DRAFT

An exploration of GOA Pacific cod stock assessment models for 2013

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 2012 assessments of the Pacific cod (*Gadus macrocephalus*) stocks in the Gulf of Alaska (A'mar et al., 2012). 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 2012 GOA Pacific cod stock assessment.

Comments from the Plan Teams and SSC

SSC Comments from the December 2012 Minutes

SSC1: "Omitting mean size-at-age data for the 27+ group (Models 3 & 4) had a large effect on biomass estimates (estimating substantially higher biomass levels in the 1980s) and a strong impact on model fits. The Plan Team recommended, and the SSC concurs, to consider down-weighting rather than omitting the mean size-at-age data to more appropriately reflect the effective sample sizes associated with the data. It would also be informative to explore how the exclusion of the size-at-age data in models 3 & 4 interacts with other features of the model to result in these apparently inflated biomass estimates."
Response: The initial results from a model configuration with downweighting the fit to the survey mean size-at-age data are included as Model 9.

SSC2: "The estimated fishery selectivities-at-length are extremely peaked for most fisheries and the resulting low selectivities for larger size classes imply high abundances of "cryptic" large Pacific cod. While similar patterns are seen in the EBS and Aleutians there is continuing large uncertainty about how to appropriately parameterize selectivity. We encourage the authors to carefully evaluate the impact of the chosen form for selectivity curves on model results and to examine how changes in selectivity interact with the treatment of growth and inclusion of mean size-at-age data."
Response: The initial values of all estimated selectivity parameters were changed from the values used in 2012 to values which allowed for more broadly defined selectivity curves. The initial results from these model configurations are included with the designation "N".

SSC3: "Of particular concern is the time varying pattern of dome-shaped selectivity with age in the survey based on very little data prior to the 1990s (Fig. 2.11). It is doubtful that age-based selectivity for the early time period can be reliably estimated if only age data from 1990-2011 was used in the model (as indicated in Table 2.7, where data from 1987 were omitted). It was not clear from the documentation if there were any composition data to inform the first time-block of selectivity for the trawl survey. The SSC encourages the

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.

DRAFT

author to develop a model with length-based survey selectivity to take advantage of available length data from all survey years."
Response: The initial results from this model configuration are included as Model 7.

SSC4: "While there are legitimate concerns about the high variability of the sub-27 group, omitting the data may not be consistent with using the best available information. However, using time varying catchability with an index that primarily reflects variability due to incoming year classes is clearly not appropriate."
Response: Model 3 is a model configuration with two catchability and selectivity periods for the sub-27 survey.

SSC5: "To improve fits to the size data, the author may also want to consider using the Richards growth curve to parameterize growth as in Model 4 in the EBS Pcod assessment."
Response: The initial results from this model configuration are included as Model 8.

Joint Plan Team Comments from the May 2013 Minutes

*JPT1: "**For the preliminary GOA assessment, the Teams recommend that the following models be included:***

0. *The 2011 final model*
1. *Last year's final model (Model 2)*
2. *Last year's Model 4, but with all selectivities forced to equal zero at age zero, growth parameters fixed at the values from Model 2, and time-invariant selectivity for the 27-plus survey*

The Teams also recommend that catchability for the 27-plus survey in the GOA models not be retuned unless the average of the product of catchability and selectivity across the 60-81 cm size range departs appreciably from the value of 0.92 estimated by Nichol et al. (2007)."
Response: The initial results from these model configurations are included as Models 1, 4, and 6, respectively.

SSC Comments from the June 2013 Minutes

SSC1: "For the preliminary GOA assessment, the Teams recommend including the following models:

- *The 2011 final model*
- *Last year's final model (Model 2)*
- *Last year's Model 4, but with all selectivities forced to equal zero at age zero, growth parameters fixed at the values from Model 2, and time-invariant survey selectivity for the 27-plus cm sized fish*

The SSC concurs with these recommendations and with the Team's recommendation to not re-tune survey catchability for the 27-plus sized fish in the GOA models unless the average of the product of catchability and selectivity across the 60-81 cm size range departs appreciably from the value of 0.92 estimated by Nichol et al. (2007). The SSC also recommends that the Author(s) investigate a more parsimonious model for comparison."
Response: The initial results from these model configurations are included as Models 1, 4, and 6, respectively.

Summary of the base model configuration

The base model configuration for 2013 is the 2012 Model 2 configuration. The software used to run all models was Stock Synthesis v3.24S as compiled on 24 July 2013 with ADMB v.10.1 (Last year's models used v3.24f as compiled on 03 August 2012 with ADMB v.11).

DRAFT

Model evaluation

Model configurations for 2013

The following details attributes of the requested models. All models with the designation "N" had the initial values for many parameters changed from their 2012 values to allow for assumption of no deviations w.r.t. pre-1996 27-plus survey catchability or initial R_0, wider bounds on R_0, and broader initial fishery and survey selectivity patterns.

Models 1 and 1N: 2011 Model 3 (the 2011 final model)

These models include:

- 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 – 2011, 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 (11 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

Models 2 and 2N: 2011 Model 3 with tail compression turned off

These models include the characteristics listed for Model 1.

Models 3 and 3N: 2011 Model 3 with tail compression turned off and the number of periods of catchability for the sub-27 survey changed from 11 to 2 and the number of periods for selectivity for the sub-27 survey changed from 1 to 2

These models include the characteristics listed for Model 1.

Models 4 and 4N: 2012 Model 2 (the 2012 final model, and the base model)

These models include:

- 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 – 2011; and
- Time-varying survey selectivity-at-age for the 27-plus survey (11 blocks)

Models 5 and 5N: 2012 Model 4 (2012 Model 2 with the 27-plus mean length-at-age data omitted)

DRAFT

These models include the characteristics listed for Model 4.

Models 6 and 6N: Model 5 with all selectivity curves forced to equal zero at age 0, growth parameters fixed at the values from 2012 Model 2, and the number of blocks for the 27-plus cm survey selectivity changed from 11 to 2

These models include:

- 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 – 2011; and
- Time-varying survey selectivity-at-age for the 27-plus survey (2 blocks)

Additional models run include:

Models 7 and 7N: Model 4 with fitting to the survey length composition data instead of the survey age composition data

Models 8 and 8N: Model 4 with the Richards growth model instead of the von Bertalanffy

Models 9 and 9N: Model 4 with the fit to the 27-plus survey mean size-at-age downweighted to 0.25

Models S-age and S-len: Sex-specific model with 3 gear types, one season, 3 periods for the trawl and longline fishery selectivity curves, two periods for the pot and survey selectivity curves, two periods for survey catchability

Model	1	2	3	4	5	6	7	8	9	S
Catchability value	1.04	1.04	1.04	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tail compression off?	no	yes	yes	yes	yes	yes	yes	yes	yes	yes
Sub-27 abundance and sizecomp data omitted?	no	no	no	yes	yes	yes	yes	yes	yes	no
Sub-27 mean size-at-age data omitted?	no	no	no	yes	yes	yes	yes	yes	yes	no
27-plus mean size-at-age data omitted?	no	no	no	no	yes	yes	no	no	no	no

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.

DRAFT

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.

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.

DRAFT

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, 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.

DRAFT

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 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 addition, all models except Models 5, 5N, 6, and 6N included a likelihood component for survey mean size-at-age.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in previous assessments, likelihood components were given an emphasis of 1.0 in the present assessment, except for Models 9 and 9N, where the likelihood component for survey mean size-at-age data was given an emphasis of 0.25.

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

DRAFT

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.

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 except for Models 2, 2N, 5, and 5N were requested or suggested by the SSC and/or Plan Team. Models 7 and 7N did not converge, and Models S-age and S-len produced unreasonable biomass and recruitment patterns.

DRAFT

Model evaluation

The 16 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.

Comparing and Contrasting the Models

The model configurations evaluated focused on exploring the impact of different combinations of 27-plus and sub-27 survey data and the survey mean size-at-age data on model fit. There are 3 sets of model configurations from the 2011 base model configuration, Models 1, 1N, 2, 2N, 3, and 3N; and 5 sets of model configurations from the 2012 base model configuration, Models 4, 4N, 5, 5N, 6, 6N, 8, 8N, 9, and 9N.

Out of each pair of model configurations, e.g., Models 1 and 1N, the model configuration with the lowest AIC value was used in the overall model comparisons. Models 8N and 9N were the only model configurations where the AIC value was less than that for their respective model configurations which used the 2012 initial values for the parameters; Model 2N had a negative log likelihood value less than that for Model 2. This results in 8 model configurations used for the comparisons below, Models 1, 2, 3, 4, 5, 6, 8N, and 9N.

