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An exploration of GOA Pacific cod stock assessment models for 2014

Teresa A'mar

Resource Ecology and Fisheries Management Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE., Seattle, WA 98115

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 2013 assessments of the Pacific cod (*Gadus macrocephalus*) stocks in the Gulf of Alaska (A'mar et al., 2013). 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 2013 GOA Pacific cod stock assessment, with fishery data updated through the end of 2013.

Comments from the Plan Teams and SSC

Joint Plan Team Comments from the March 2014 Minutes

*JPT1: "**For the GOA, the subcommittee recommended that the following models be developed for this year's preliminary assessment:***

- *Model 0: Final model from 2011*
- *Model 1: Final model from 2013*
- *Model 2: Model 6 from the 2013 preliminary assessment, but with:*
    - *empirical weight at age*
    - *all agecomp data omitted*
    - *use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean*
    - *retuned input sample sizes and survey abundance standard deviations*
- *Model 3: Final model from 2013, but with:*
    - *use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean*
    - *retuned input sample sizes and survey abundance standard deviations*
    - *empirical weight at age*
- *Model 4: Final model from 2013, but with:*
    - *use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean*
    - *retuned input sample sizes and survey abundance standard deviations*
    - *age 1 abundance split out as a separate index*

The subcommittee noted that the above list does not contain several of the model proposals contained in the GOA Team's November 2013 minutes (the SSC's December 2013 minutes simply endorsed the Team's November 2013 model proposals). However, the subcommittee also noted that the SSC could add another model to the above list and still stay within the traditional limit of six requested models."

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Response: The initial results from these model configurations are included as Models P0, P1, P2, P3, and P4, respectively.

SSC Comments from the June 2014 Minutes

*SSC1: "**The SSC recommends exploring a time-varying, non-parametric function (i.e., a random walk) that directly estimates age-specific selectivity coefficients in lieu of splitting the data into two independent sources.**"*
Response: The initial results from this model configuration are included as Models S1a and S1b.

*SSC2: "**Additionally, profiling over the natural mortality rate should be conducted to gain a better understanding of the relationship between global scaling (Q and its associated priors) and natural mortality rate.**"*
Response: The results from this analysis come from Models P0 and S1a.

Summary of the base model configuration

The software used to run all models was Stock Synthesis v3.24S as compiled on 24 July 2013 with ADMB v.11.1.

Model evaluation

Model configurations for 2014

The following details attributes of the requested models.

Model P0: the 2011 final model (2011 Model 3) with tail compression turned off

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);
- 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

Model P1: the 2013 final model

This model has the same fishery properties as Model P0, with:

- All data for and modeling of the sub-27 survey omitted;
- Two blocks for catchability for the 27-plus survey, 1984 – 1993 and 1996 – 2013, with the catchability for the latter period set to 1.0;
- Time-varying survey selectivity-at-age for the 27-plus survey (12 blocks); and
- Age-0 recruits estimated through 2009 and recruits for 2010 on set to the average for 1977 – 2009

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Model P2: Model 6 from the 2013 preliminary assessment

This model has the same fishery properties as Model P0, with:

- All data for and modeling of the sub-27 survey omitted;
- Two blocks for catchability for the 27-plus survey, 1984 – 1993 and 1996 – 2013, with the catchability for the latter period set to 1.0;
- Two blocks for survey selectivity-at-age for the 27-plus survey, 1984 – 1993 and 1996 – 2013;
- Growth parameters fixed at the values from 2012 Model 2;
- Empirical weight-at-age;
- All age comp data omitted;
- The use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean; and
- Retuned input sample sizes and survey abundance standard deviations

Model P3: the 2013 final model with adjustments

This model has the same fishery properties as Model P0, with:

- All data for and modeling of the sub-27 survey omitted;
- Two blocks for catchability for the 27-plus survey, 1984 – 1993 and 1996 – 2013, with the catchability for the latter period set to 1.0;
- Time-varying survey selectivity-at-age for the 27-plus survey (12 blocks);
- Empirical weight-at-age;
- The use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean; and
- Retuned input sample sizes and survey abundance standard deviations

Model P4: the 2013 final model with adjustments (aka the 2011 final model with adjustments)

This model has the same fishery properties as Model P0, with:

- Two blocks for catchability for the 27-plus survey, 1984 – 1993 and 1996 – 2013, with catchability for the latter period set to 1.04;
- Time-varying survey selectivity-at-age for the 27-plus survey (12 blocks);
- Age 1 abundance split out as a separate index;
- The use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean;
- Retuned input sample sizes and survey abundance standard deviations

The main difference between the 2011 final model and the 2012 and 2013 final models is the omission of the sub-27cm survey data. The sub-27 survey index is essentially an index of age-1 abundance, as the average proportion of age-1 fish in these samples for 1990 – 2011 is 95%. Including an index of age-1 abundance as a separate index in the 2013 final model is thus very similar to using the 2011 final model with adjustments.

There are two versions of Model P4, one with 12 periods for the sub-27 survey catchability and constant selectivity-at-age, and one with 2 periods for the sub-27 survey catchability and selectivity-at-age, 1984 – 1993 and 1996 – 2013. These versions are labels "Model P4 – 12 per" and "Model P4 – 2 per", respectively.

Model S1a: the 2013 final model with adjustments

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This model has the same fishery properties as Model P0, with:

- The bottom trawl survey is treated as one data source, not two (sub-27 and 27-plus);
- Two blocks for catchability for the survey, 1984 – 1993 and 1996 – 2013;
- 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 S1b: the 2013 final model with adjustments

This model has the same fishery properties as Model P0, with:

- The bottom trawl survey is treated as one data source, not two (sub-27 and 27-plus);
- Two blocks for catchability for the survey, 1984 – 1993 and 1996 – 2013;
- Three blocks for selectivity-at-age for the survey, 1984 – 1993, 1996 – 2003, and 2005 – 2013;
- Conditional age-at-length survey data;
- Spline survey selectivity curves; and
- The use of the SS "multiplier" on σ_R instead of setting recent recruitments equal to the mean

Summary of model properties

Model	2009 Age0 estim	σ_R Multiplier	Tuned	Empirical wt-at-age	Age 1 split out	Cond age-at-length	Survey as aggregated	Spline
P0					X			
P1	X							
P2		X	X	X				
P3		X	X	X				
P4		X	X		X			
S1a		X				X	X	
S1b		X				X	X	X

For the model configurations using empirical weight-at-age: There are few Pacific cod age samples from the fishery observer program, so no fishery age composition data are available, particularly for each season and gear type. The use of empirical weight-at-age data in Stock Synthesis usually requires the use of fishery and survey selectivity-at-age curves, which requires fishery and survey age composition data. There are no weight-at-age data for the fisheries, so the relationship between weight and age was estimated from the survey weight-at-age data for 1990 – 2011; the data from 1987 were omitted due to the limited range of ages of the samples (Fig. 1). This relationship was then used to calculate the weight-at-age for ages 0 – 12 at

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different times of the year for each fishery and season. The weight-at-age for age-0 fish in season 1 was set to 0.0, as spawning occurs in the model at the beginning of season 2. The calculated empirical weight-at-age values are constant for each fishery and season for 1977 – 2013.

Parameter estimates for age-weight relationship

	W_∞ (g)	k	a_0
R estimates	26,361.7	0.109	-0.150
ADMB estimates	27,986.8	0.105	-0.185

Calculated weight-at-age (kg) at the beginning of the year

Age	0	1	2	3	4	5	6
Weight (kg)	0.000	0.028	0.195	0.568	1.159	1.952	2.915
Age	7	8	9	10	11	12	
Weight (kg)	4.010	5.199	6.446	7.722	8.999	10.258	

For the model configurations using the SS "multiplier" on σ_R: The Stock Synthesis User Manual describes this functionality as the factor applied to the likelihood component of the forecast recruitment deviations that occur before end_year+1, which would be for recruits for 2011 – 2013 in the model configurations in this analysis. Different values of the multiplier were evaluated for the 2013 final model, 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 and the values for the 2011 – 2013 estimates for age-0 recruits using the 2013 final model.

For the model configurations using the retuned input sample sizes and survey abundance standard deviations: After reasonable versions of each model configuration were determined, the "Q_extraSD" functionality was enabled to estimate a survey-specific parameter that contains an additive constant to be added to the input standard deviation of the survey variability. After reasonable versions of each model configuration with this functionality were determined, the "Variance_adjustments_to_input_values" functionality was enabled by calculating the ratio of the harmonic mean of the effective sample sizes to the mean of the input sample sizes for each fleet and survey. These values were then used to calculate the lambda value applied to the length composition likelihood component for each fleet and survey, after which the model configurations were run. This procedure was repeated several times per model configuration such that the ratio of the harmonic mean of the effective sample sizes to the mean of the input sample sizes multiplied by the adjustment was 1 for all fleets and surveys.

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:

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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.

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:

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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, 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, except where otherwise specified. 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

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deviations of the estimated *dev*s. The same input standard deviations were 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.

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

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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.

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.

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.

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 SSC and/or Plan Team. Models S1a and S1b would benefit from further refinement of the survey selectivity curves.

Model evaluation

The 8 sets of 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 27-plus and sub-27 survey indices and the survey age composition data, reasonable curves for fishery sand survey selectivity, and that the model estimated the variance-covariance matrix.

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Comparing and Contrasting the Models

The model configurations evaluated focused on exploring the impact of different combinations of survey data, and the estimation of additional survey variance and the iterative reweighting of the length composition data. The number of parameters and likelihood components for each model configuration are in Table 1, the growth parameters and additional standard deviation for survey variability are in Table 2, and the final lambda adjustments to the fishery and survey length composition sample sizes for each fishery and survey are in Table 3.

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; spawning biomass for the recent period is flat in Models P2, P3, P4 – 12 per, and P4 – 2 per, and increasing in the other model configurations (Fig. 2). The estimates of age-0 recruits differ across all model configurations (Fig. 3).

The estimates of the 27-plus survey indices vary somewhat for 1984 – 1987, very little for 1990 – 1993, and vary considerably for 1996 on (Fig. 4). Models P2, P3, P4 – 12 per, and P4 – 2 per include additional variance on the survey, so the fit to the survey data for the more recent years is poor. Models S1a and S1b are fit to the full survey data and use conditional age-at-length, so the survey data and fits are somewhat different than those from the other models (Fig. 5). Models P0, P4 – 12 per, and P4 – 2 per fit to the sub-27 survey data; the first two model configurations estimate time-varying catchability, so their estimates are virtually identical to the data (Fig. 6).

The estimates of growth parameters are similar among Models P0, P4 – 12 per, P4 – 2 per, S1a, and S1b, as these models include all of the survey data, represented as one survey or two independent surveys.

The survey selectivity for Model S1a did not result in higher selectivity for age 1 and lower selectivity for age 2 (Fig. 7); the survey selectivity for Model S1b did have higher selectivity for age 1 and lower selectivity for age 2 for the period 1996 – 2003, but not for periods 1987 – 1993 and 2005 – 2013 (Fig. 8).

The summary of the fits to the fishery length composition data are similar across all models, with some differences in fits to the survey length composition data (Figs. 9 – 16). The estimated age-at-length relationships are similar for Models S1a and S1b for smaller and mid-sized fish, but Model S1b has poor estimates for larger, older fish (Figs. 17 and 18).

The estimation of additional standard deviation on survey variability had a significant impact on model results, as did the sample size tuning. Compared to the initial version of Model P3, the additional standard deviation estimation decreased spawning biomass over the historical period, and the tuning increased spawning biomass in the first half of the historical period and decreased it in recent years (Fig. 18). The patterns in estimated age-0 recruitment were similar for the three models, but the initial version of the model had higher estimates in recent years (Fig. 19). The fits to the survey were poor for 1996 on for the models with additional standard deviation estimation, but the tuning improved the fit relative to additional standard deviation estimation alone (Fig. 20). There were similar patterns for Model P4 – 2 (Figs. 21 – 24).

Likelihood profiles were produced for Models P0 and S1a, with M fixed between 0.2 and 0.5 in 0.01 increments (Fig. 25); Model P0 has a minimum at M = 0.47 and Model S1a has a minimum at M = 0.42. The estimated value of Q for the early period, 1984 – 1993, was inversely related to M (Fig. 26).

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Tables

Table 1 – The likelihood components and number of parameters for the SS3 model configurations

Model	P0	P1	P2	P3	P4 - 12	P4 - 2	S1a	S1b
# parameters	259	253	202	260	264	256	229	229
Total NLL	4403.95	3959.74	5701.02	6208.28	6460.22	6459.88	5135.40	5250.51
Survey	8.74	7.70	8.34	3.27	-9.48	2.92	-11.88	-10.53
Fishery length comp	3452.15	3373.53	5588.27	5580.86	5607.90	5607.94	3377.13	3389.29
Survey length comp	190.76	60.99	119.98	100.56	113.60	102.00	111.27	132.09
Survey age comp	140.34	77.81	-	74.55	130.14	130.24	1676.21	1762.92
Survey size-at-age	634.47	461.20	-	467.97	633.30	632.78	-	-
Recruitment	-22.68	-21.62	-16.17	-19.29	-17.34	-17.31	-23.39	-24.76

Table 2 – Parameter estimates for growth, median recruitment, and additional survey variance

Model	P0	P1	P2	P3	P4 - 12	P4 - 2	S1a	S1b
Length at A_{min}	20.47	27.80	24.86	27.18	20.46	20.47	20.85	19.44
Length at A_{max}	100.59	101.73	100.51	99.24	99.72	99.73	100.64	101.49
k	0.180	0.165	0.176	0.176	0.184	0.184	0.161	0.172
$\ln(R_0)$	12.45	12.37	12.64	12.70	12.36	12.36	12.63	12.46
27plus extra SD	-	-	0.973	0.592	0.441	0.468	-	-
Sub27 extra SD	-	-	-	-	-	0.298	-	-

Table 3 – Input variance adjustments so that the mean(adjustment*N) = harmonic mean(effN) for fishery and survey length composition data

Model	Fl1	Fl2	Fl3	Fl4	Fl5	Fl6	Fl7	Fl8	Fl9	27plus	Sub27
P2	0.682	2.143	1.276	2.050	3.036	1.942	1.898	2.037	1.917	1.906	-
P3	0.684	2.198	1.314	2.038	3.008	1.921	1.911	2.038	1.923	1.593	-
P4 – 12	0.709	2.149	1.262	1.989	2.994	1.915	2.007	1.988	1.938	0.477	0.475
P4 - 2	0.709	2.147	1.262	1.988	2.994	1.915	2.007	1.995	1.939	0.481	0.520

