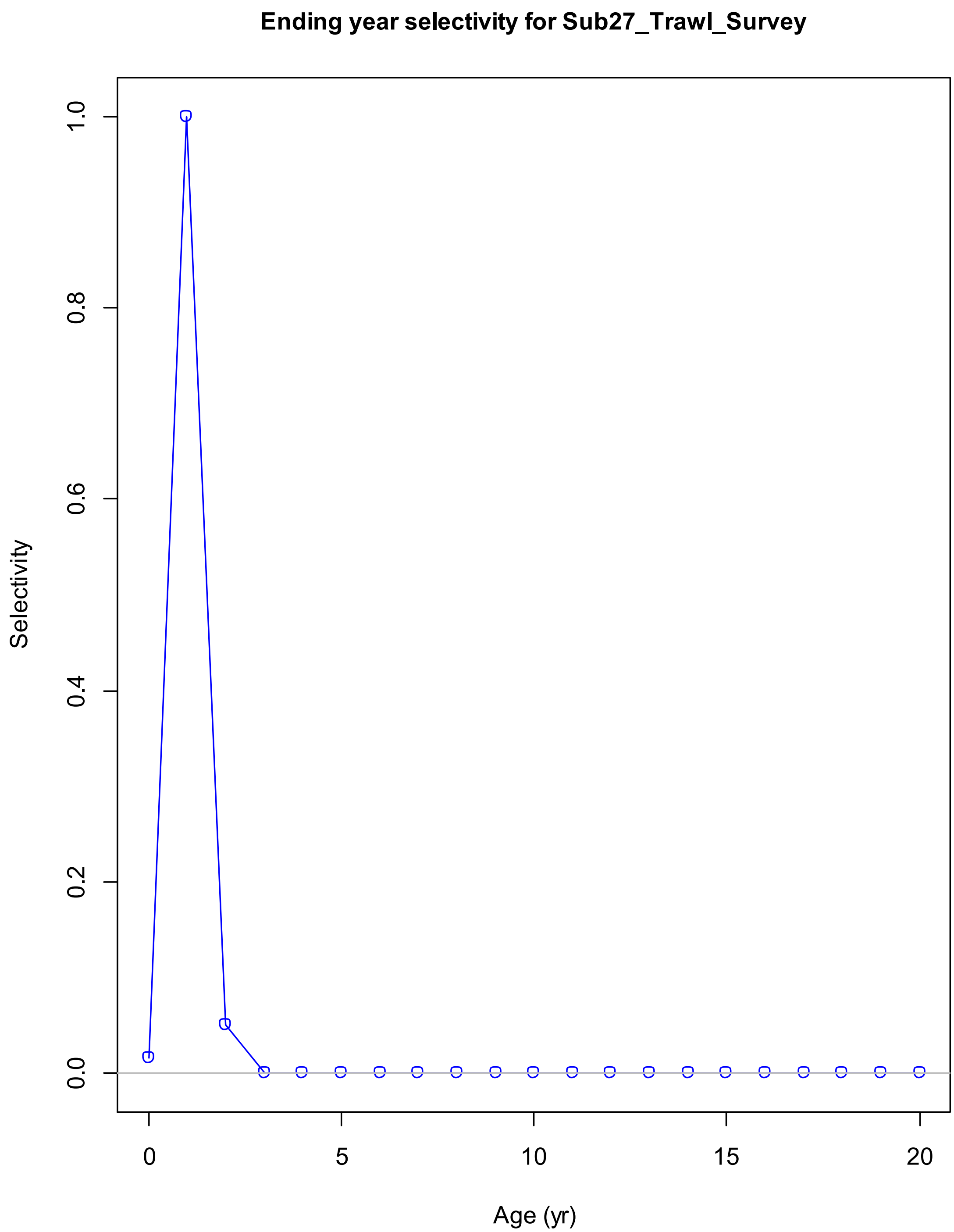

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Figure 12 – Survey selectivity-at-age for the trawl survey for Model 3