Evaluation Criteria

The estimates of spawning biomass are similar across all model configurations, although spawning biomass for the recent period is flat in Model 3 and increasing in the other model configurations (Figs. 1 and 2). The estimates of age-0 recruits are similar across all model configurations through the year 2000; the last 10 years of estimates are somewhat similar in pattern but differ significantly in magnitude (Figs. 3 and 4).

The estimates of the 27-plus survey indices vary somewhat for 1984 through 1993, and vary considerably for 1996 on (Figs. 5 and 6). Models 1, 2, 3, 4, 5, 8N, and 9N estimate 11 selectivity curves for the 27-plus survey; and Model 6 estimates 2 selectivity curves. The estimates of the sub-27 survey log indices are virtually identical for Models 1, 1N, 2, and 2N, and significantly different for Models 3 and 3N. Models 1, 1N, 2, and 2N have 11 catchability values and one selectivity curve for the sub-27 survey, and Models 3 and 3N have two catchability values and two selectivity curves.

The estimates of growth parameters are similar among Models 1, 1N, 2, 2N, 3, and 3N; and similar among Models 4, 4N, 6, 6N, 9, and 9N. Models 5 and 5N have growth parameters that were fixed on values estimated in 2012, which differ from the values estimated in the other 2012 model configurations. Models 8 and 8N estimate an additional growth parameter for the Richards growth curve, which differs from the value which would match the von Bertalanffy growth curve, 1.0, for both model configurations.

DRAFT

Tables

Table 1 – The likelihood components, number of parameters, and AIC values for the SS3 model configurations.

Model	1	2	3	4	5	6	7	8	9
AIC	**8100.38**	**8441.74**	**8295.02**	**7332.18**	**6231.56**	**6495.90**	x	7323.88	6568.88
# parameters	253	253	245	239	239	199		240	239
Total NLL	3797.19	3967.87	3902.51	3427.09	2876.78	3048.95	x	3421.94	3045.44
Survey	2.89	3.54	12.45	1.18	-6.90	-8.00		2.49	0.96
Fishery length comp	2889.35	2920.85	2913.31	2798.05	2784.49	2806.49		2801.53	2785.69
Survey length comp	186.01	266.73	225.53	95.83	77.82	116.19		91.27	95.81
Survey age comp	117.70	161.97	142.10	93.80	42.28	149.31		95.80	49.15
Survey size-at-age	623.15	636.60	632.25	459.96	0.00	0.00		452.47	137.55
Recruitment	-22.06	-21.98	-23.36	-21.86	-21.01	-15.17		-21.76	-23.81
Model	1N	2N	3N	4N	5N	6N	7N	8N	9N
AIC	8226.54	8454.98	8405.24	7571.16	6296.36	6566.74		**7283.92**	**6560.10**
# parameters	263	262	255	244	241	199		244	249
Total NLL	3850.27	3965.49	3947.62	3541.58	2907.18	3084.37	x	3397.96	3031.05
Survey	49.95	3.57	9.44	47.99	-4.85	-2.53		5.55	-3.03
Fishery length comp	2877.96	2919.63	2932.55	2825.38	2816.16	2834.44		2790.02	2782.82
Survey length comp	185.82	266.46	236.11	140.51	74.94	115.43		87.05	90.53
Survey age comp	123.69	157.46	148.09	86.35	39.85	152.35		92.24	43.64
Survey size-at-age	633.41	641.58	644.00	462.74	0.00	0.00		444.91	139.50
Recruitment	-20.79	-23.37	-22.80	-21.72	-19.09	-15.51		-21.95	-22.52

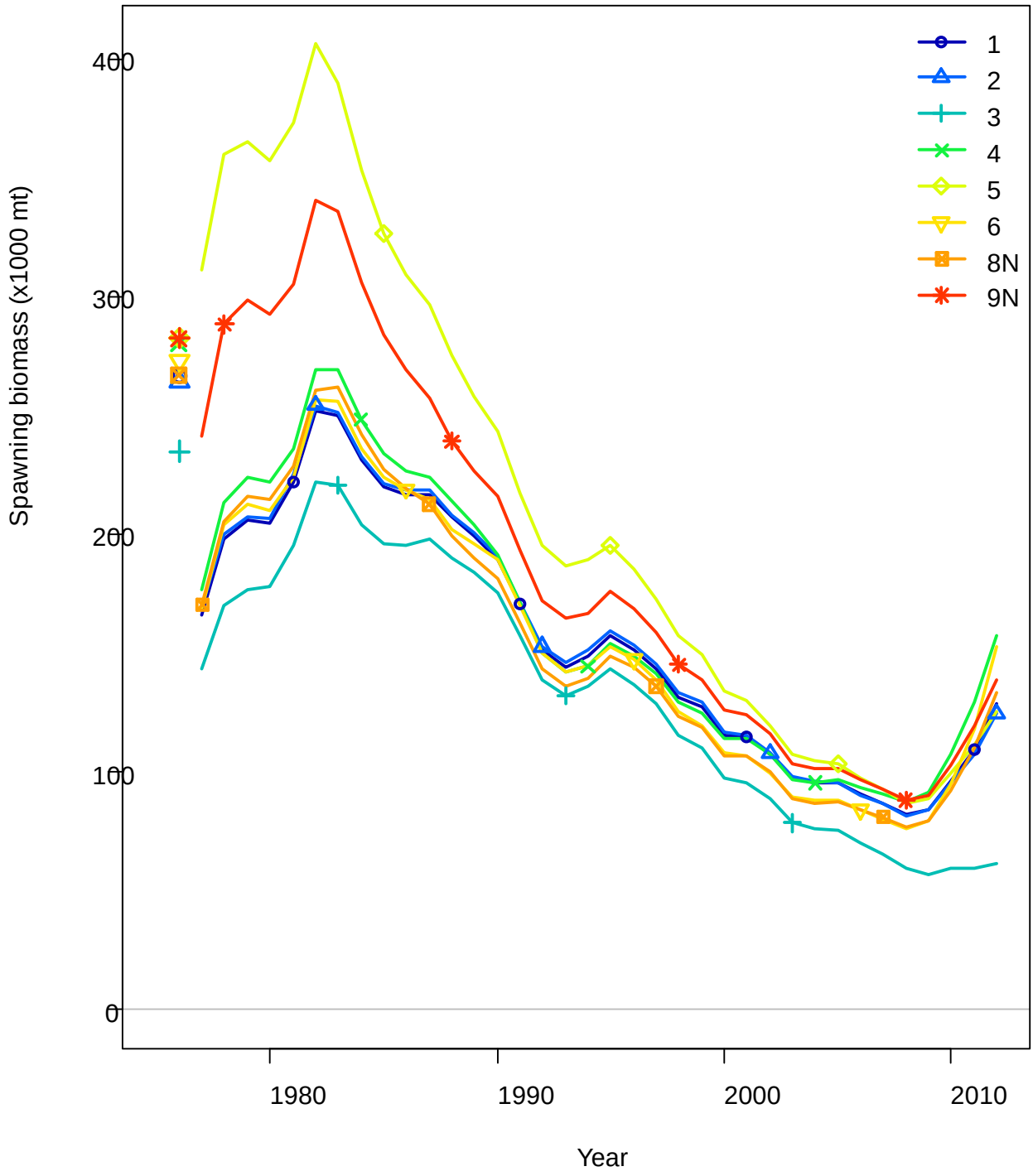
Table 2 – Parameter estimates for growth and median recruitment

Model	1	2	3	4	5	6	7	8	9
Length at A_{min}	20.64	20.55	20.59	26.71	27.07	24.86		27.19	27.11
Length at A_{max}	99.73	100.14	101.35	100.88	99.77	100.51		99.05	99.57
k	0.185	0.181	0.178	0.171	0.161	0.176		0.195	0.172
$\ln(R_0)$	12.43	12.43	12.31	12.45	12.54	12.43		12.44	12.47
Richards	1.0	1.0	1.0	1.0	1.0	1.0		0.750	1.0
Model	1N	2N	3N	4N	5N	6N	7N	8N	9N
Length at A_{min}	20.66	20.56	20.61	28.23	28.24	24.86		28.05	27.91
Length at A_{max}	100.32	99.98	100.56	108.61	101.28	100.51		99.19	99.64
k	0.183	0.182	0.181	0.143	0.150	0.176		0.197	0.169
$\ln(R_0)$	12.22	12.42	12.29	12.10	12.47	12.37		12.39	12.48
Richards	1.0	1.0	1.0	1.0	1.0	1.0		0.687	1.0