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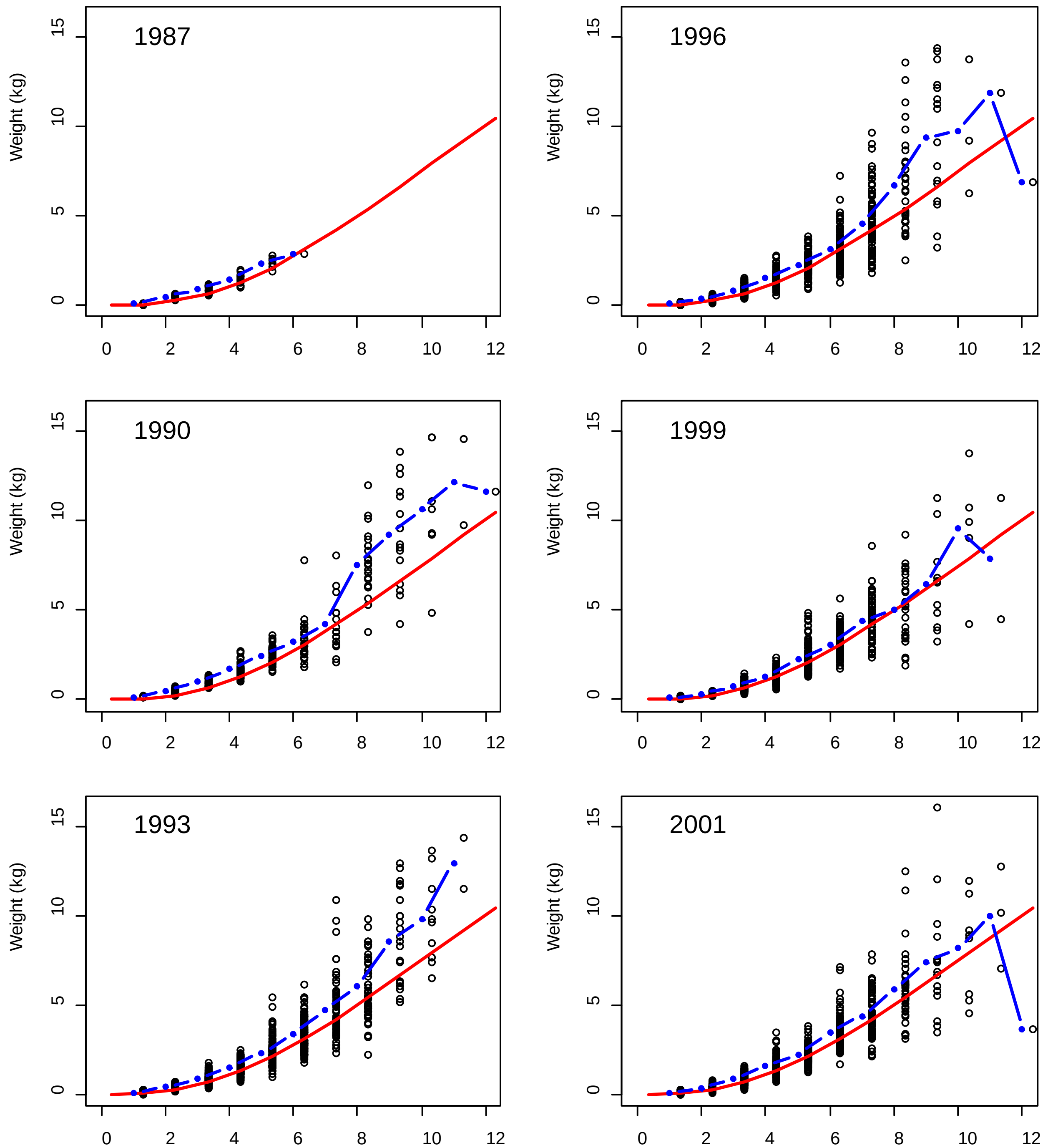
Figures

Figure 1 – Survey weight-at-age samples (points), the estimated age-weight relationship (red lines) for all survey data for 1990 – 2011, and the mean survey weight-at-age values, at integer ages for clarity (blue points and lines)



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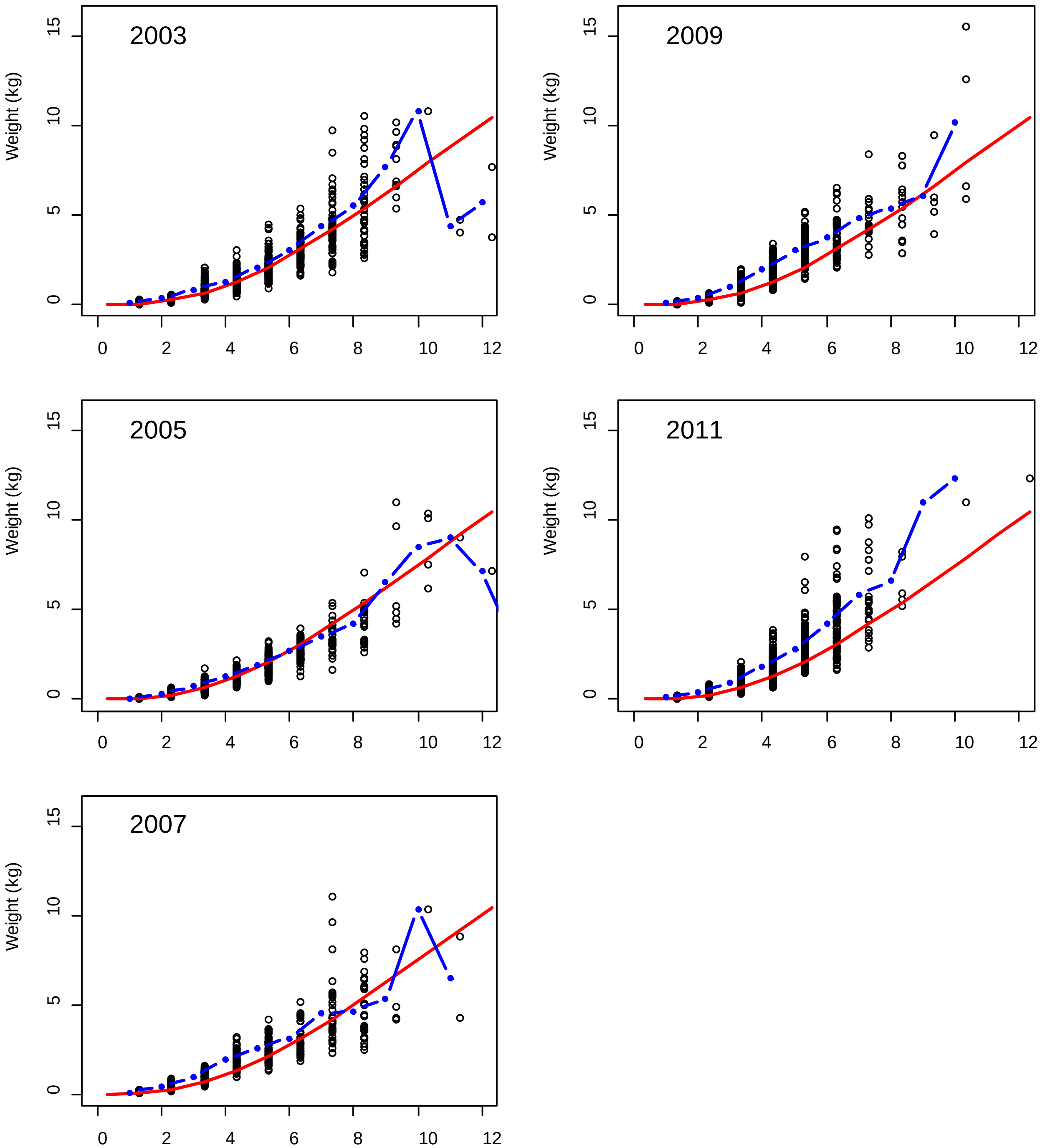

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Figure 2 – Estimates of spawning biomass for Models P0, P1, P2, P3, P4 – 12 per, P4 – 2 per, S1a, and S1b

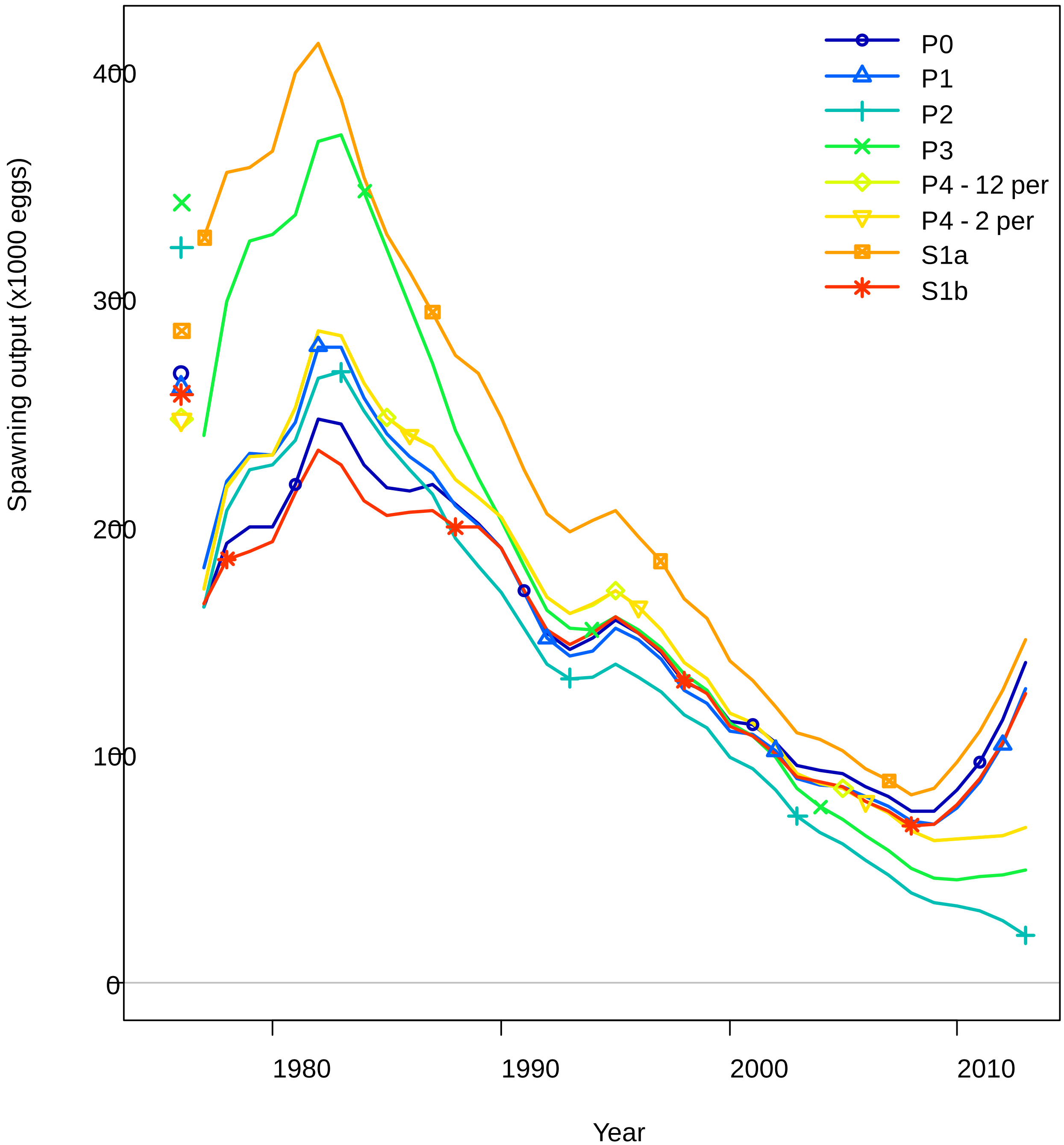

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Figure 3 – Estimates of age-0 recruitment for Models P0, P1, P2, P3, P4 – 12 per, P4 – 2 per, S1a, and S1b

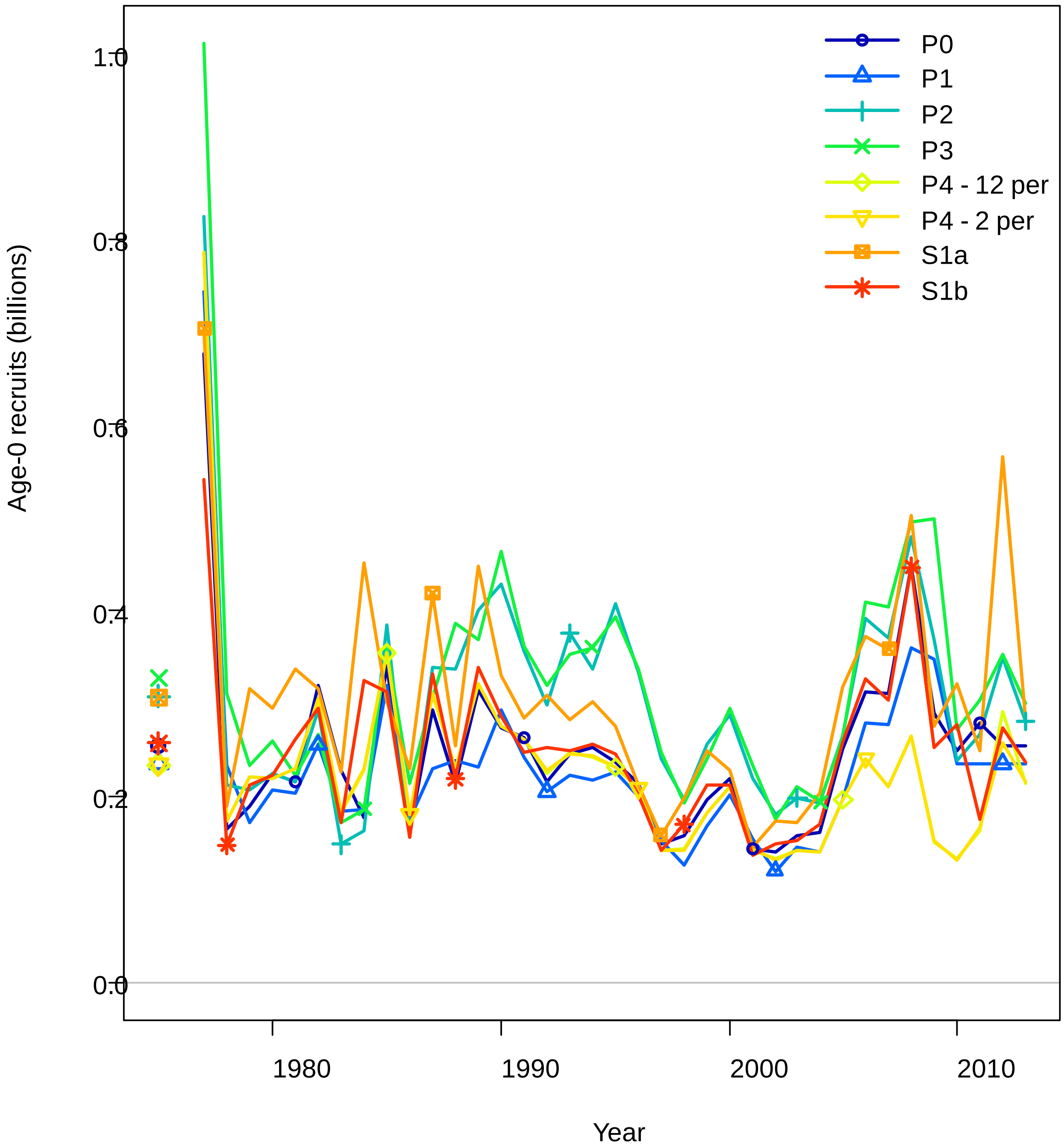

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Figure 4 – The 27-plus survey for Models P0, P1, P2, P3, P4 – 12 per, and P4 – 2 per