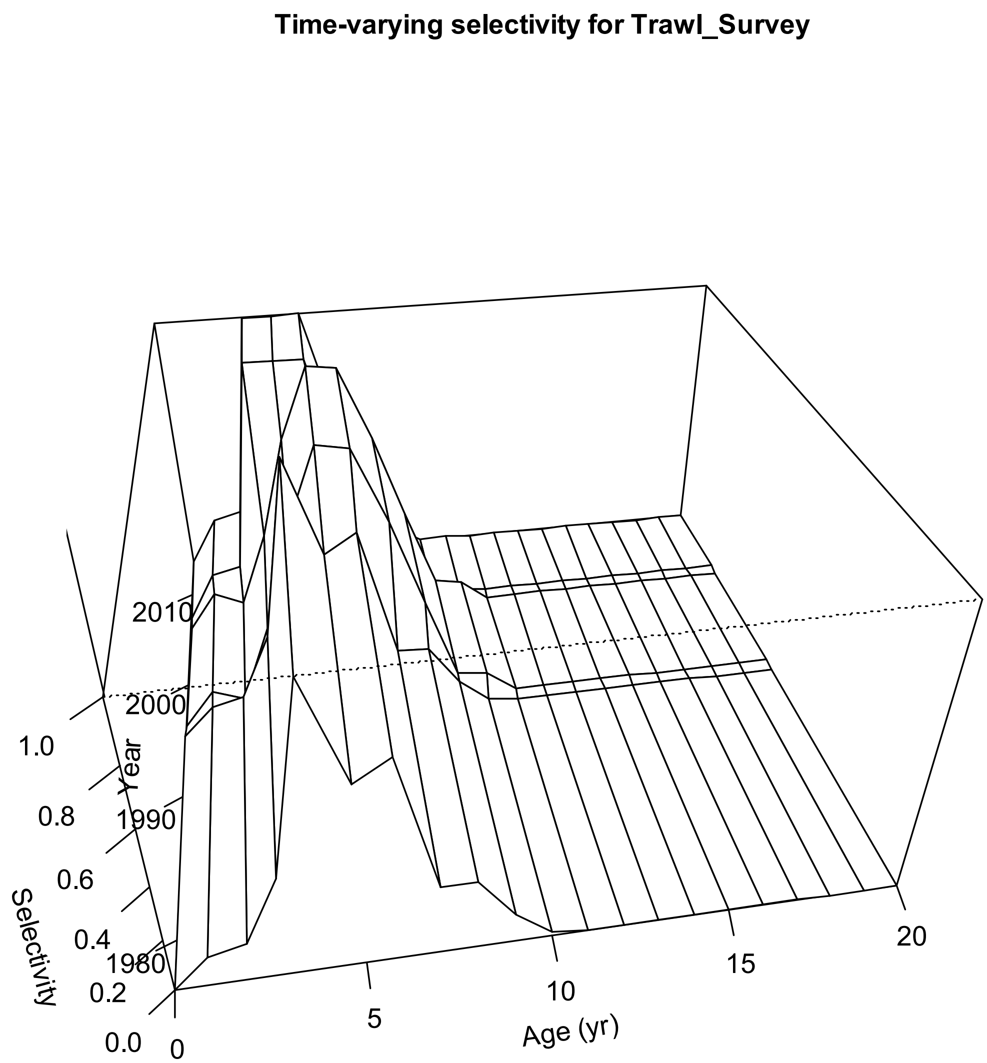

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Figure 13 – Survey selectivity-at-age for the trawl survey for Model 4 with 3 periods of non-parametric selectivity