DRAFT

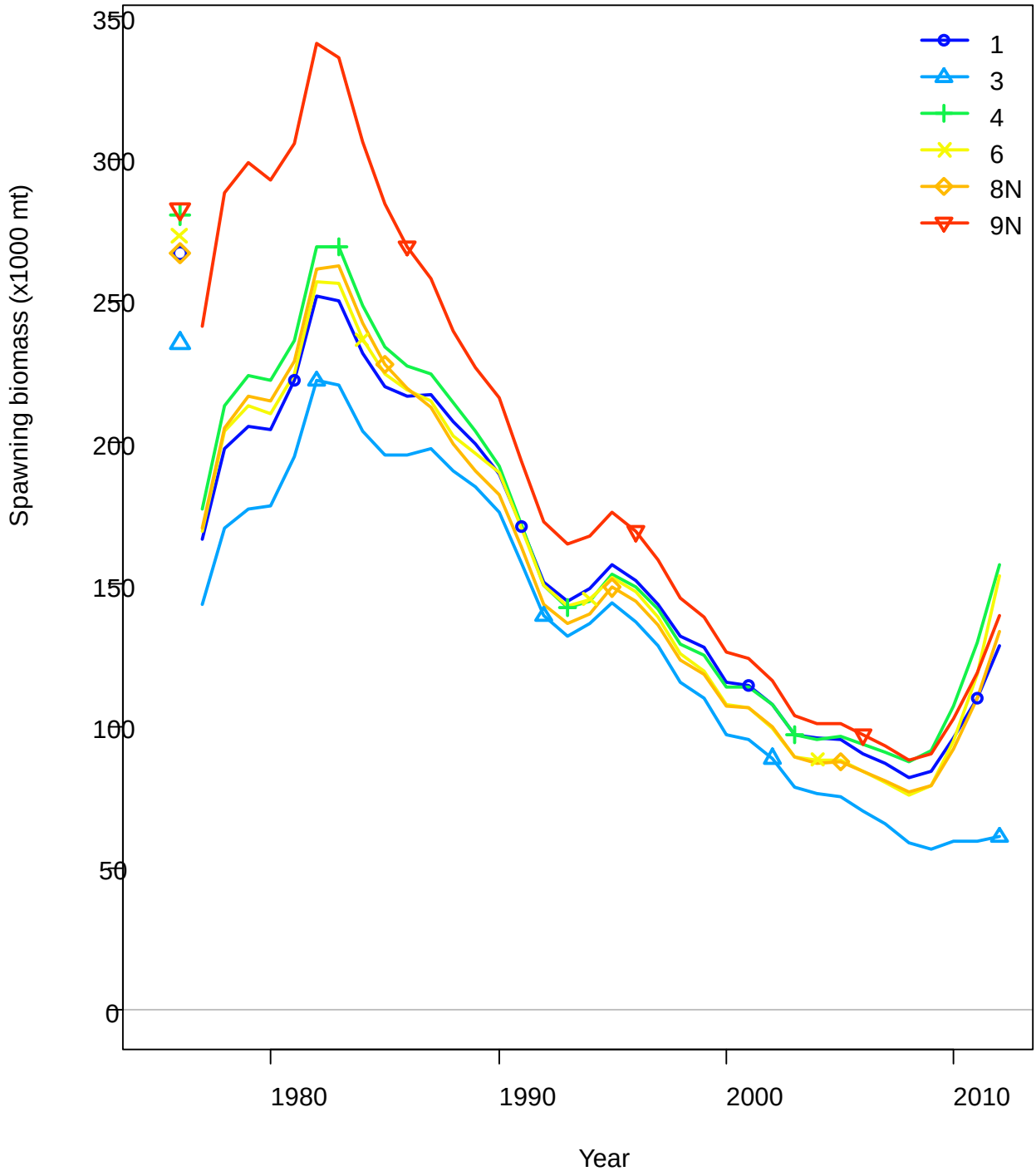
Figures

Figure 1 – Estimates of spawning biomass for Models 1, 2, 3, 4, 5, 6, 8N, and 9N



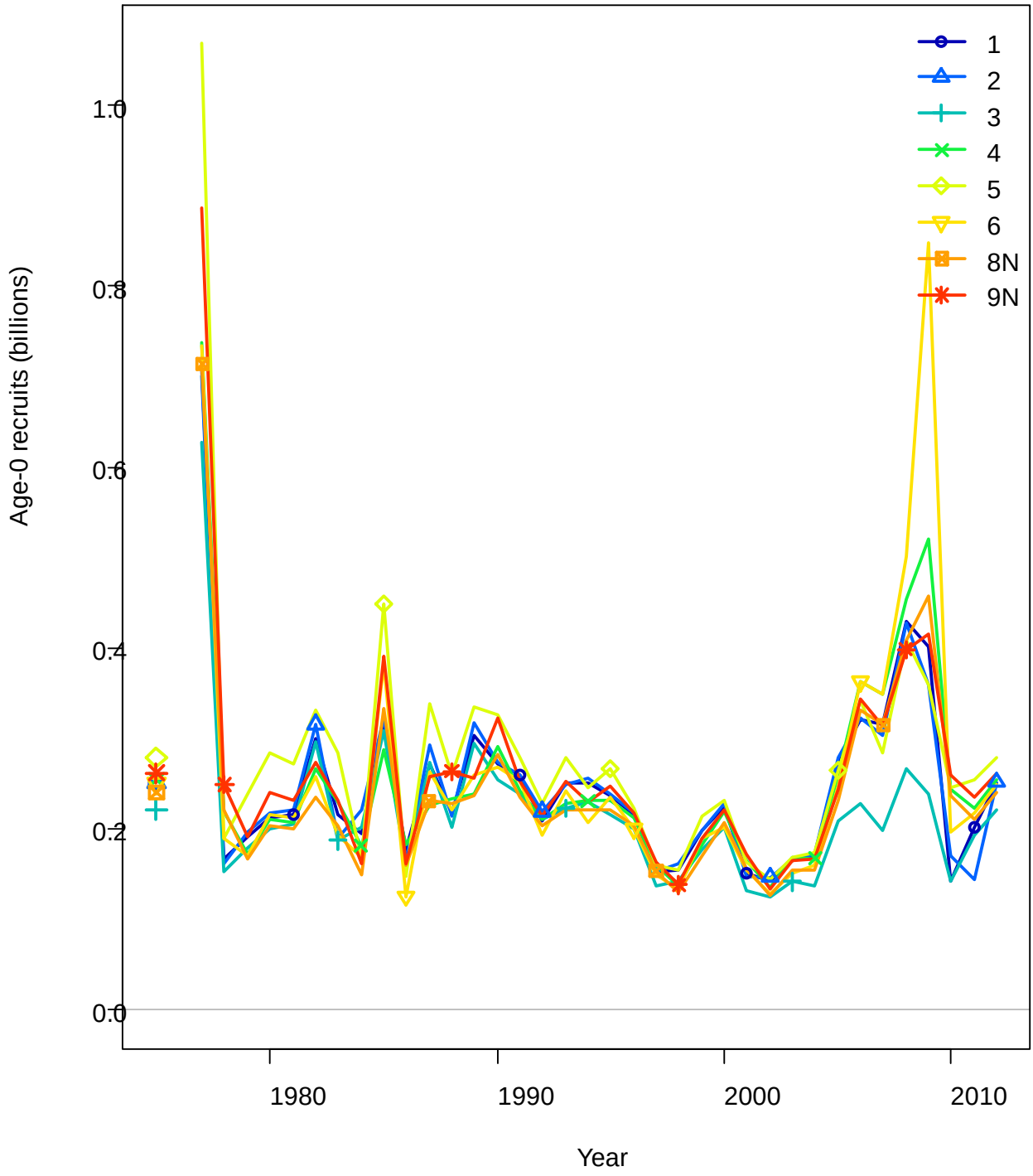
DRAFT

Figure 2 – Estimates of spawning biomass for Models 1, 3, 4, 6, 8N, and 9N



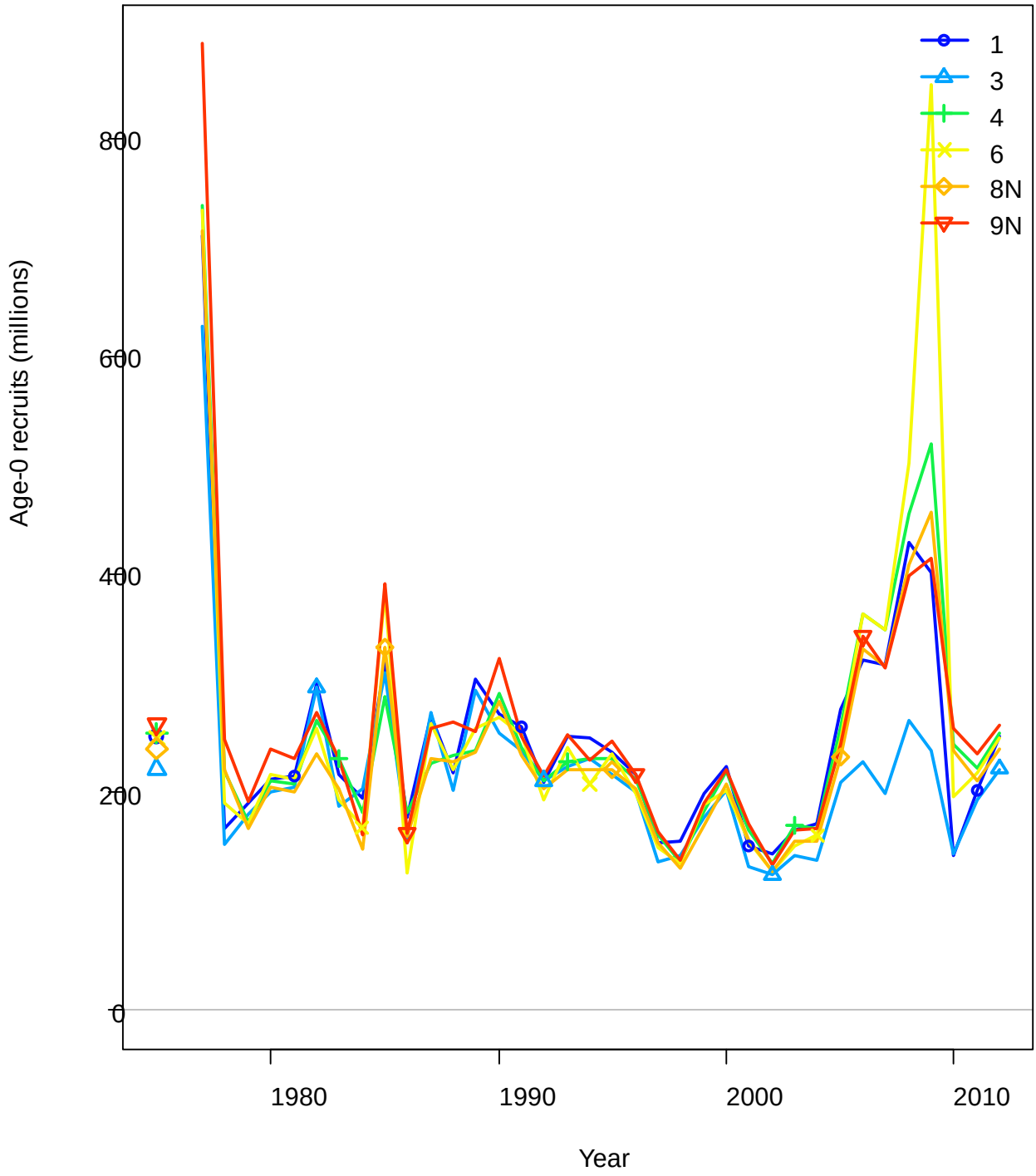
DRAFT

Figure 3 – Estimates of age-0 recruitment for Models 1, 2, 3, 4, 5, 6, 8N, and 9N