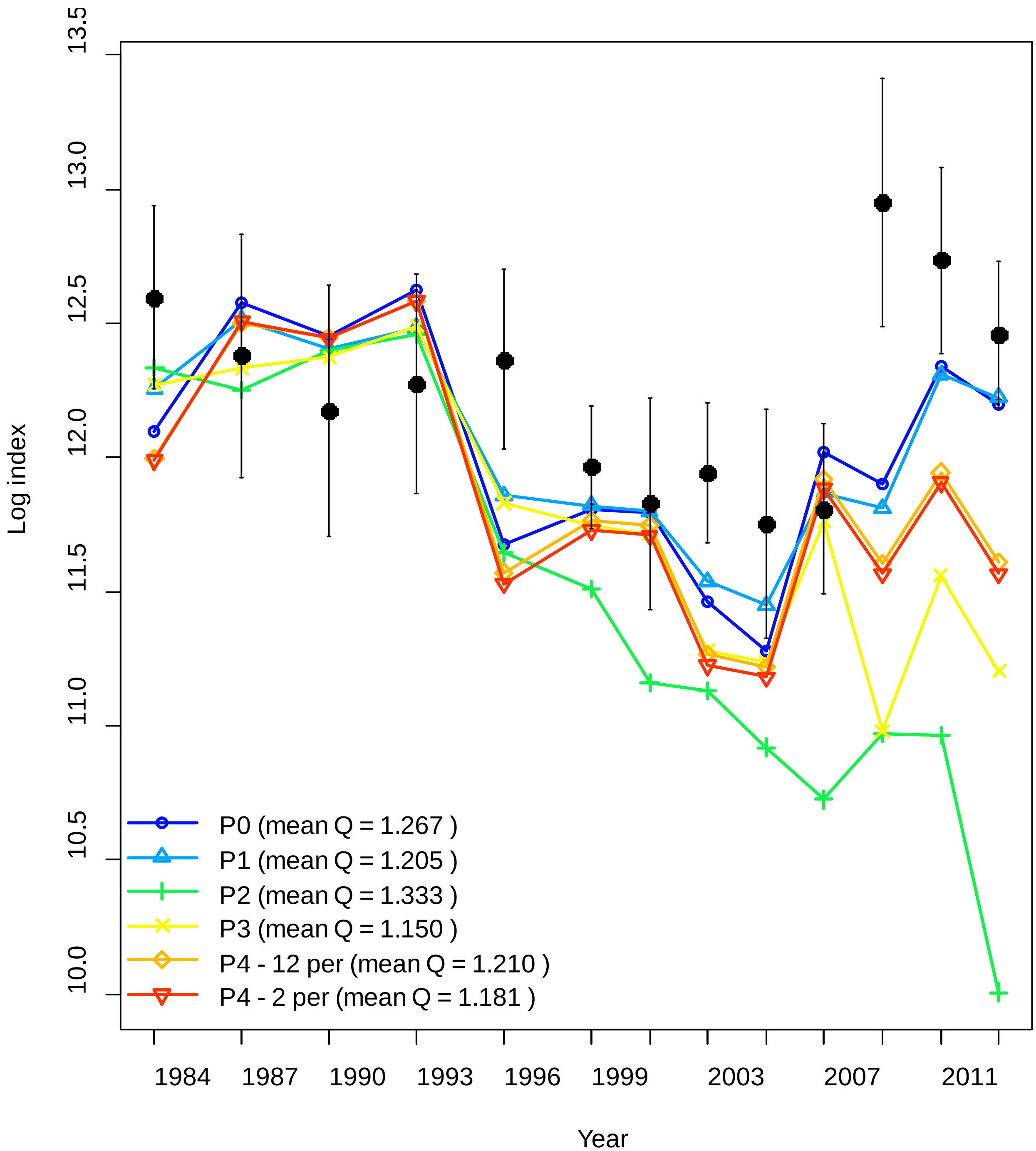

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Figure 5 – The full survey for Models S1a and S1b

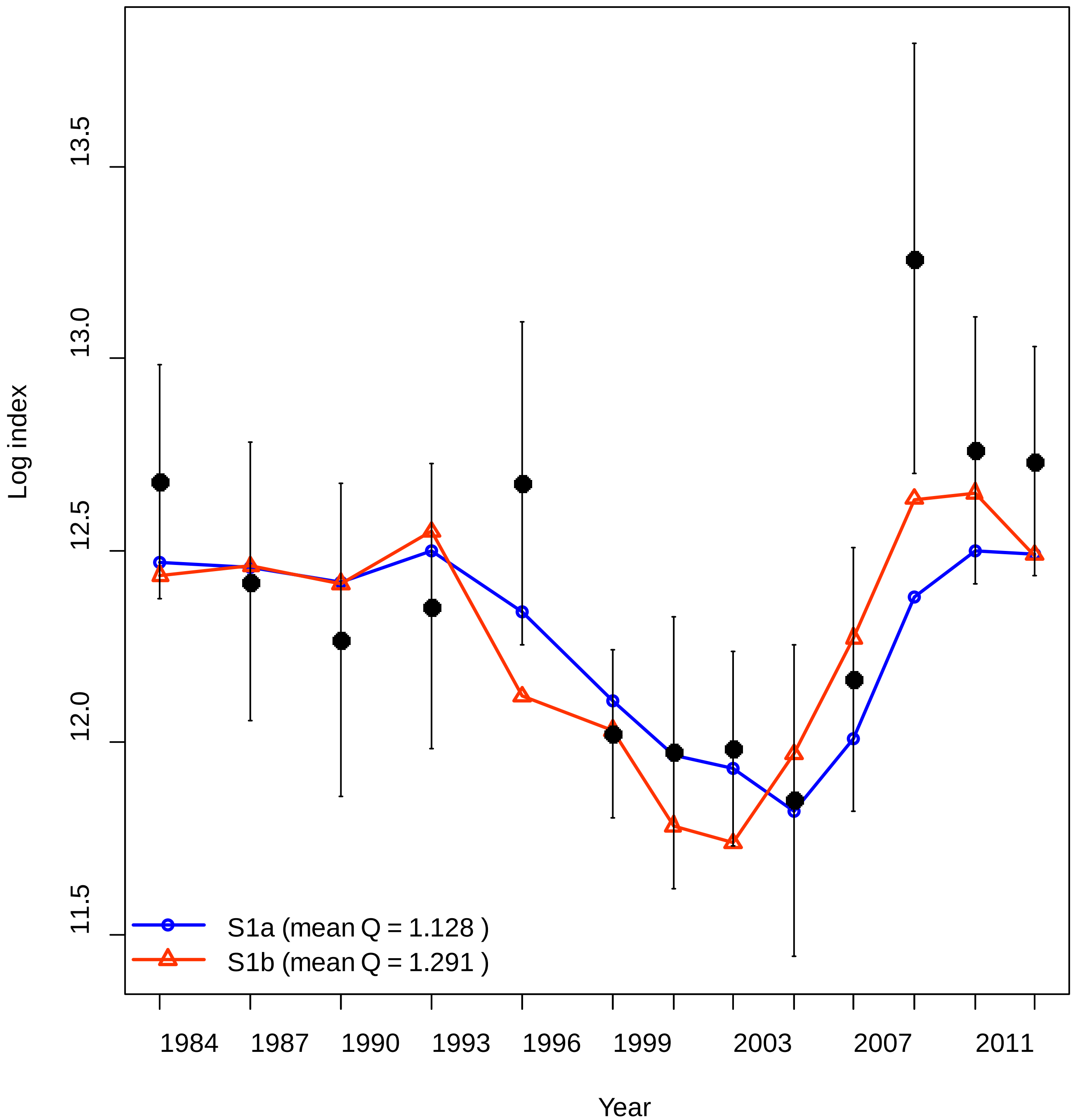

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Figure 6 – The sub-27 survey for Models P0, P4 – 12 per, and P4 – 2 per

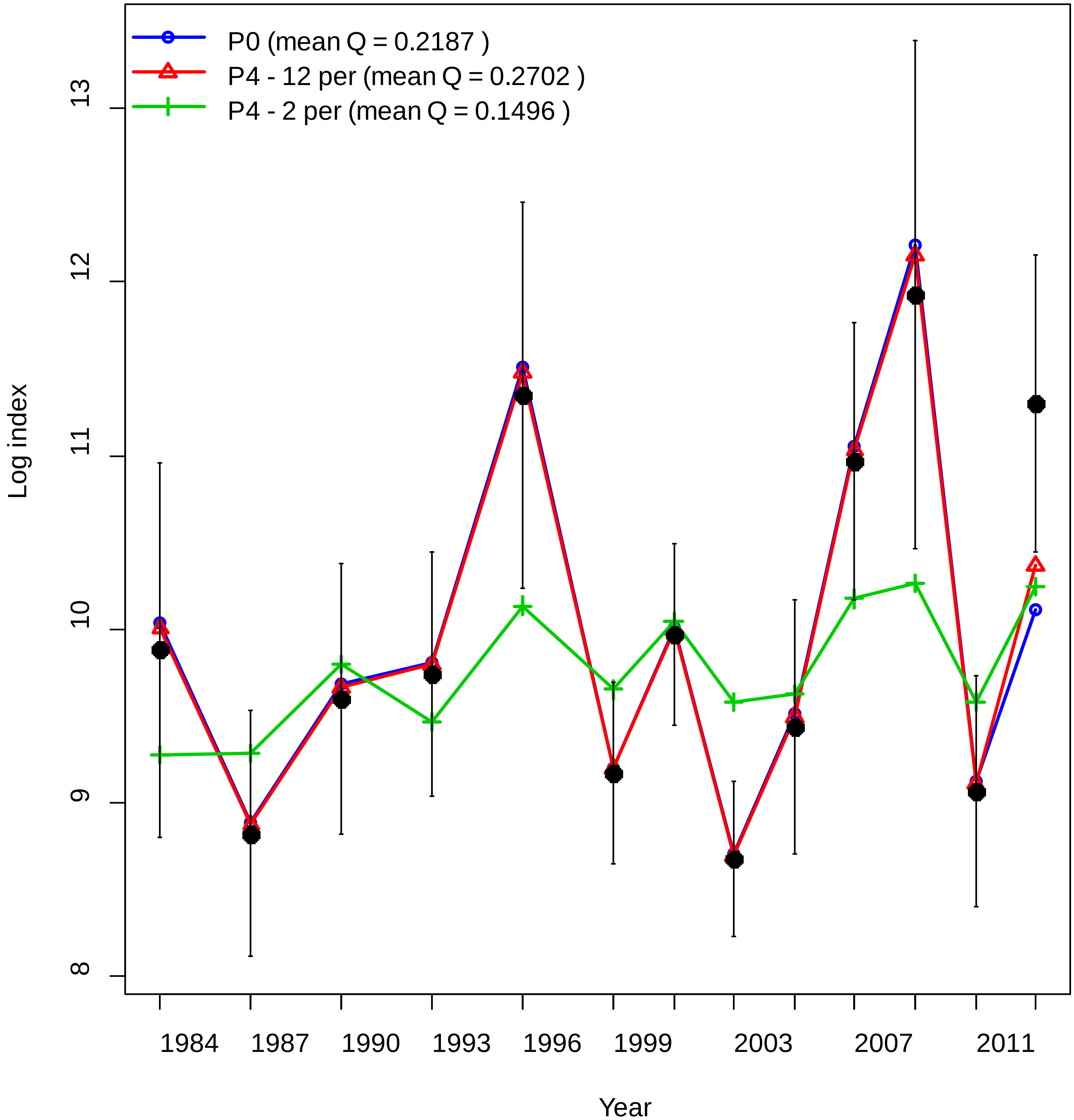

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Figure 7 – Estimated survey selectivity-at-age for Model S1a

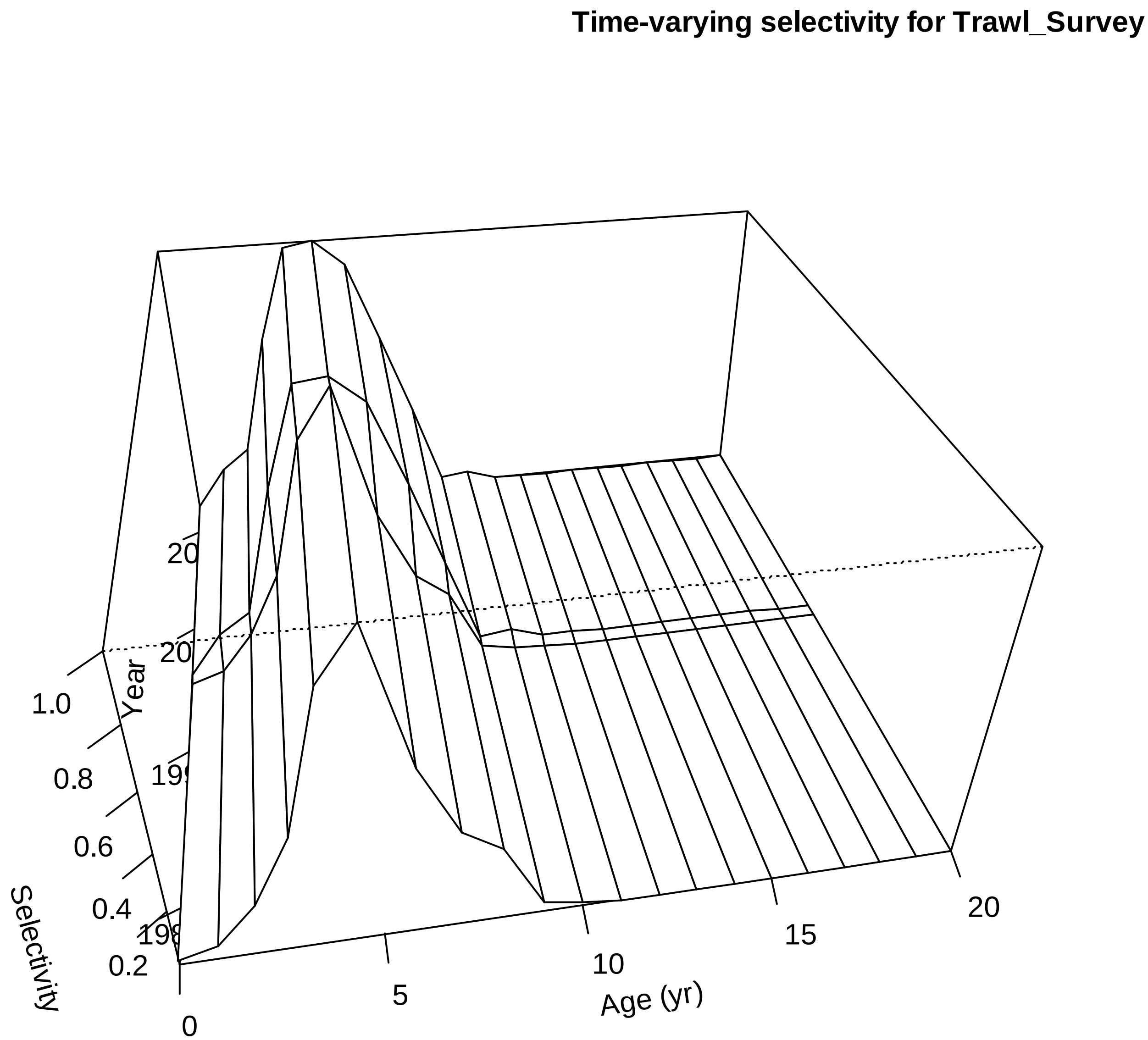

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Figure 8 – Estimated survey selectivity-at-age for Model S1b