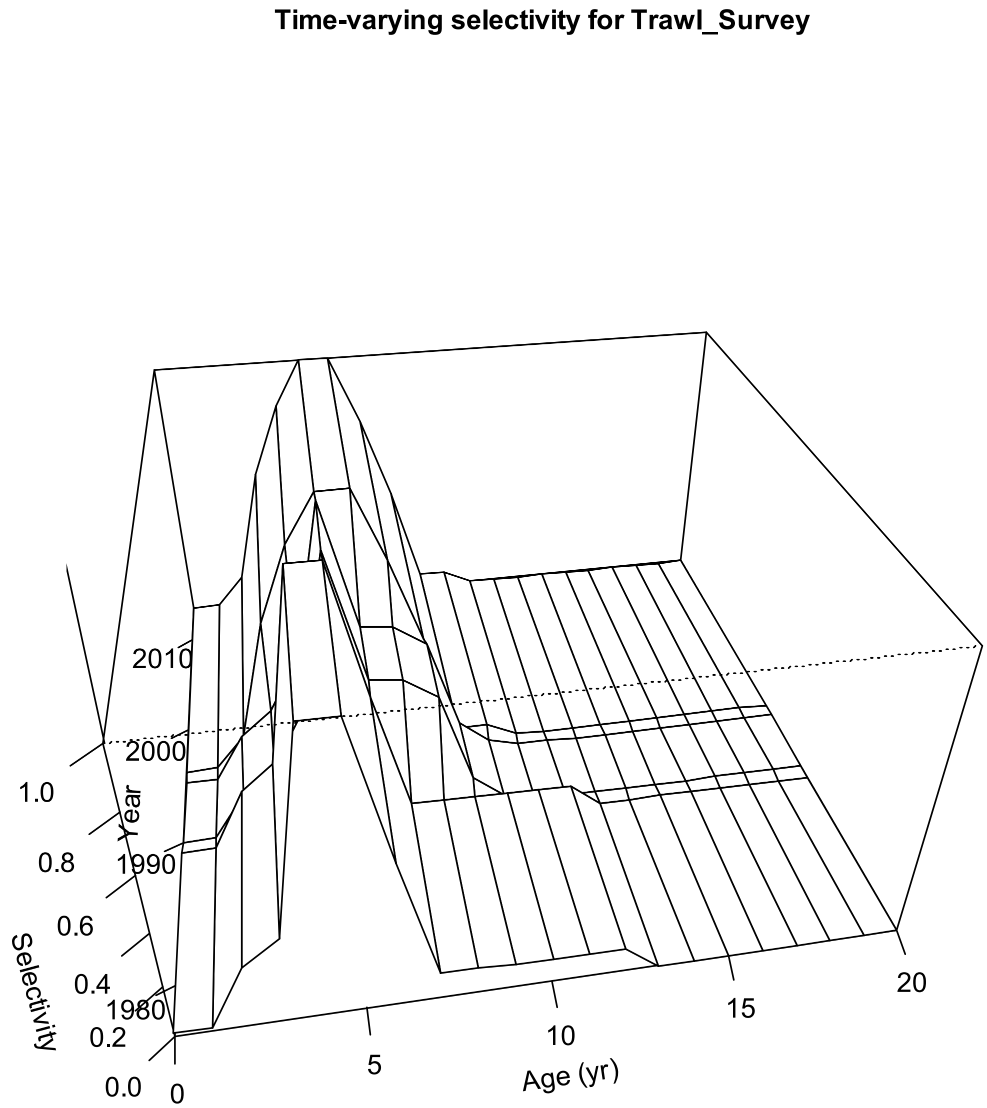

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Figure 14 – Survey selectivity-at-age for the trawl survey for Model 4 with 4 periods of non-parametric selectivity