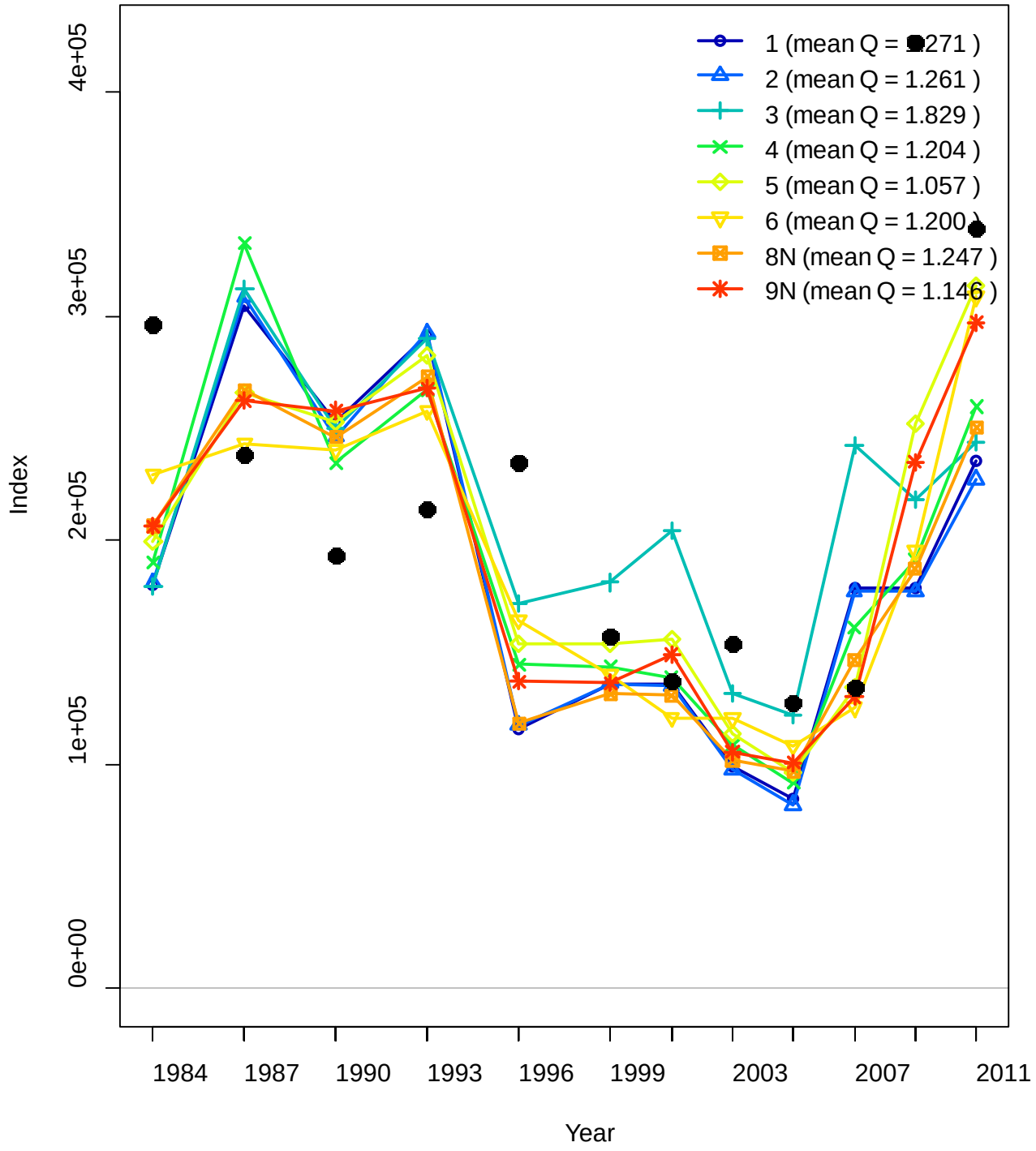
DRAFT

Figure 4 – Estimates of age-0 recruitment for Models 1, 3, 4, 6, 8N, and 9N



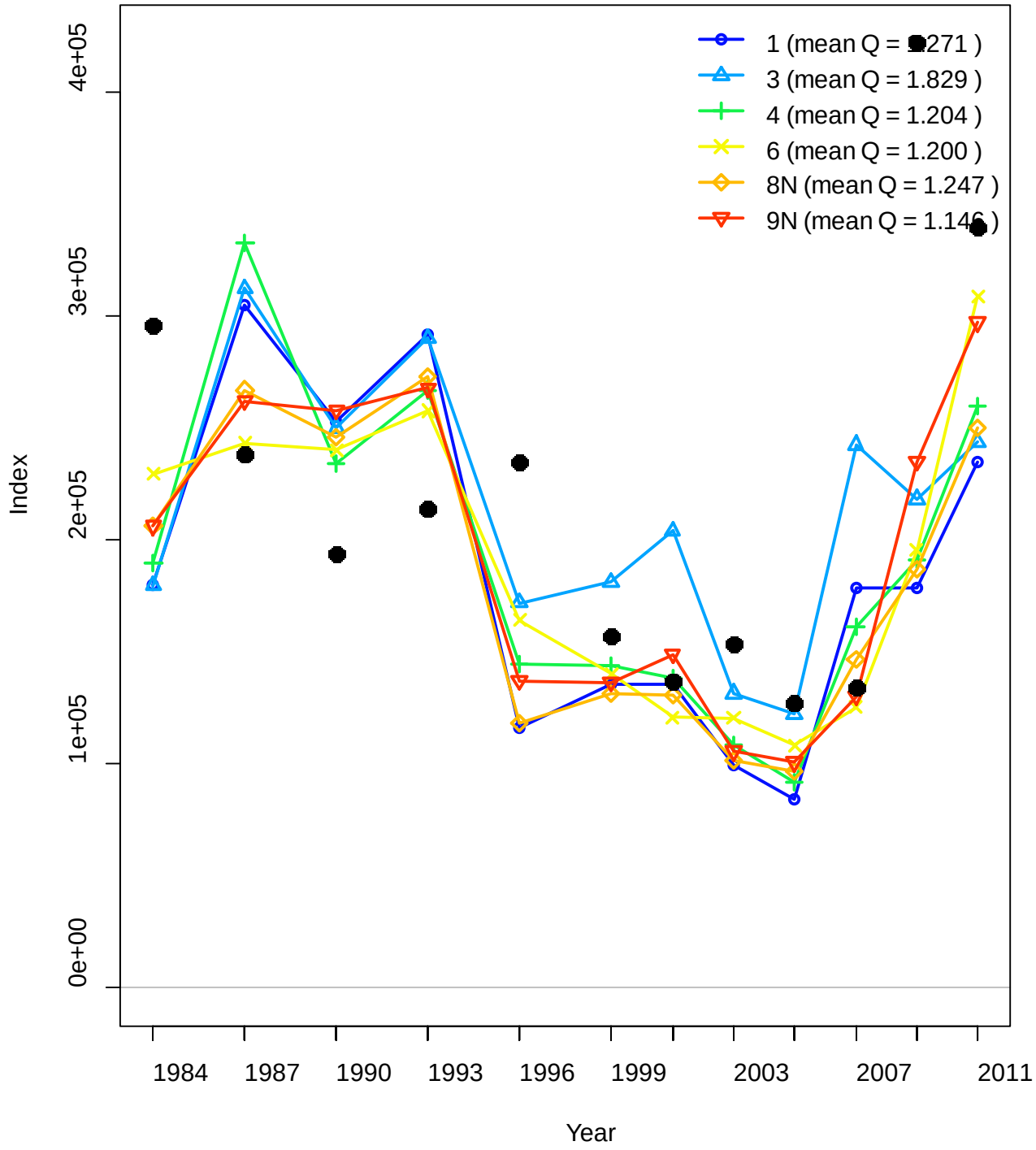
DRAFT

Figure 5 – The 27-plus survey for Models 1, 2, 3, 4, 5, 6, 8N, and 9N