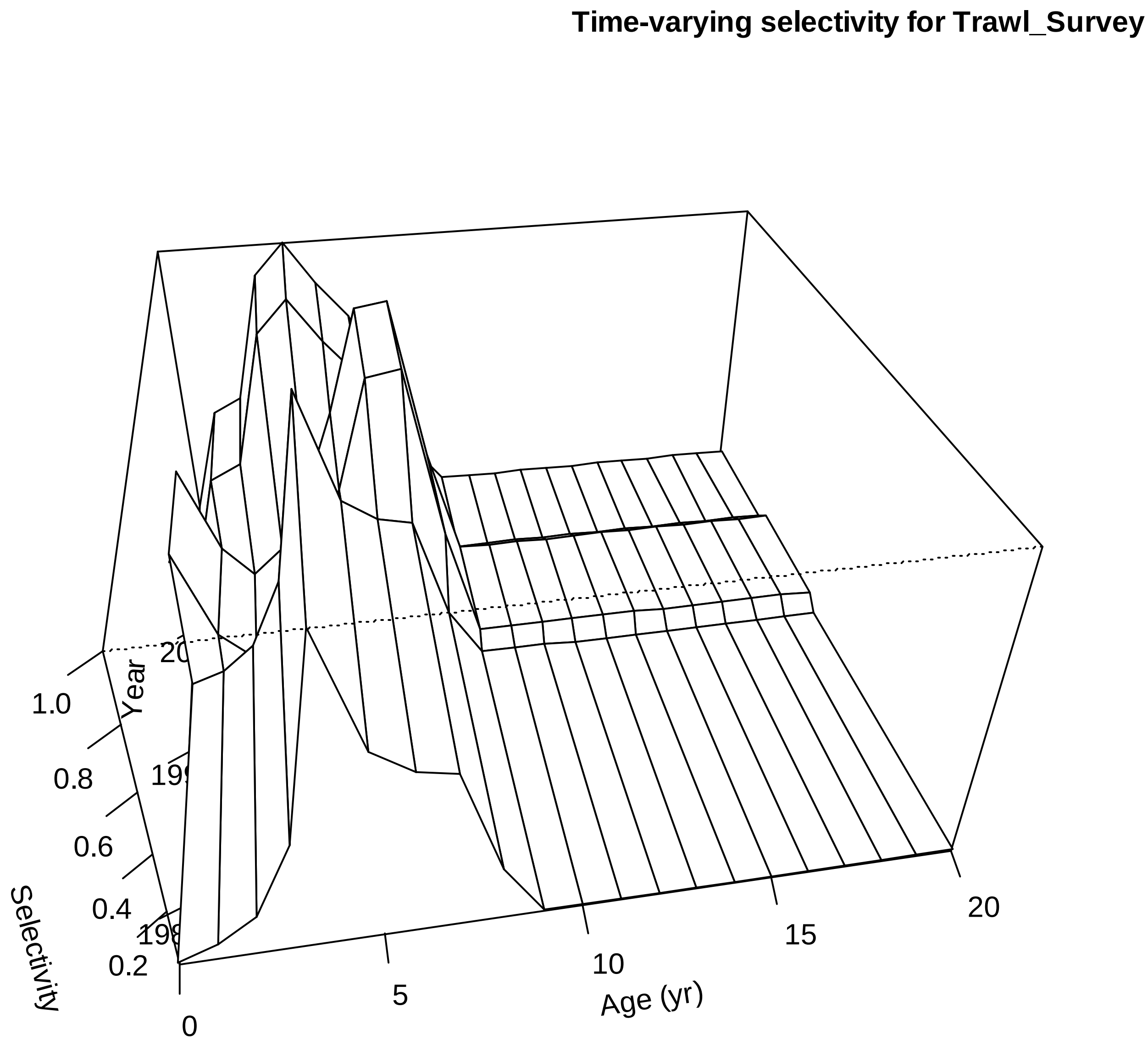

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Figure 9 – Length comps aggregated by season and gear for Model P0

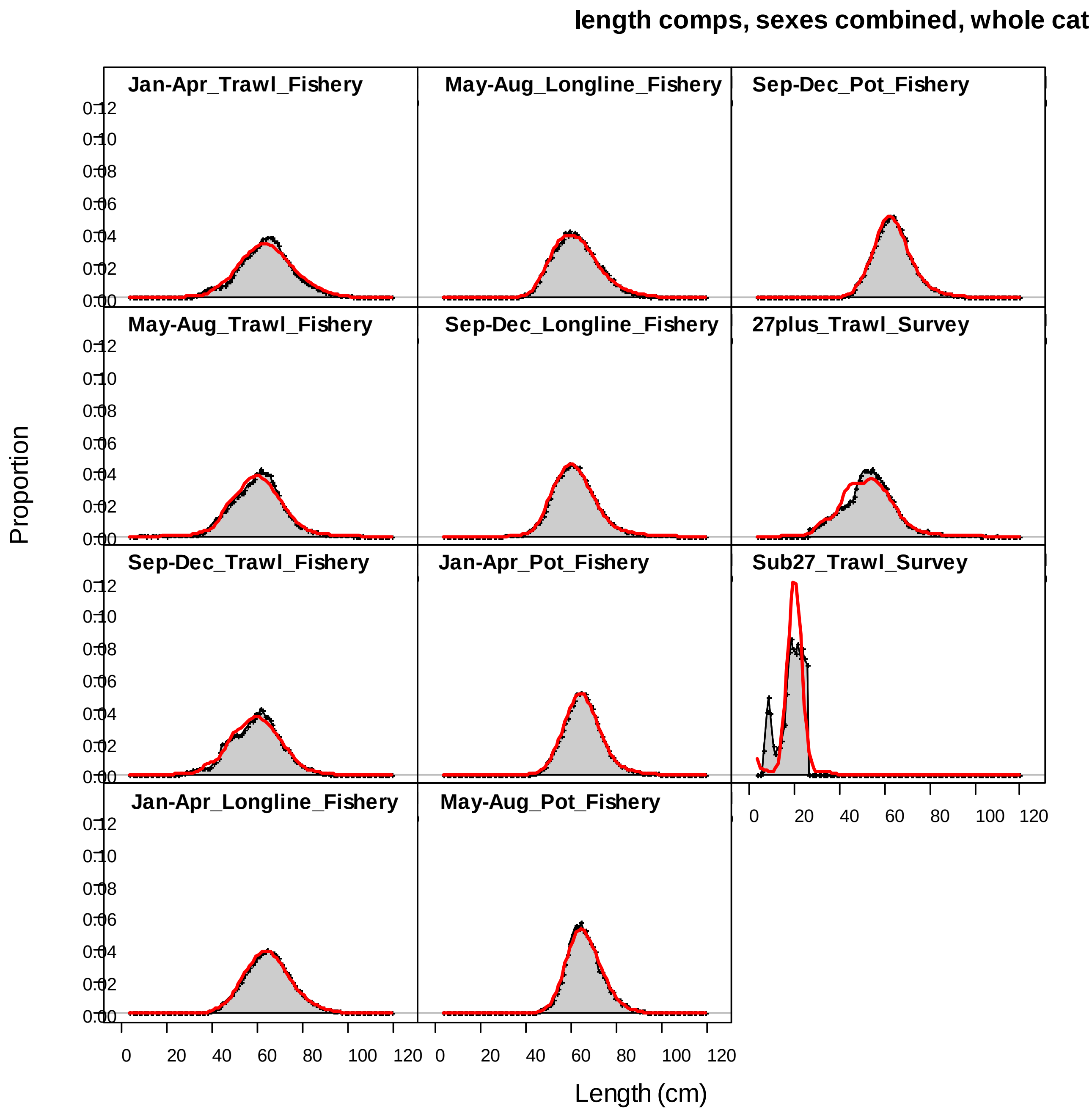

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Figure 10 – Length comps aggregated by season and gear for Model P1

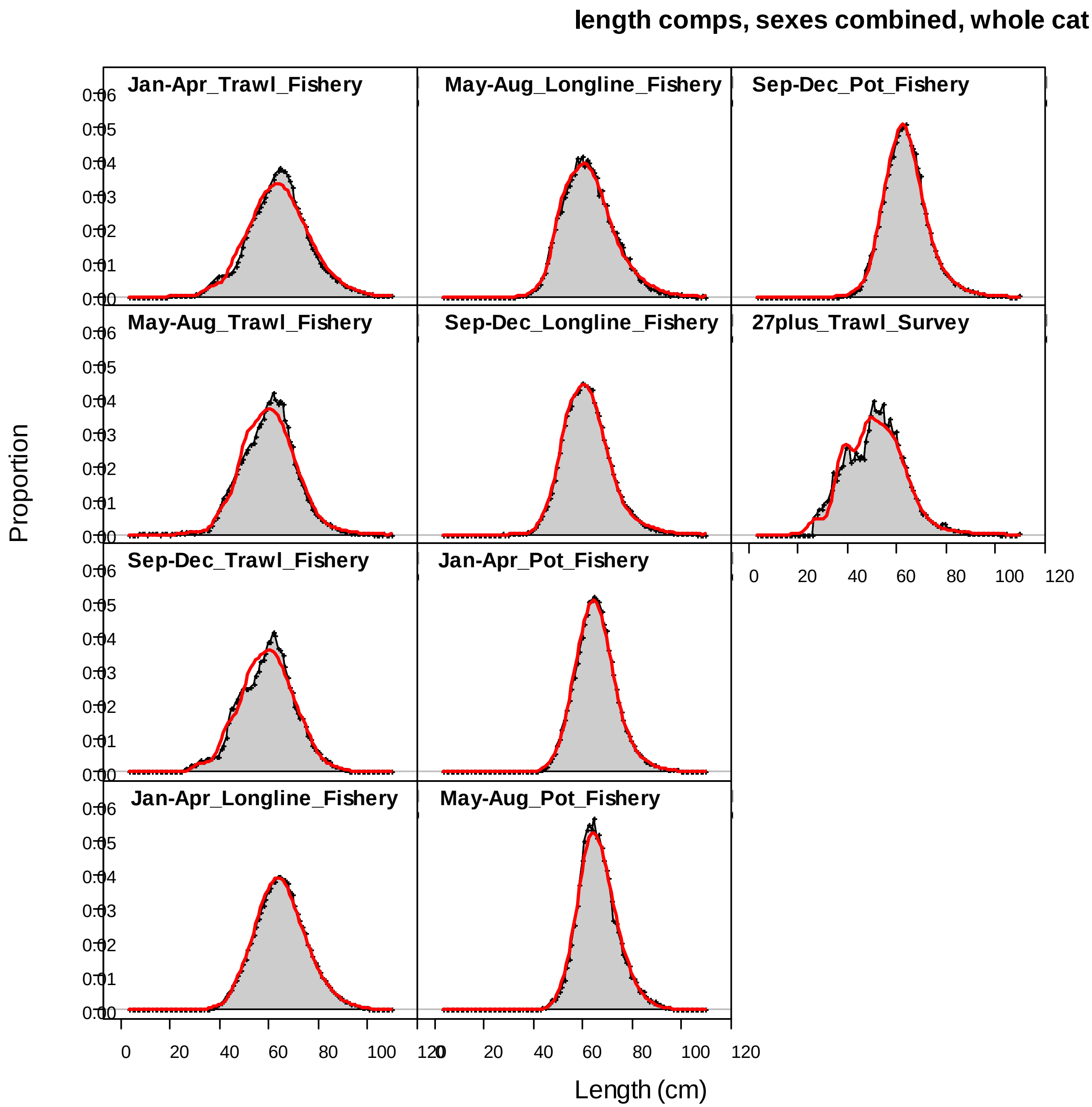

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Figure 11 – Length comps aggregated by season and gear for Model P2

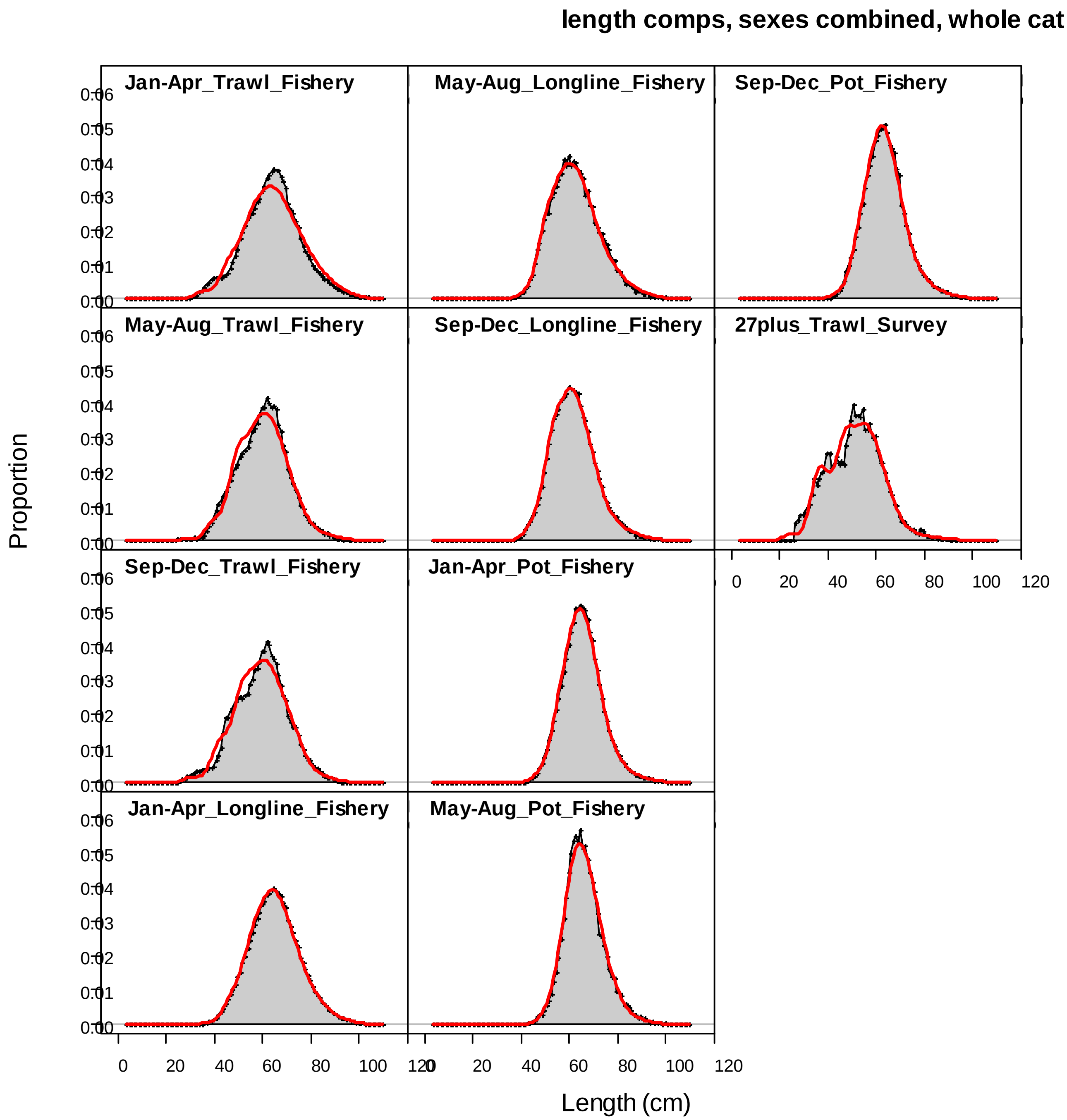

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Figure 12 – Length comps aggregated by season and gear for Model P3