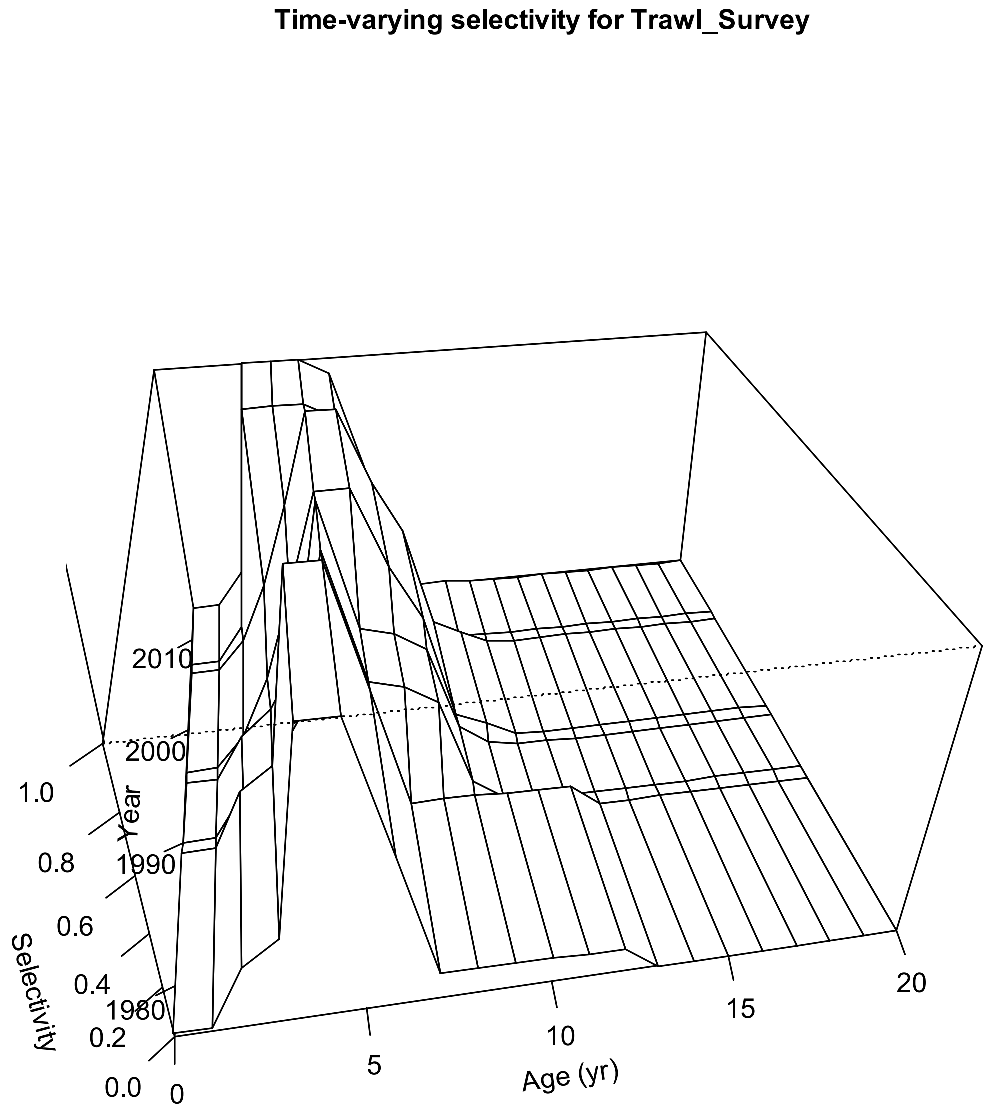

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Figure 15 – Survey selectivity-at-age for the trawl survey for Model 4 with 3 periods of double normal selectivity

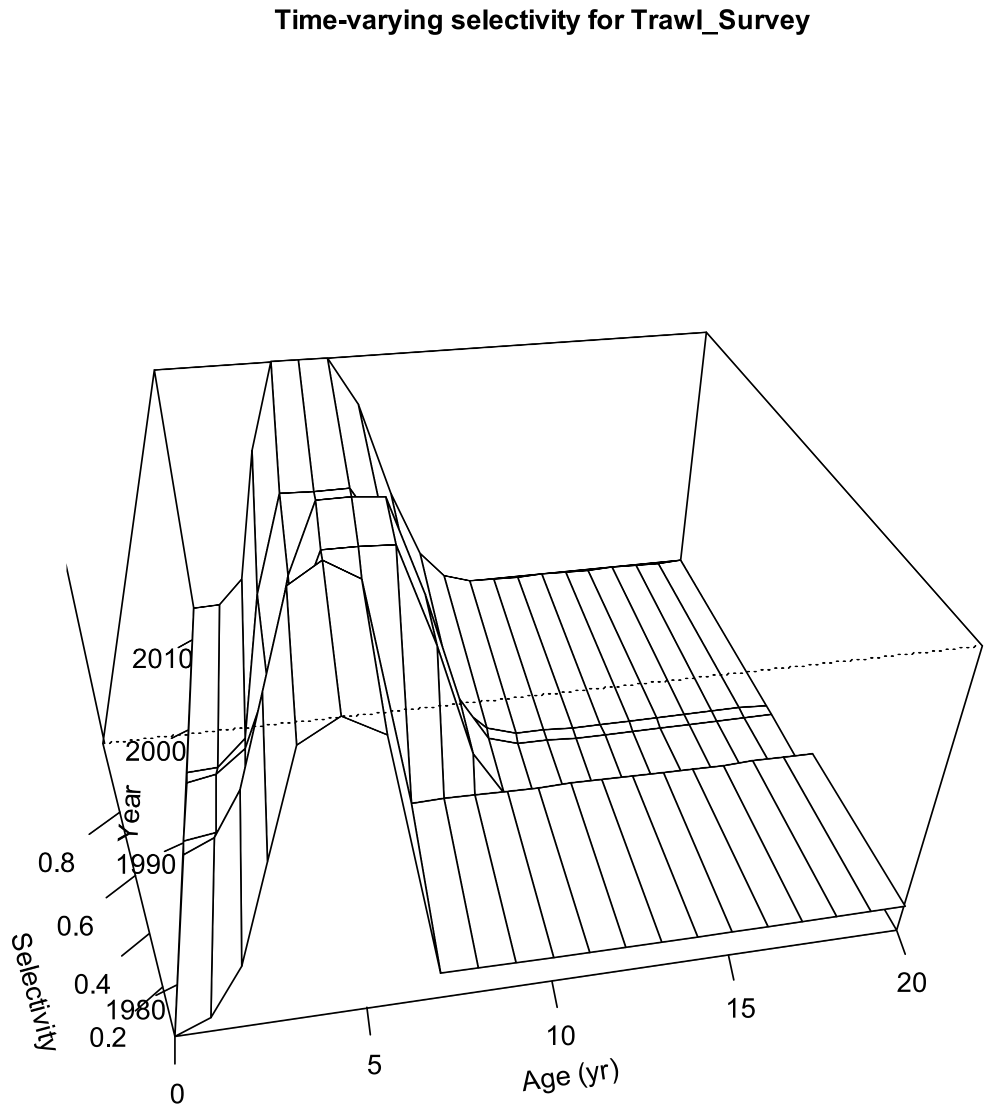

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Figure 16 – Survey selectivity-at-age for the trawl survey for Model 4 with 4 periods of double normal selectivity