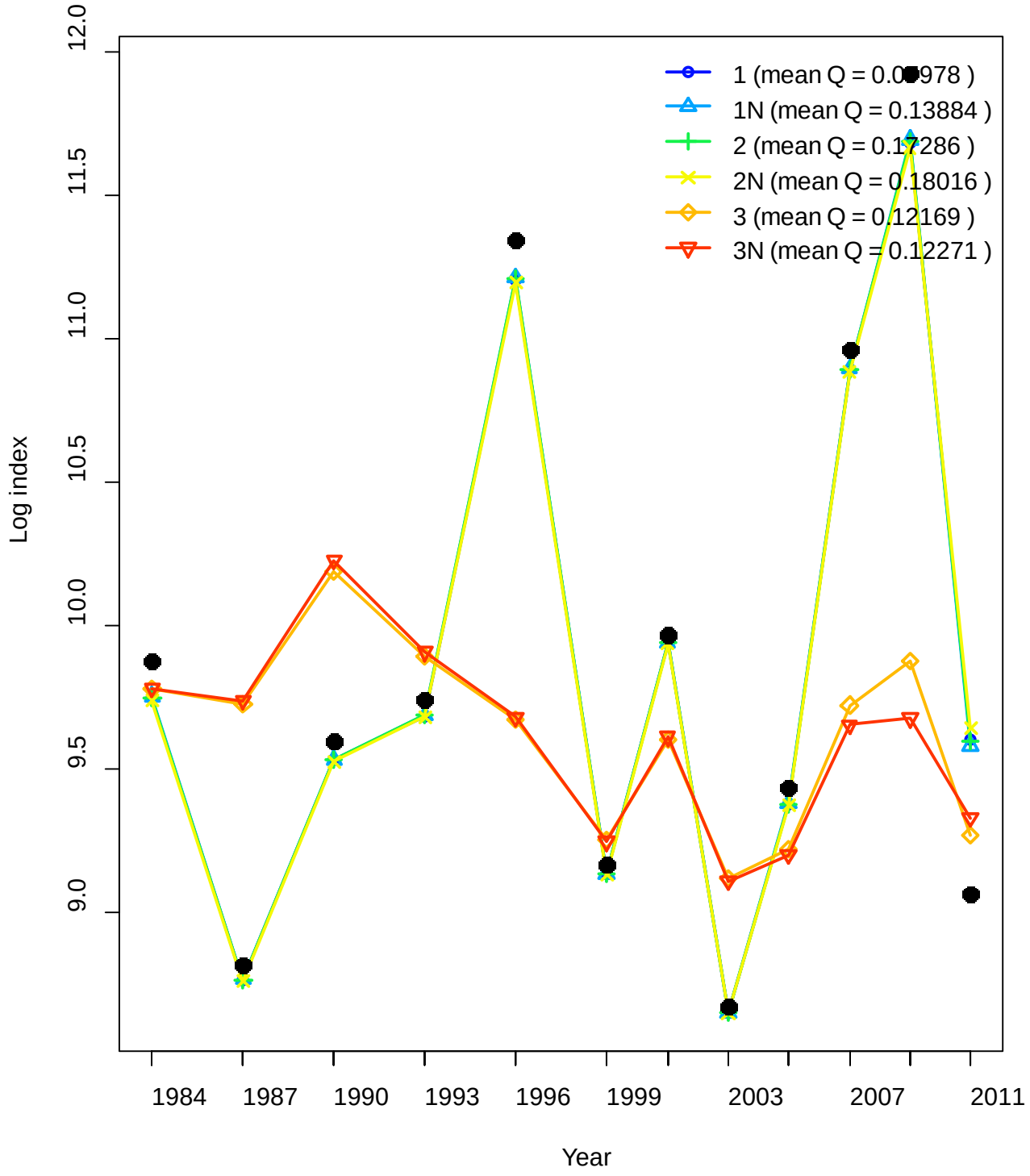
DRAFT

Figure 6 – The 27-plus survey for Models 1, 3, 4, 6, 8N, and 9N



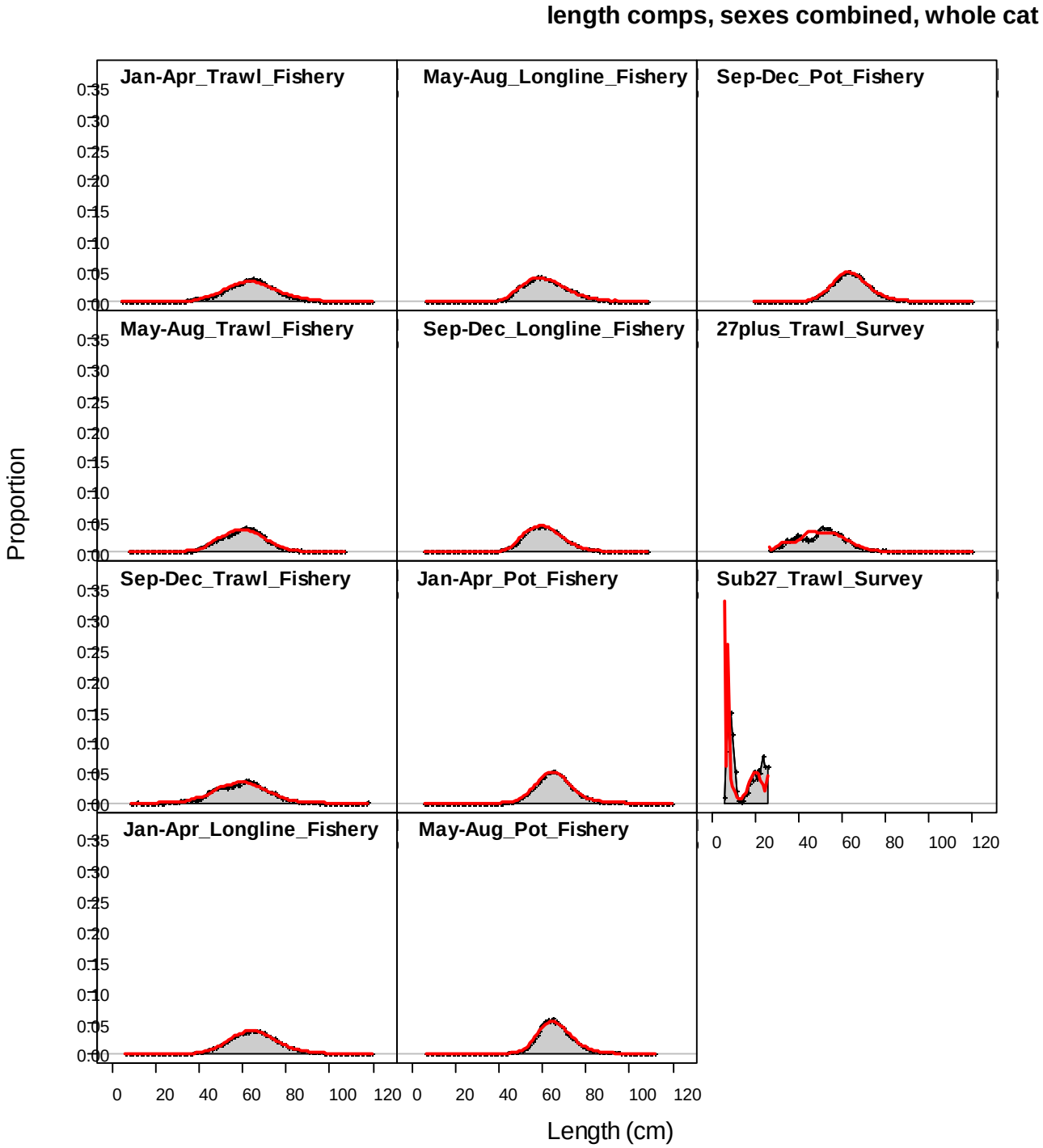
DRAFT

Figure 7 – The sub-27 survey for Models 1, 1N, 2, 2N, 3, and 3N