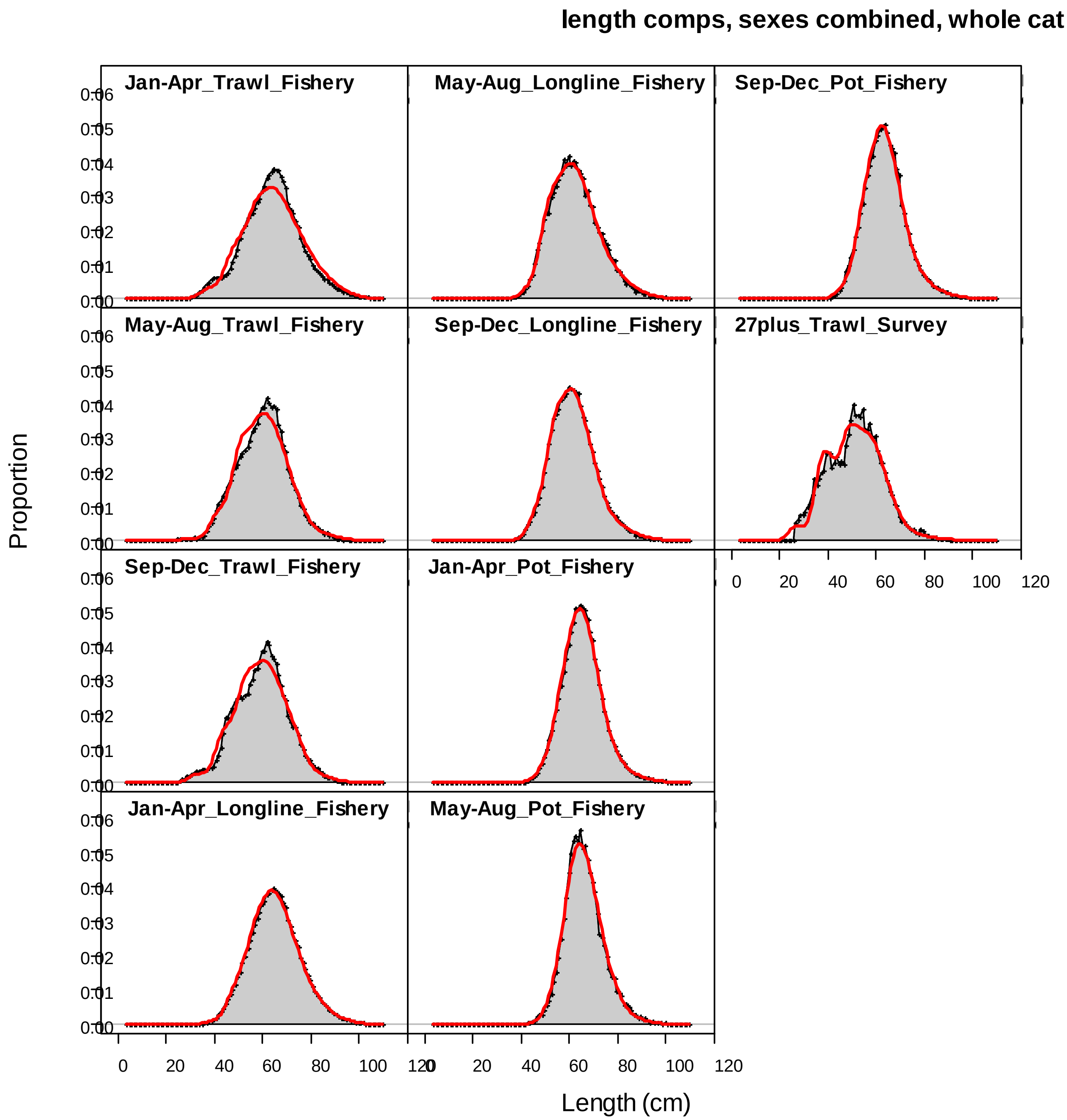

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Figure 13 – Length comps aggregated by season and gear for Model P4 – 12 per

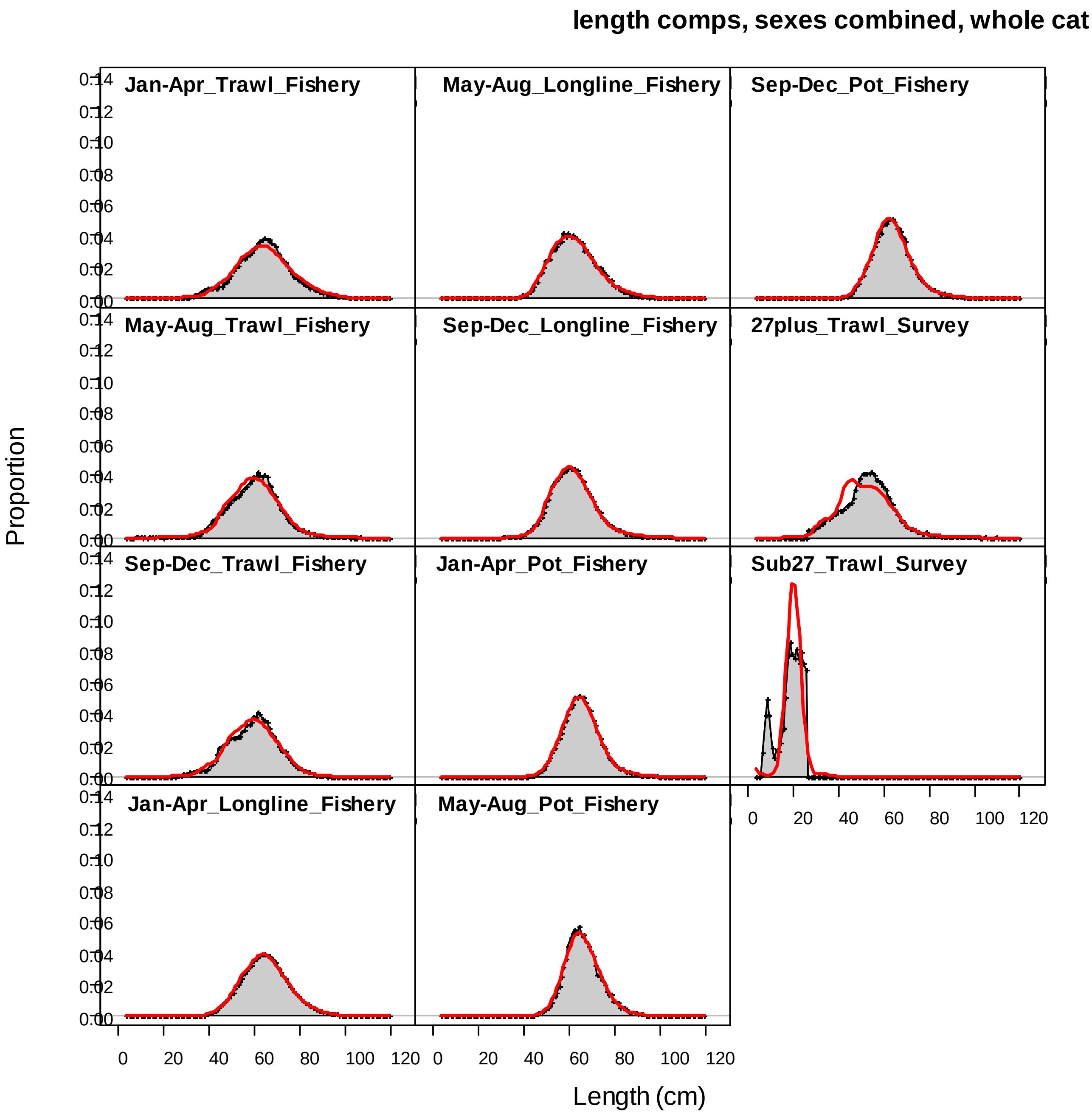

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Figure 14 – Length comps aggregated by season and gear for Model P4 – 2 per

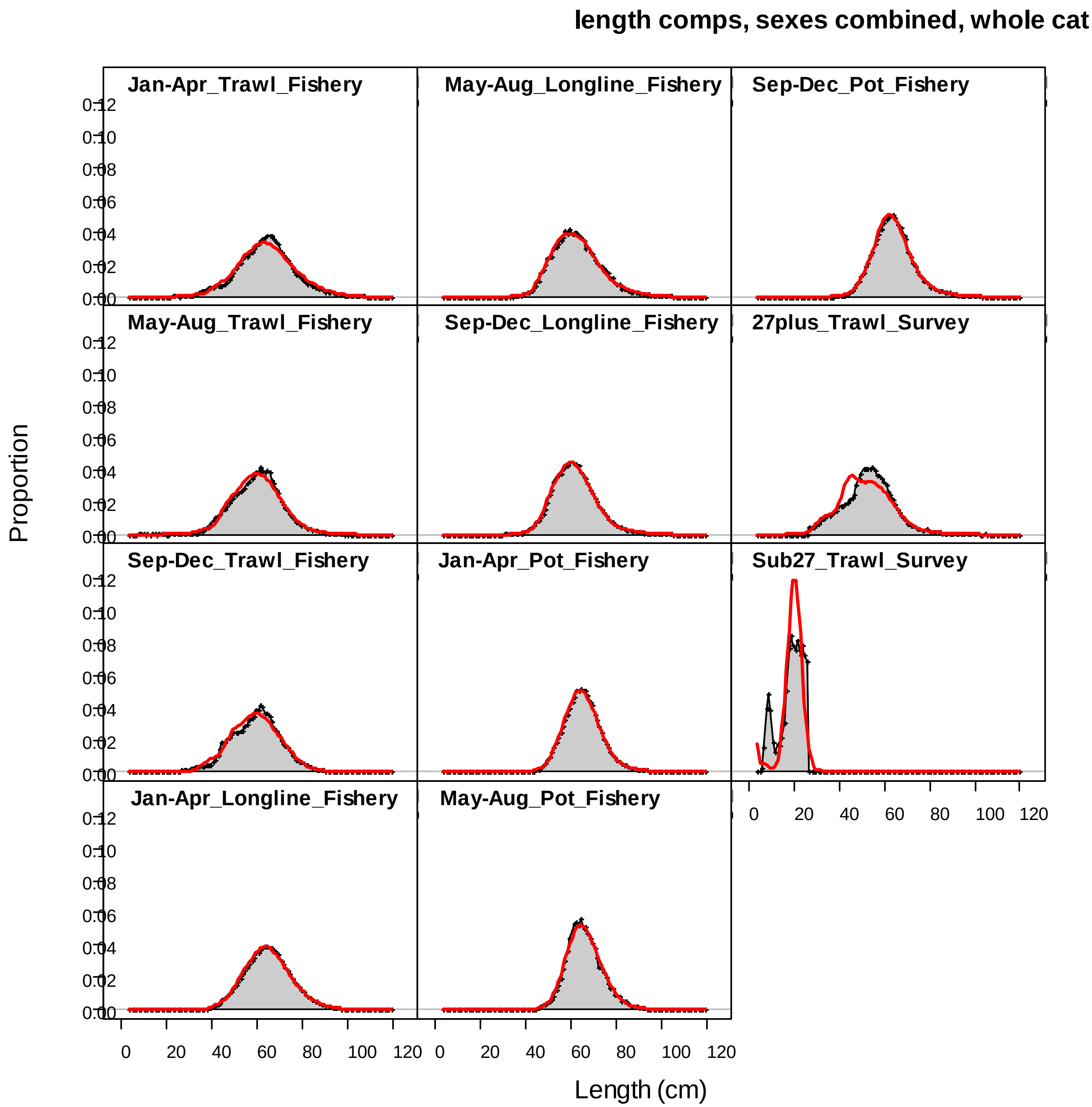

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Figure 15 – Length comps aggregated by season and gear for Model S1a

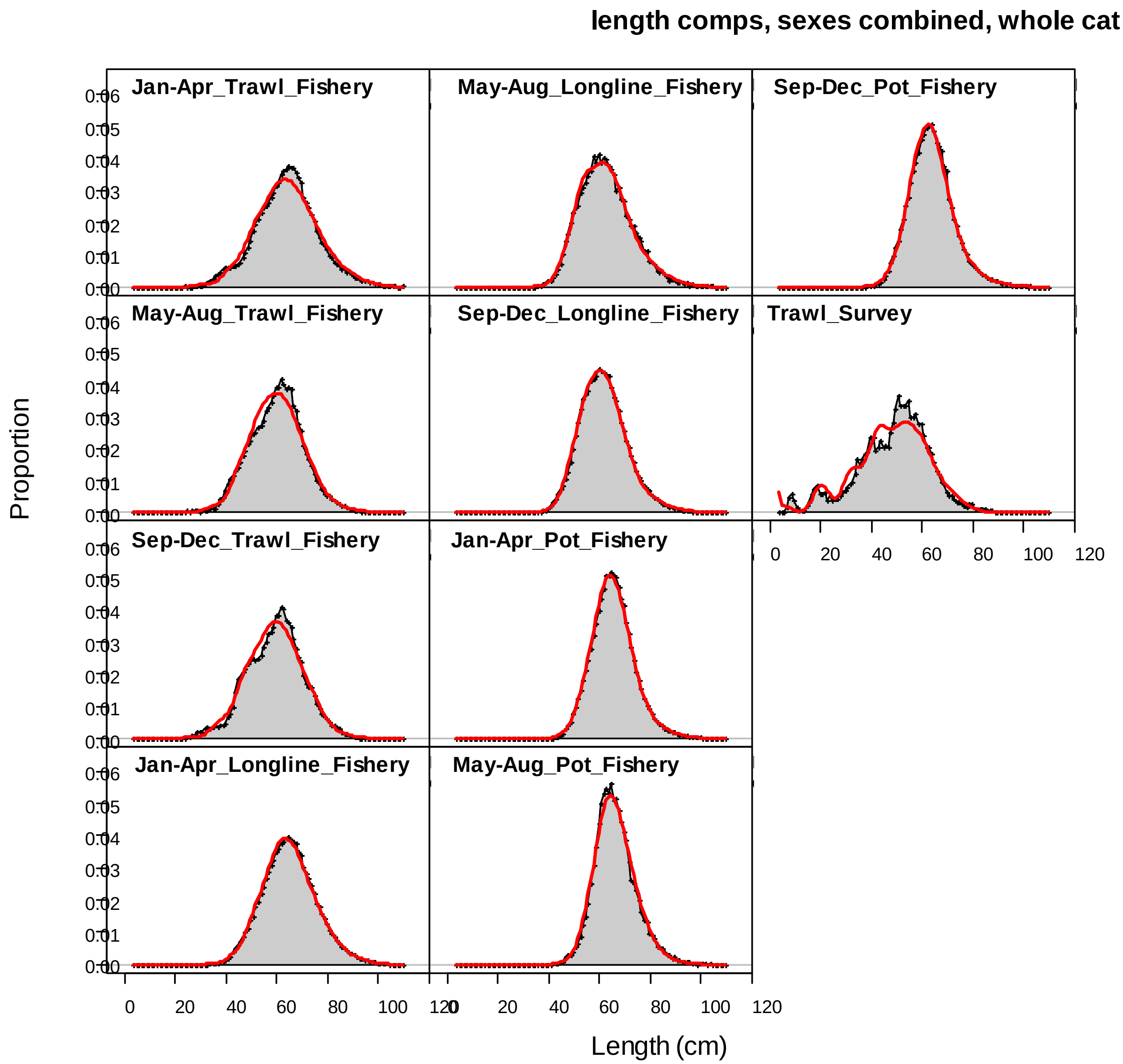

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Figure 16 – Length comps aggregated by season and gear for Model S1b