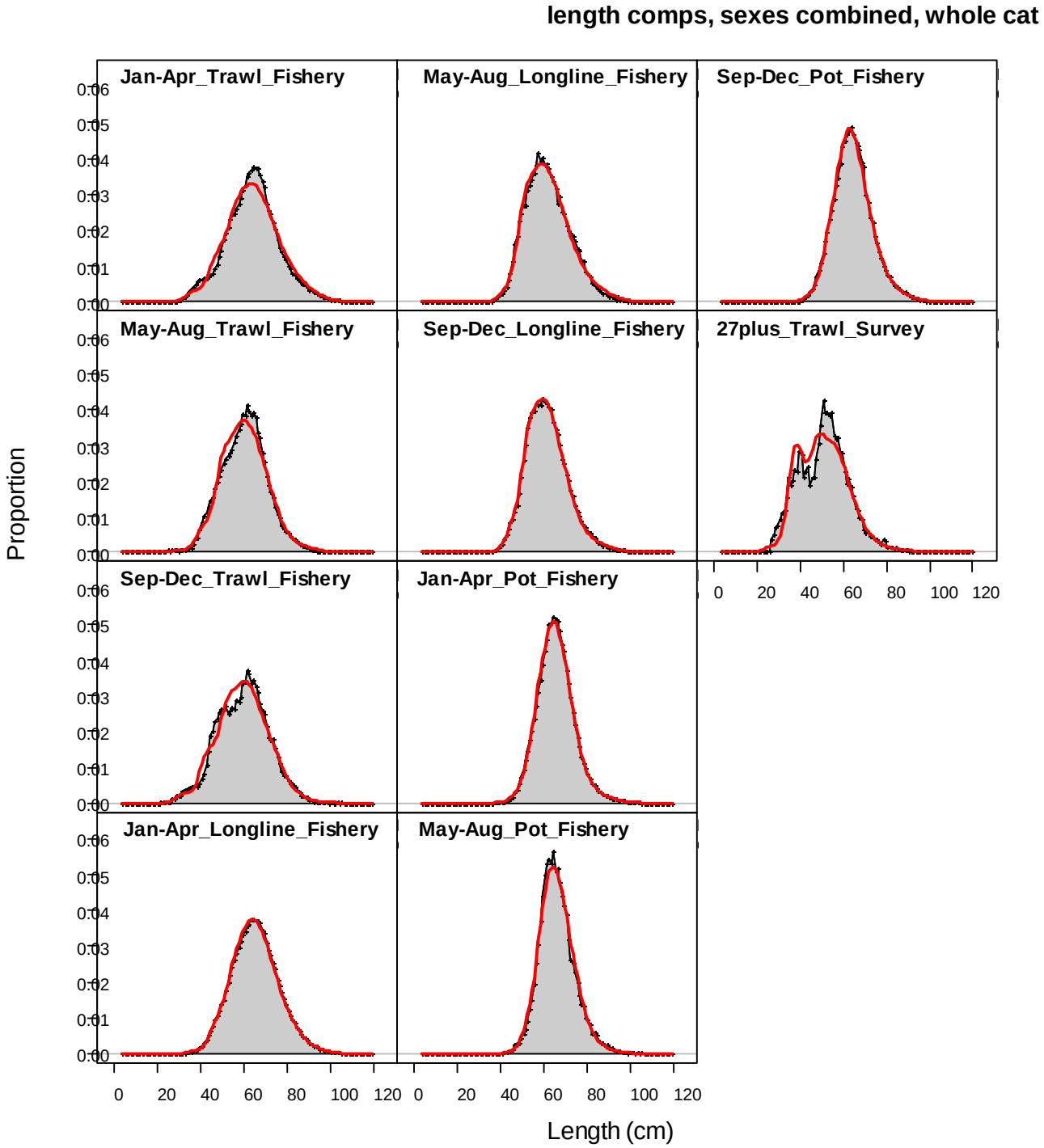
DRAFT

Figure 8 – Length comps aggregated by season and gear for Model 1



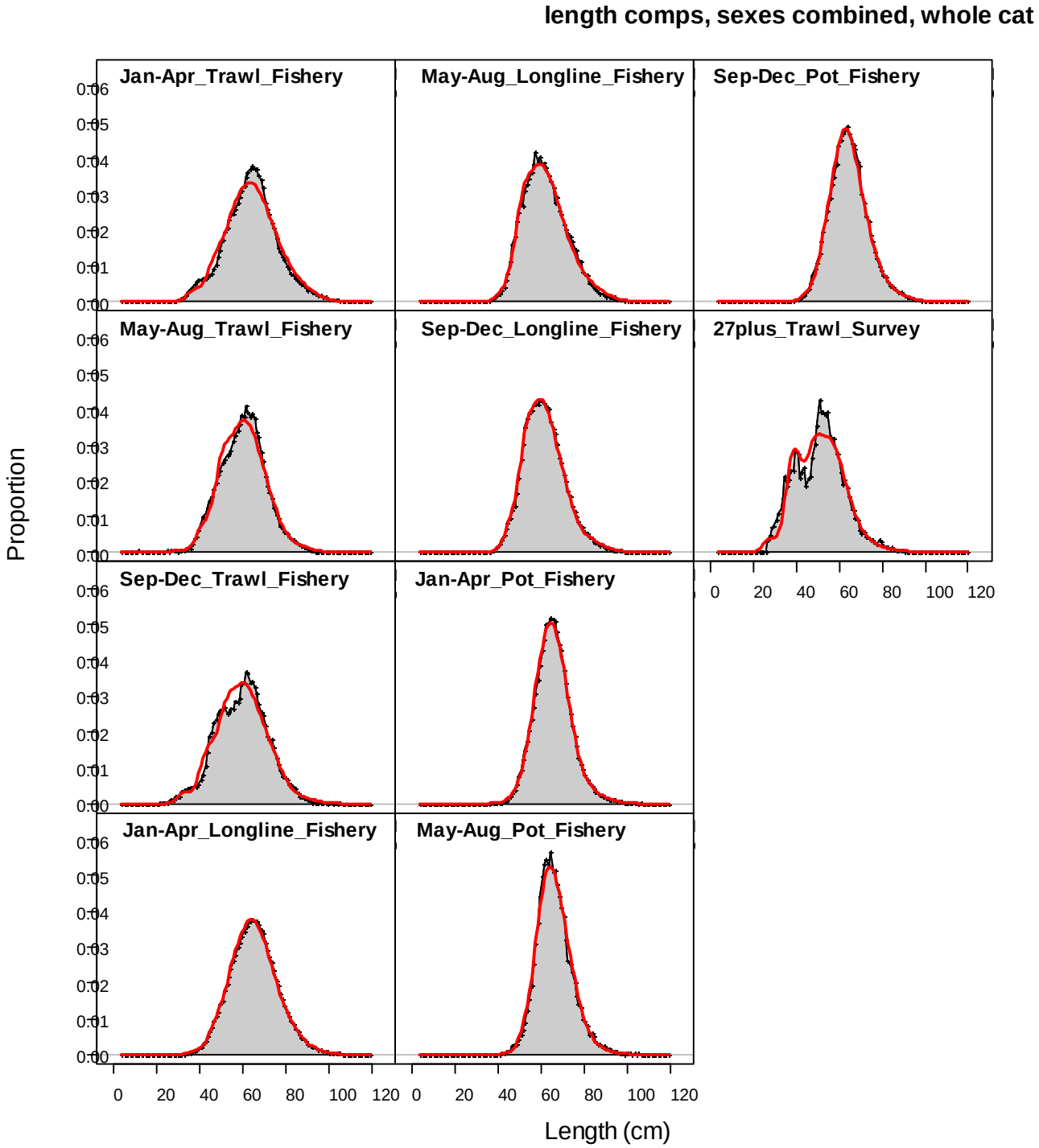
DRAFT

Figure 9 – Length comps aggregated by season and gear for Model 4



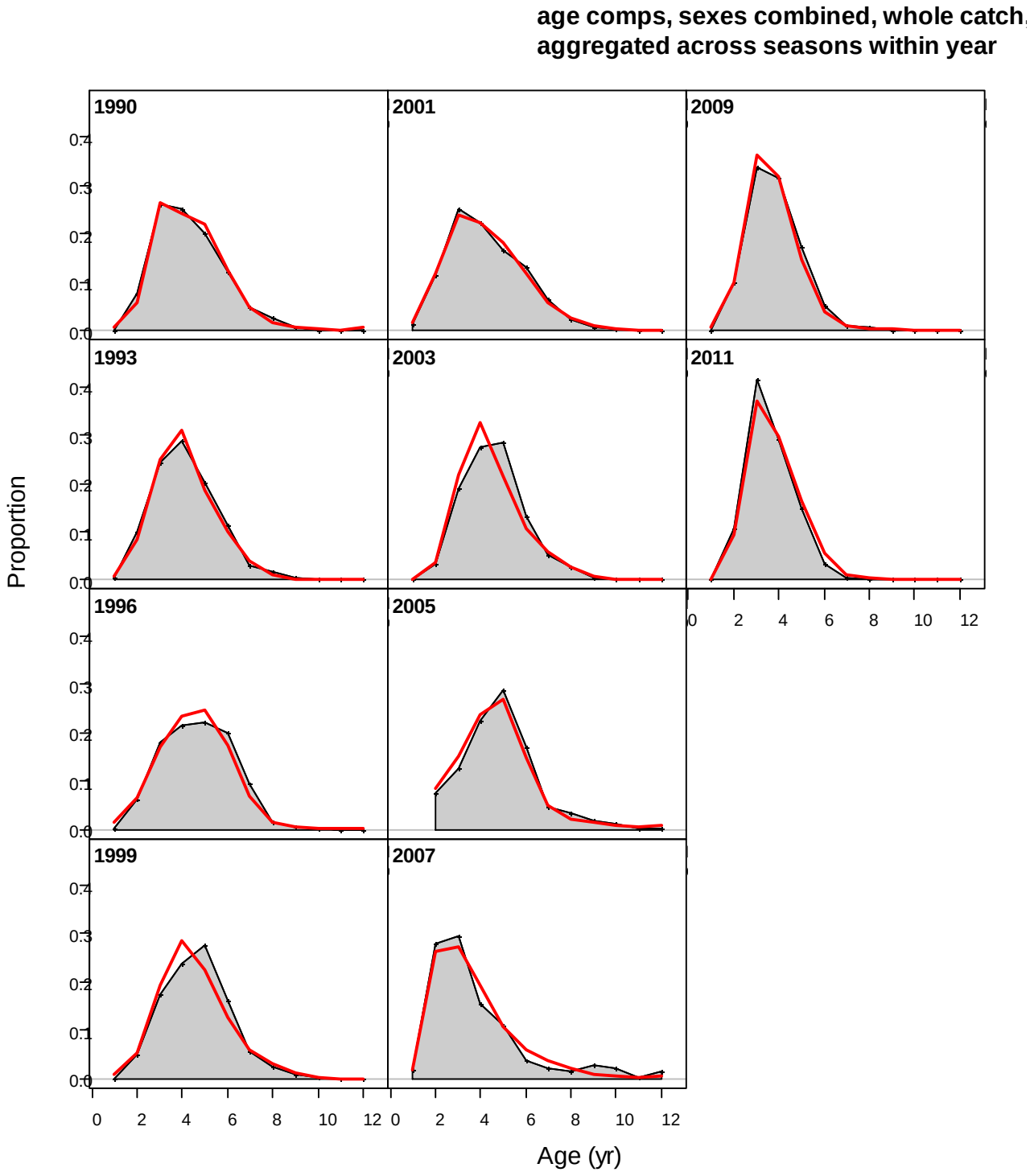
DRAFT

Figure 10 – Length comps aggregated by season and gear for Model 9N



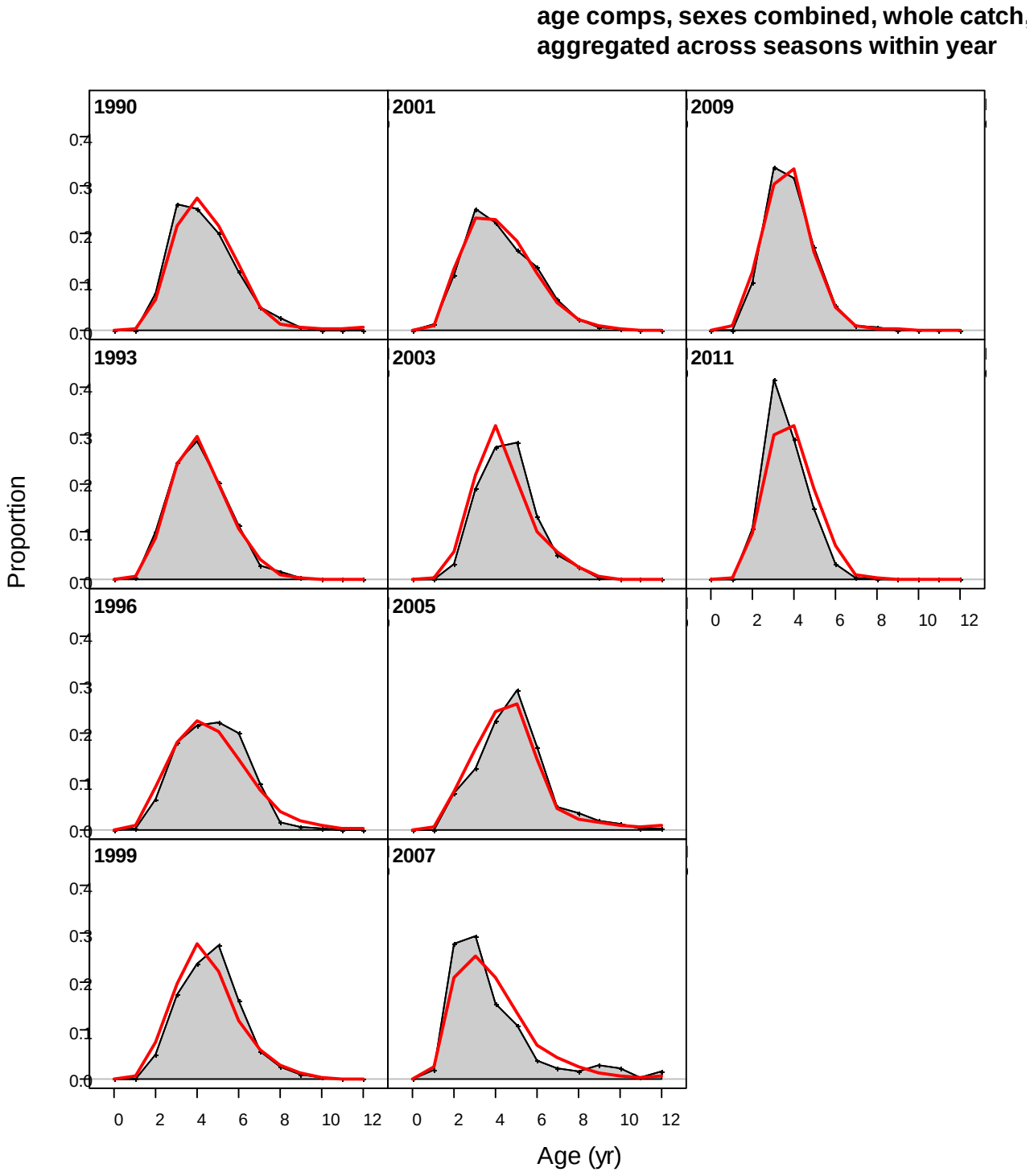
DRAFT

Figure 11 – Age comps for the 27-plus survey for Model 1