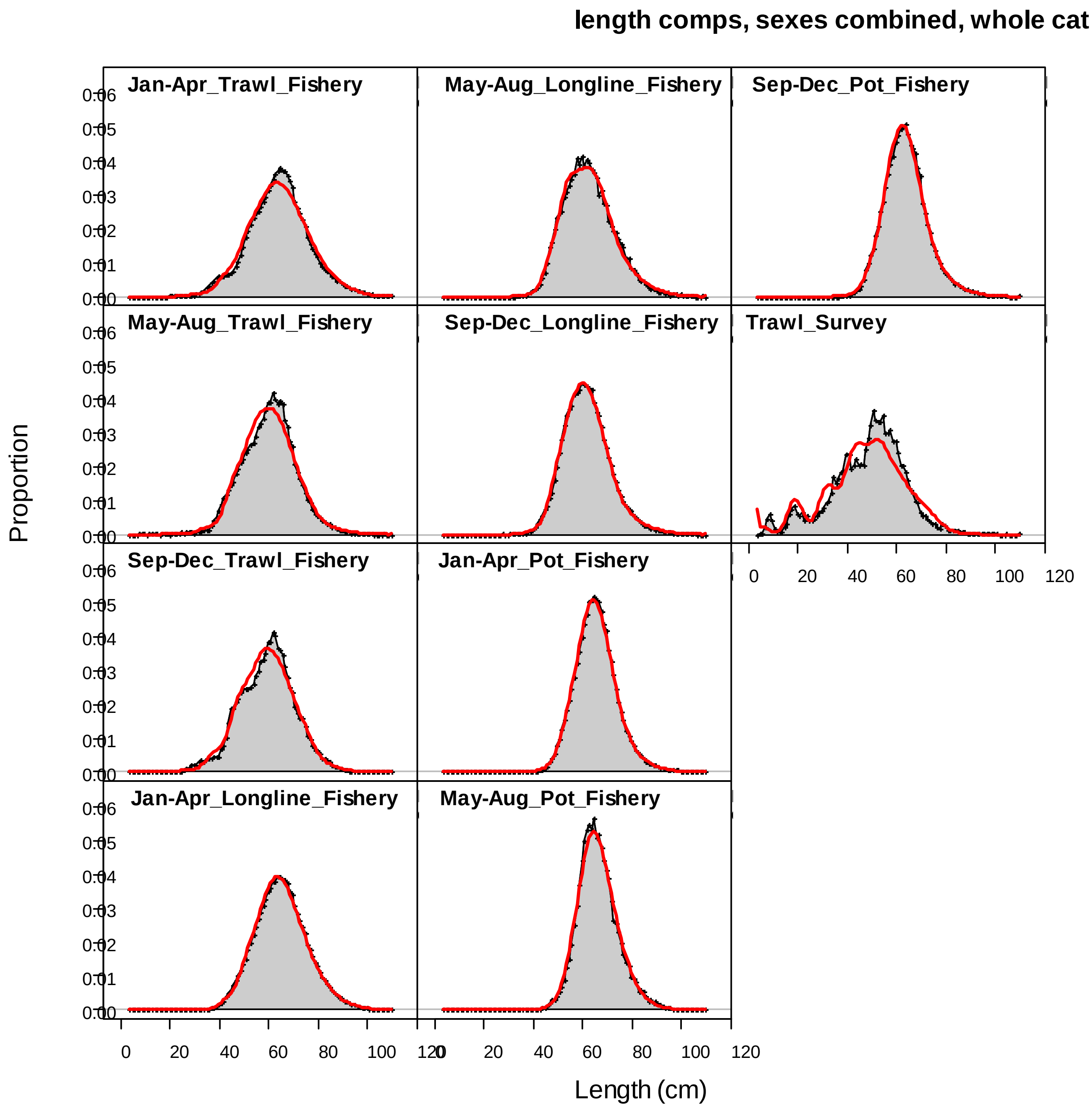

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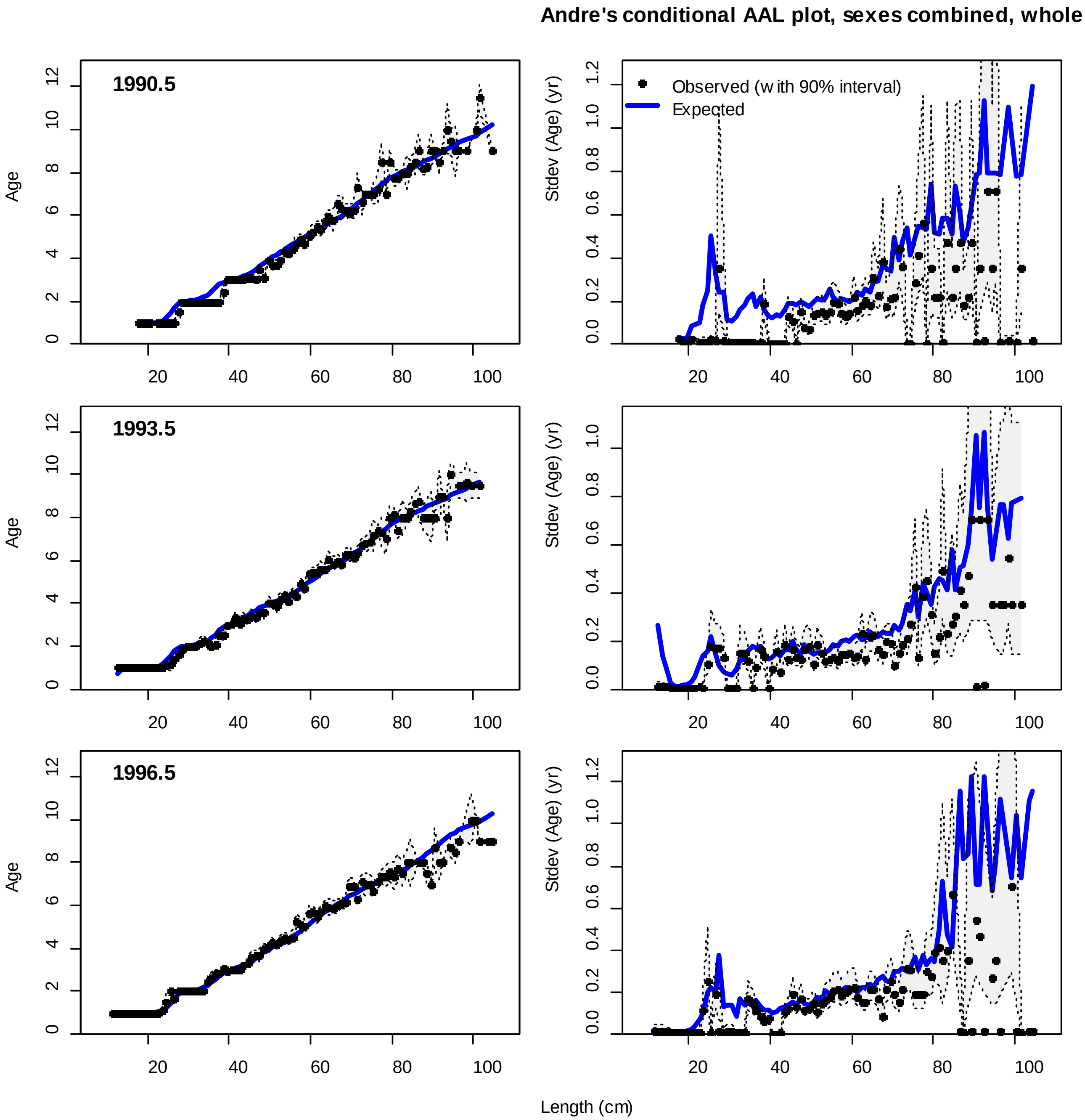
Figure 17 – Conditional age-at-length for Model S1a



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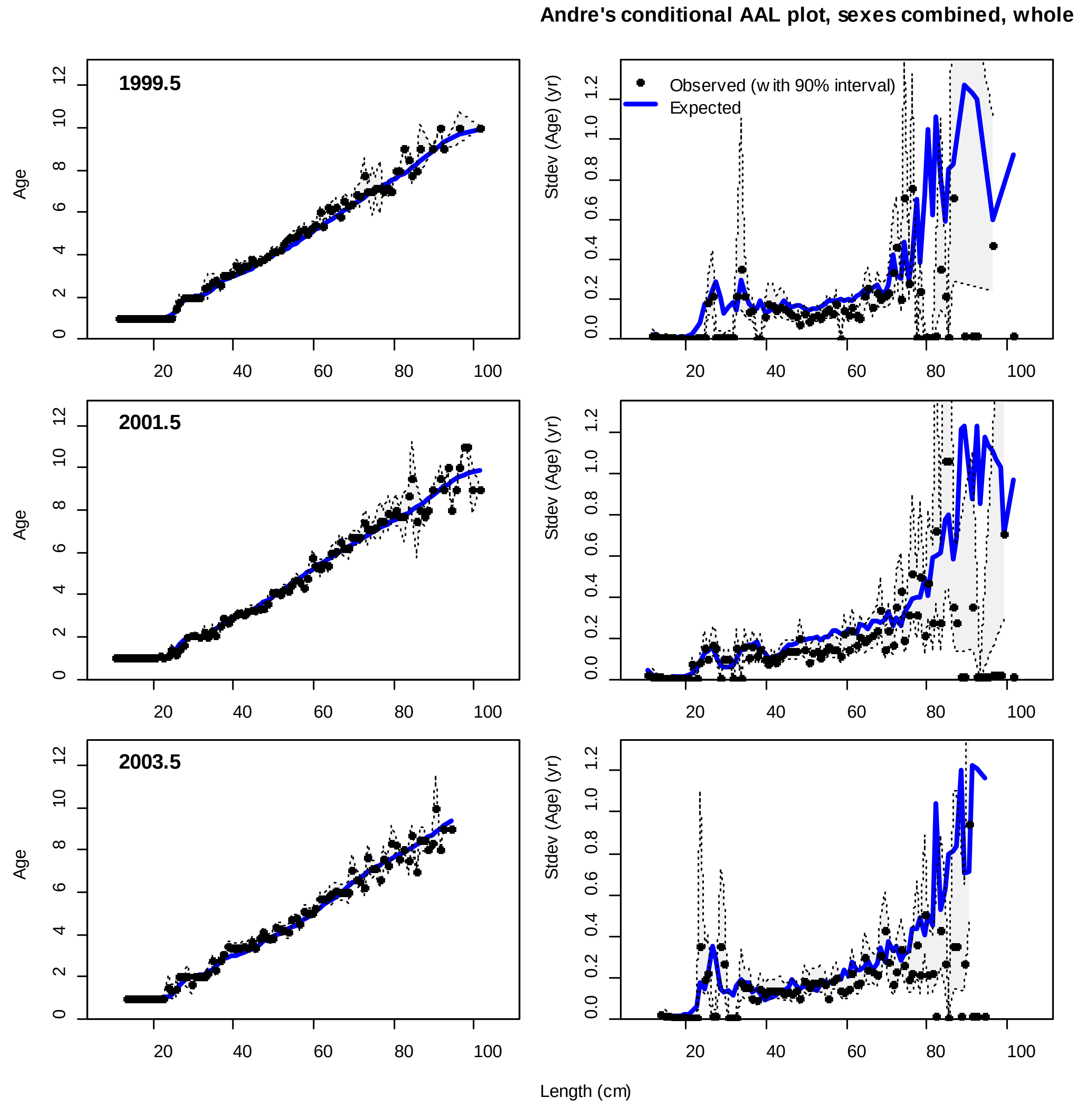
Andre's conditional AAL plot, sexes combined, whole
1999.5
2001.5
2003.5
Age
Stdev (Age) (yr)
Observed (with 90% interval)
Expected
Length (cm)

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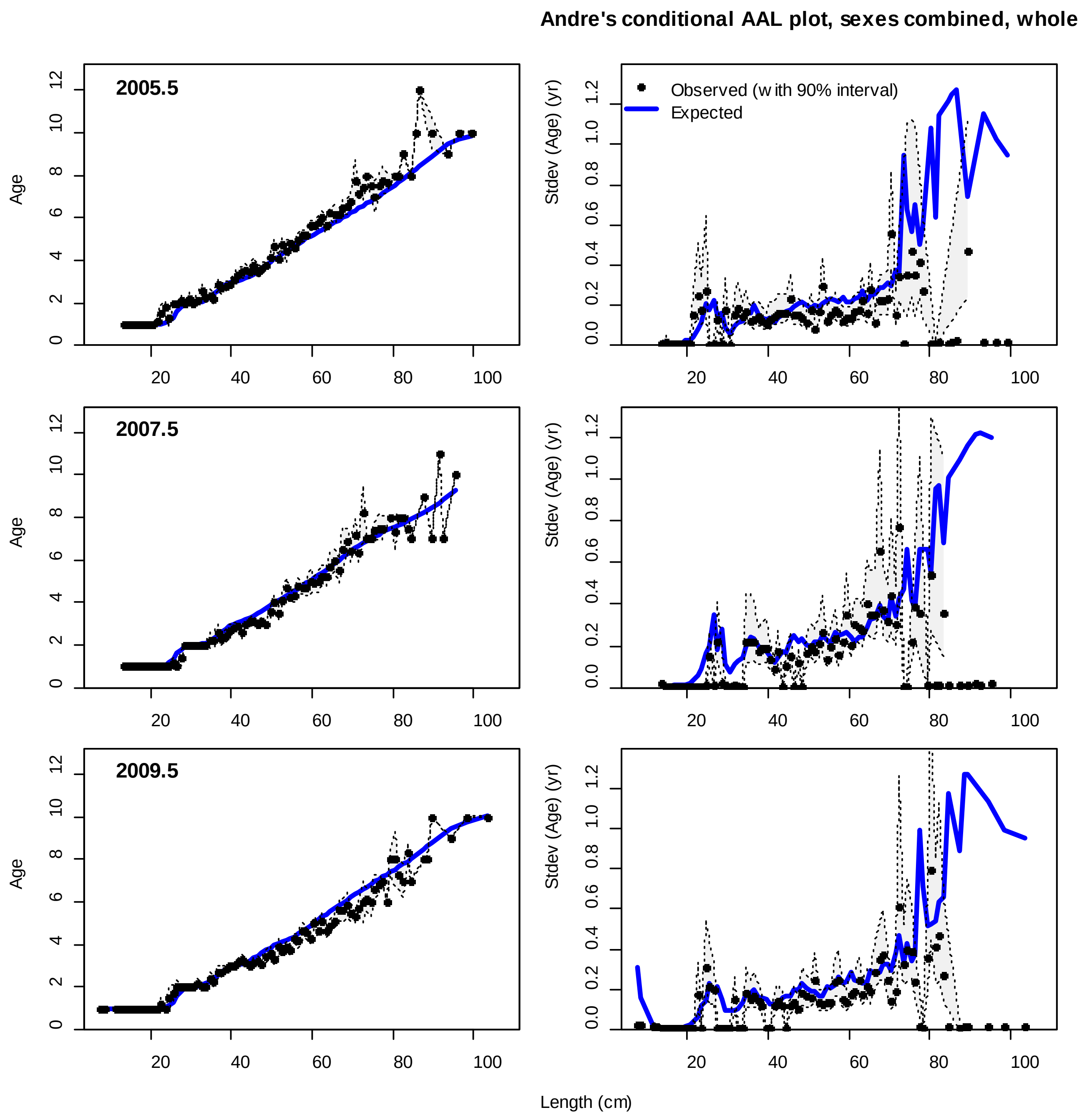
Andre's conditional AAL plot, sexes combined, whole
2005.5
2007.5
2009.5
Age
Stdev (Age) (yr)
Observed (with 90% interval)
Expected
Length (cm)

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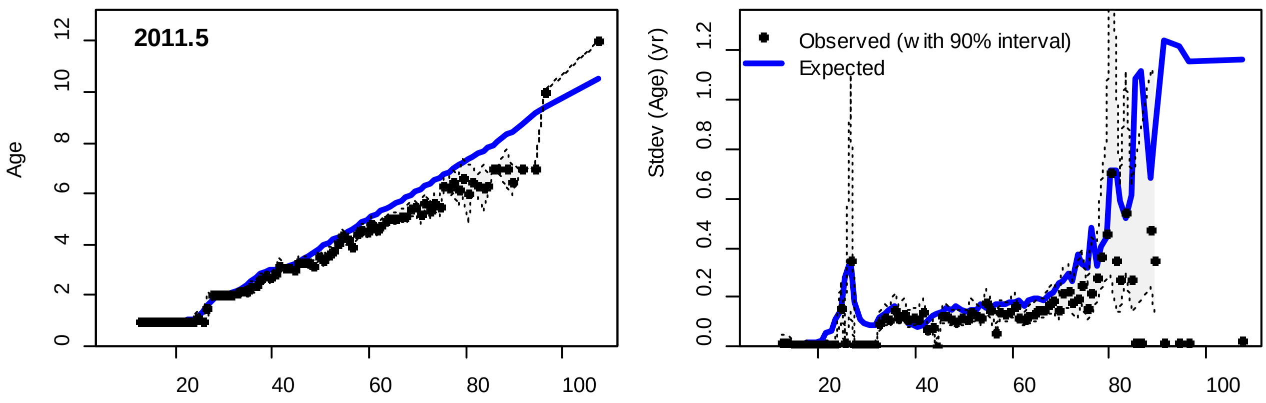
Andre's conditional AAL plot, sexes combined, whole



Length (cm)

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Figure 18 – Progression of Model P3 through additional survey variance and sample size tuning – spawning biomass

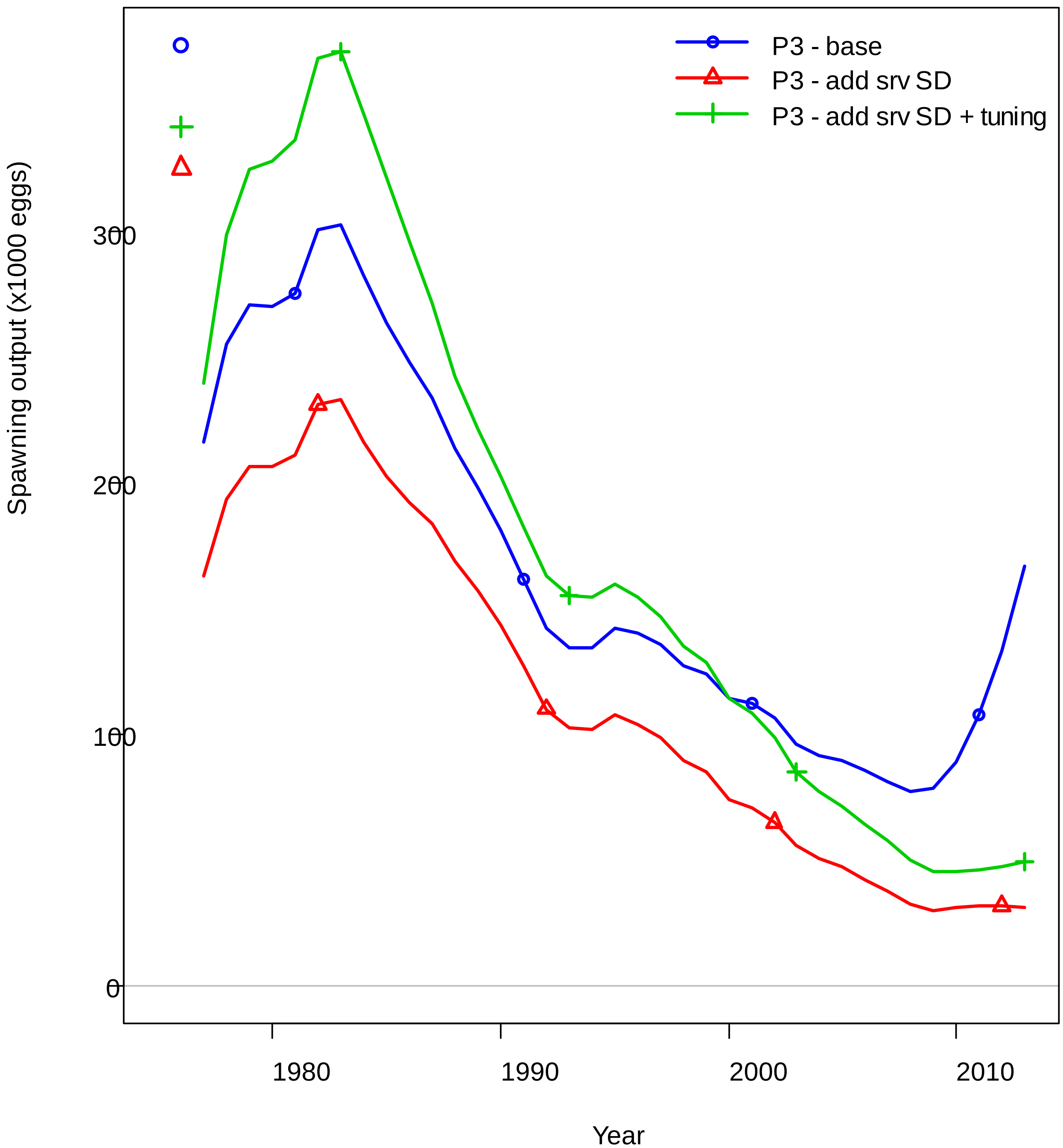

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Figure 19 – Progression of Model P3 through additional survey variance and sample size tuning – age-0 recruits

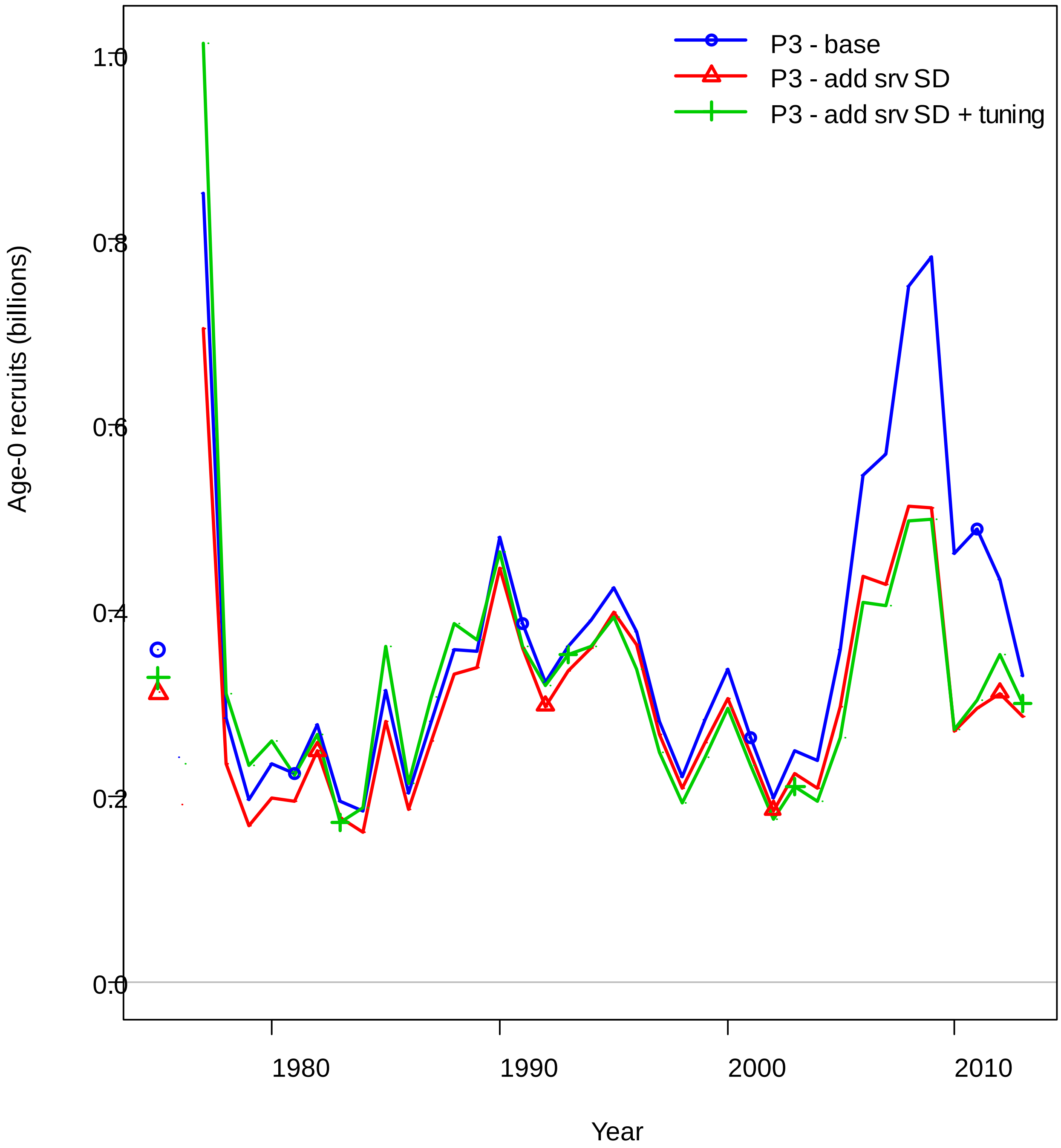

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Figure 20 – Progression of Model P3 through additional survey variance and sample size tuning – 27plus survey

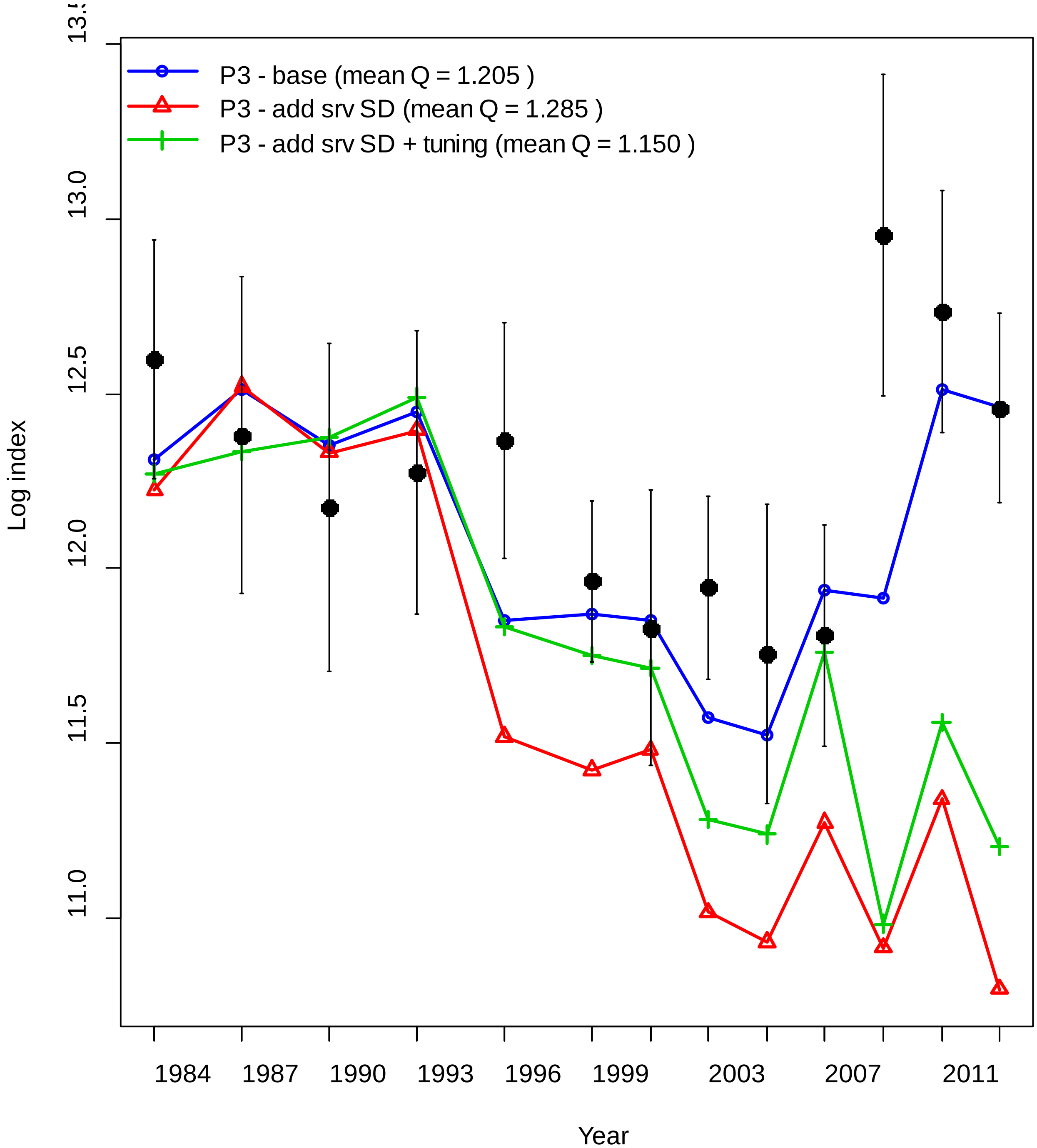

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Figure 21 - Progression of Model P4 – 2 per through additional survey variance and sample size tuning – spawning biomass

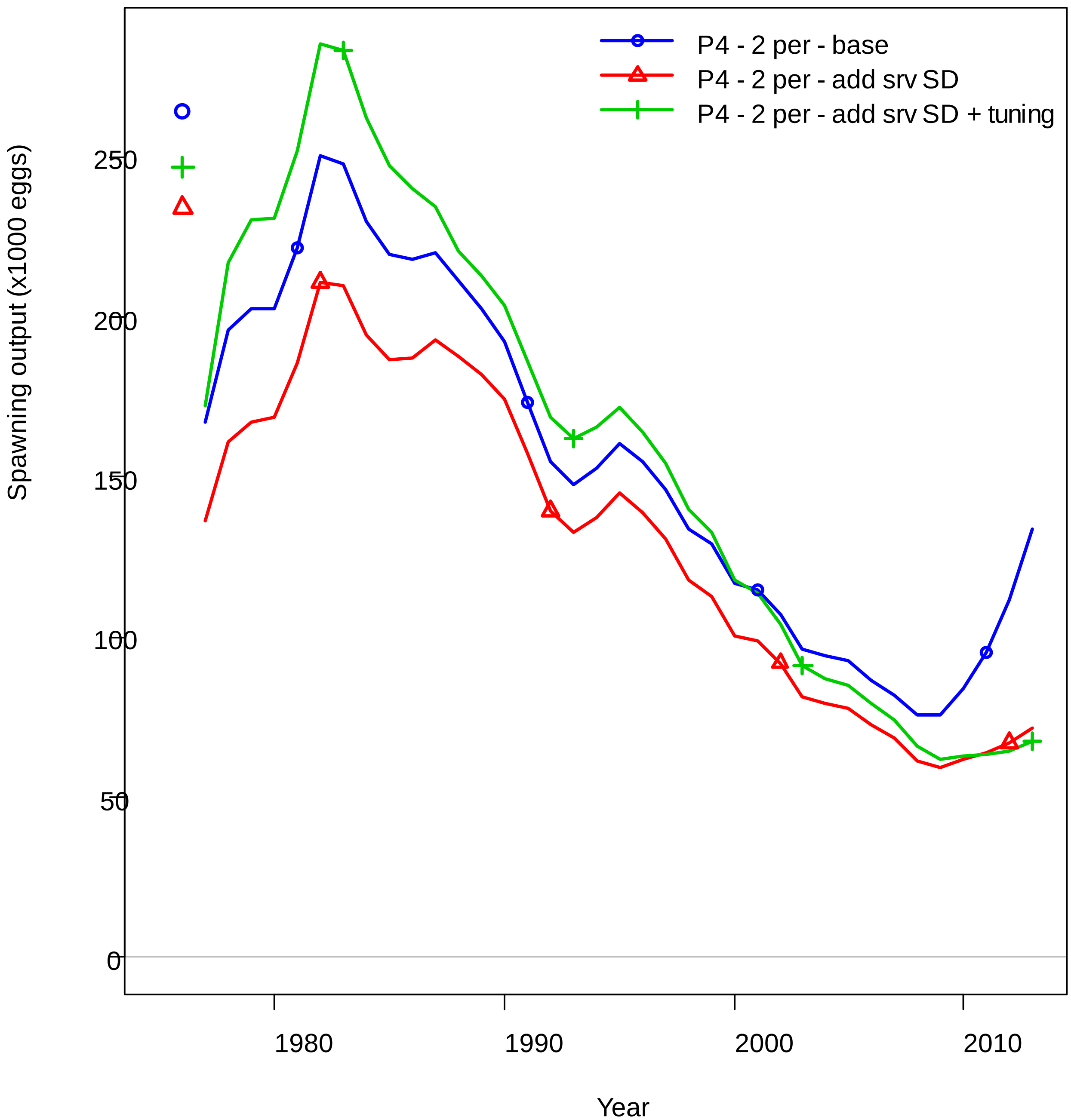

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Figure 22 – Progression of Model P4 – 2 per through additional survey variance and sample size tuning – age-0 recruits

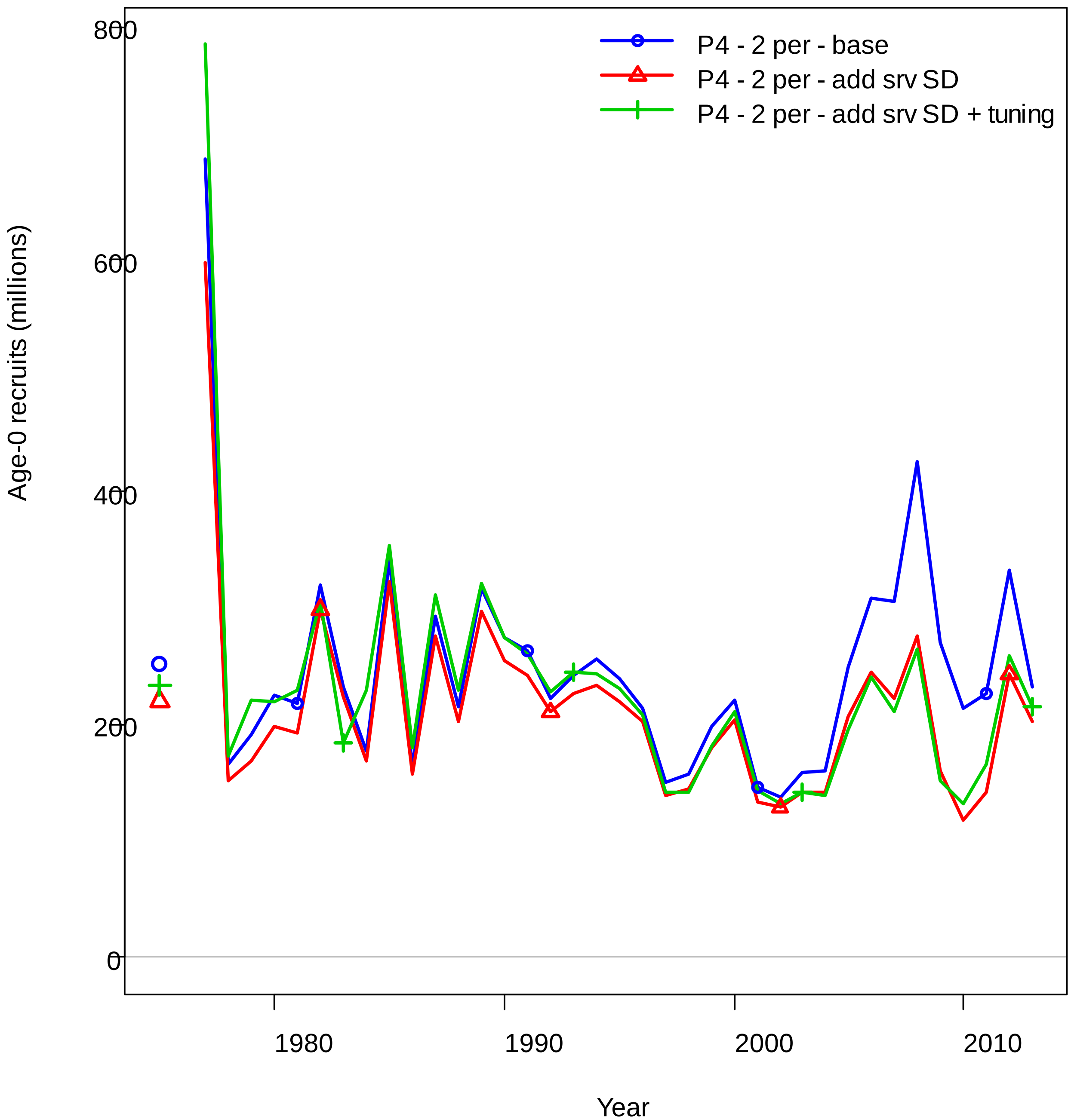

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Figure 23 – Progression of Model P4 – 2 per through additional survey variance and sample size tuning – 27plus survey

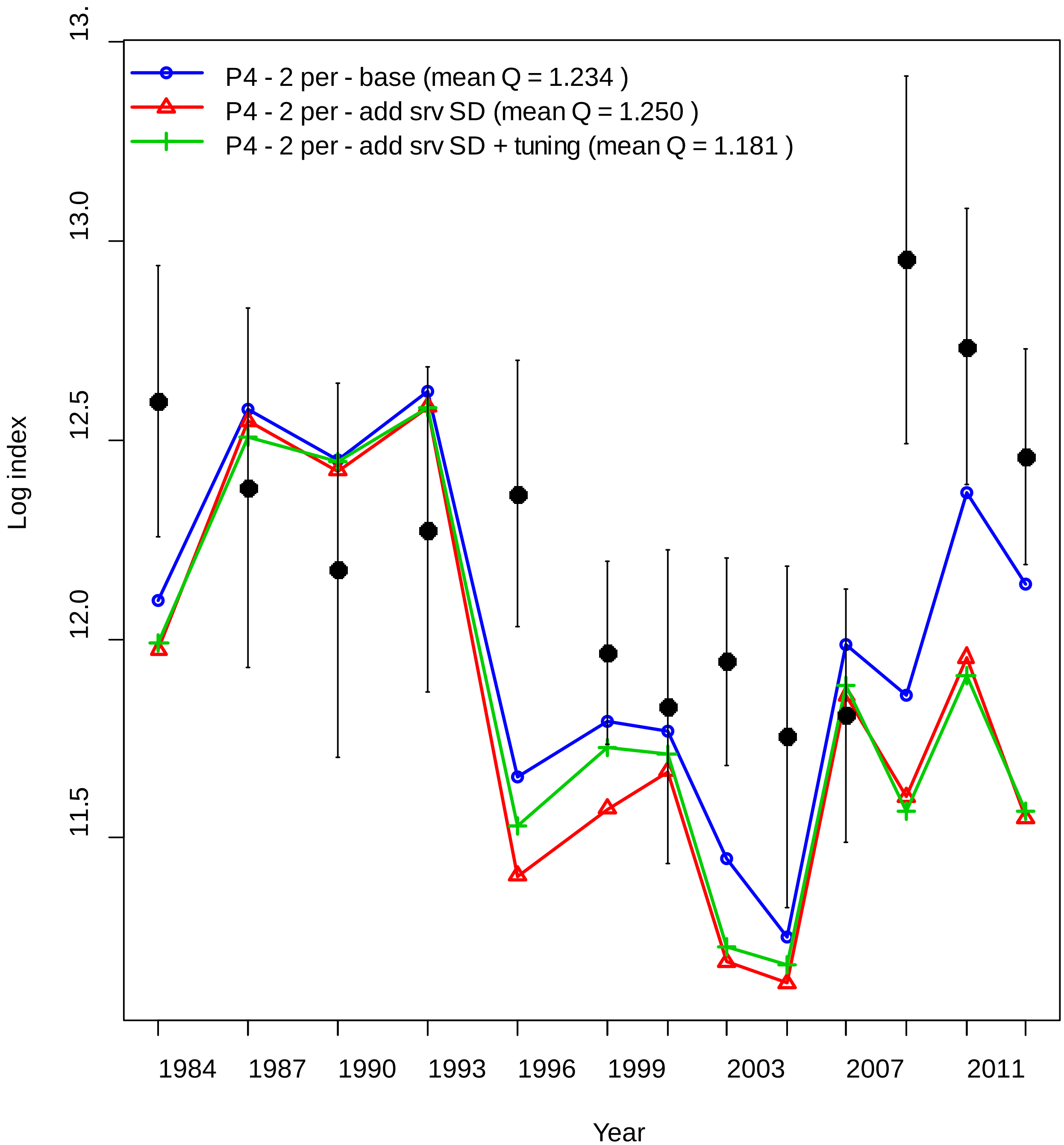

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Figure 24 – Progression of Model P4 – 2 per through additional survey variance and sample size tuning – sub27 survey

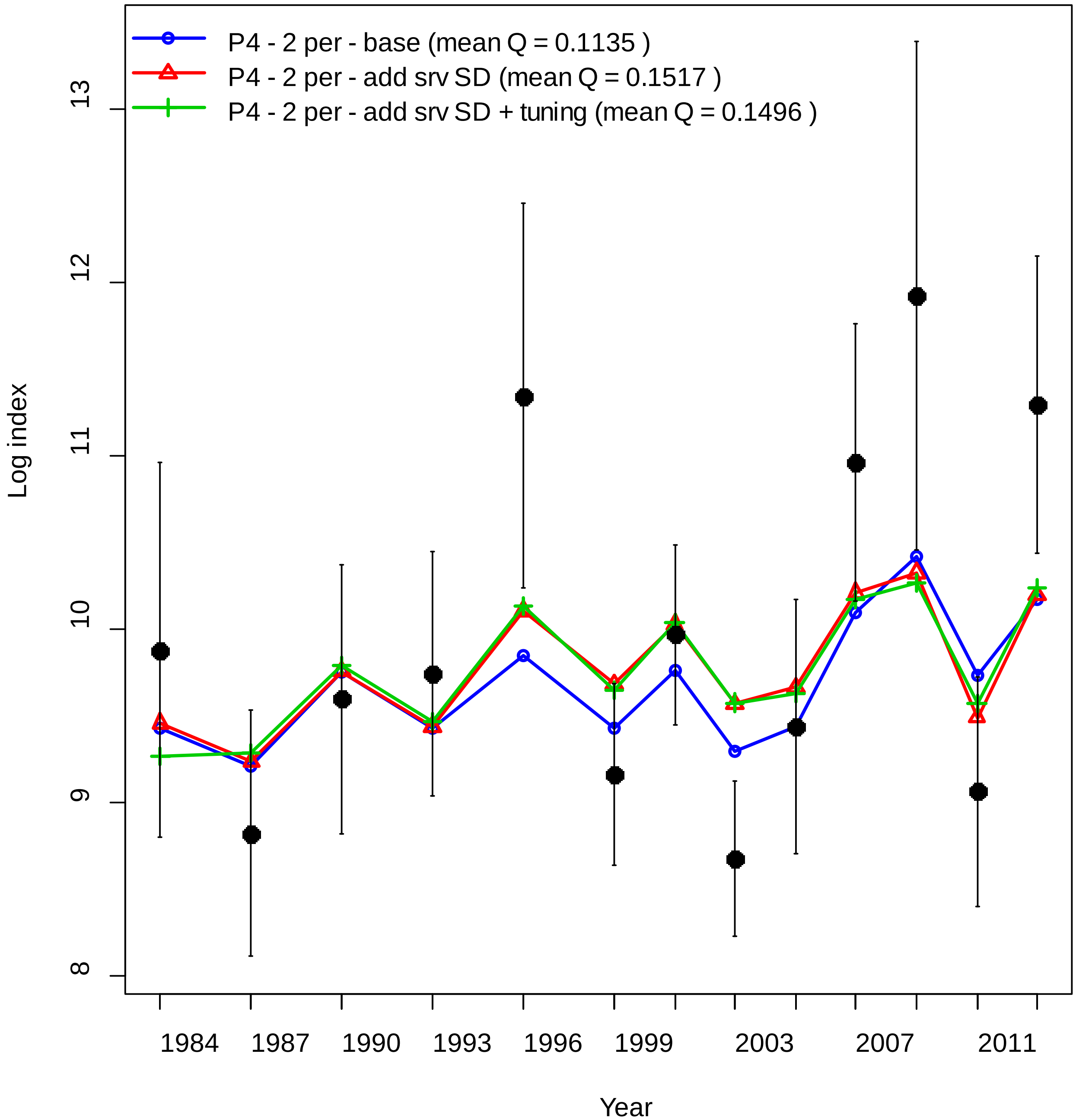

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Figure 25 – Likelihood profiles for Models P0 and S1a

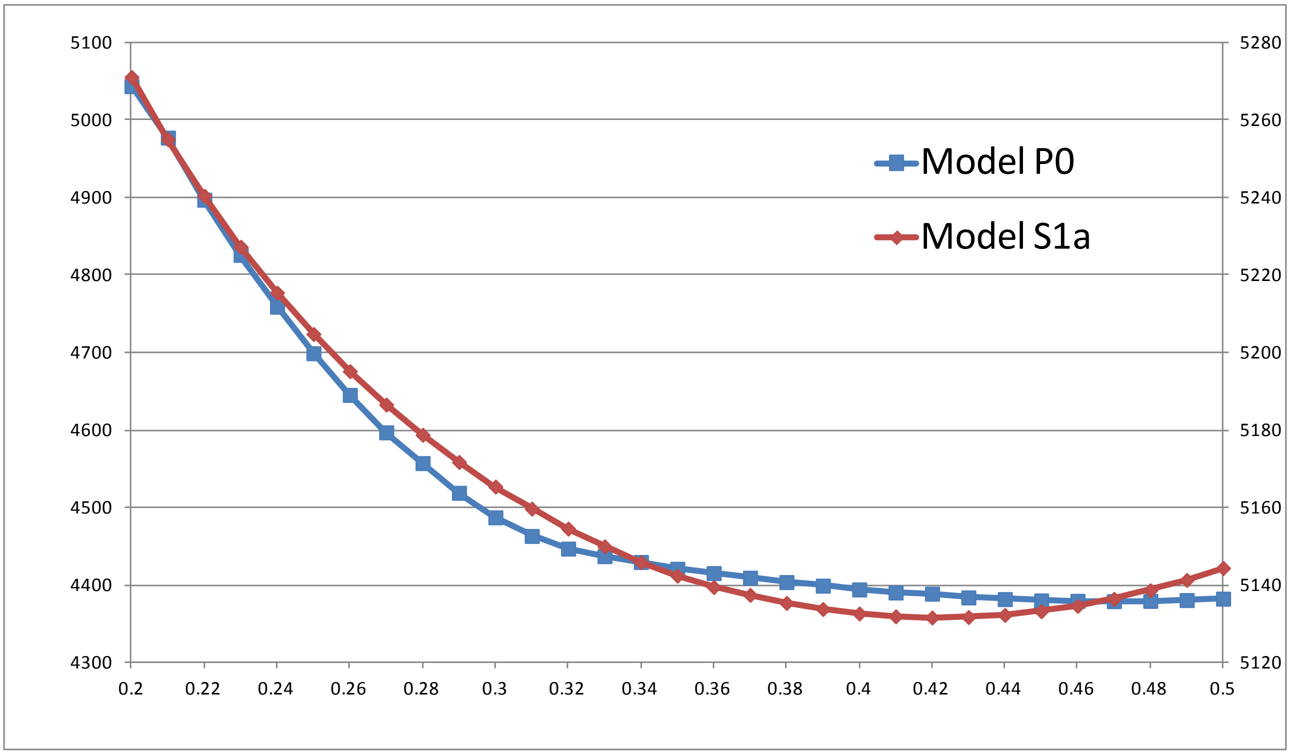

Figure 26 – Likelihood profile values for estimated Q for the early period (1984 – 1993)