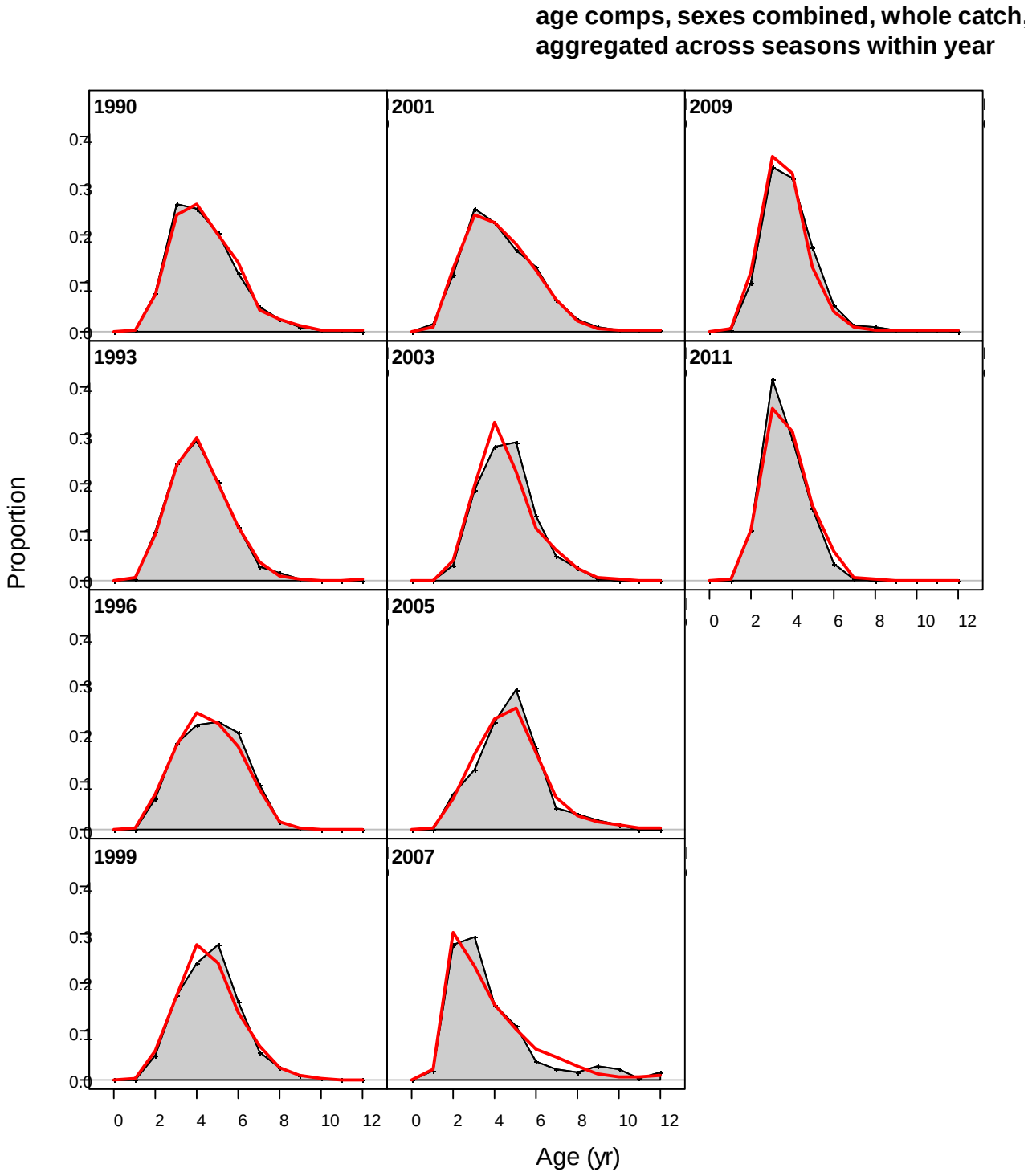
DRAFT

Figure 12 – Age comps for the 27-plus survey for Model 4



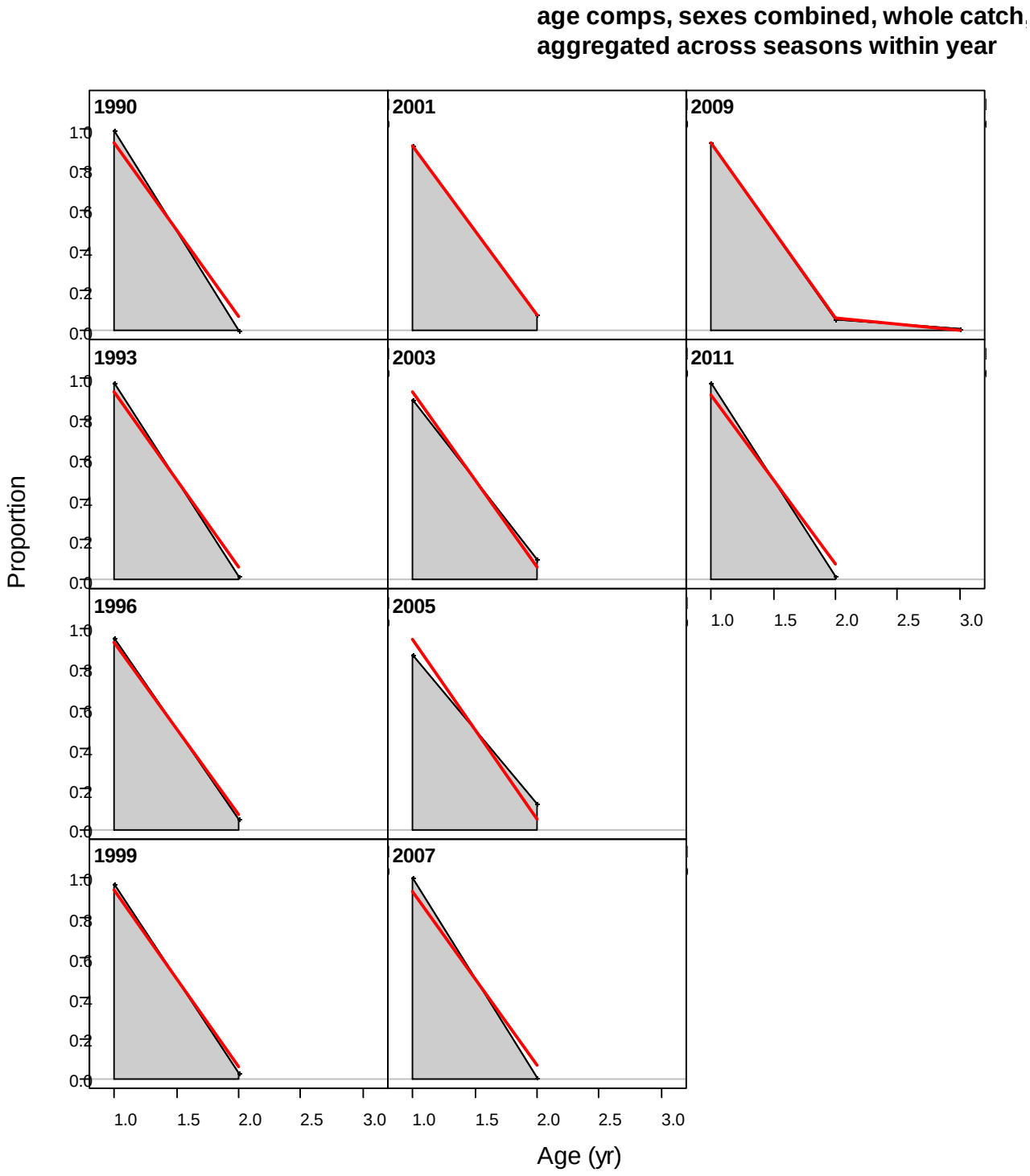
DRAFT

Figure 13 – Age comps for the 27-plus survey for Model 9N



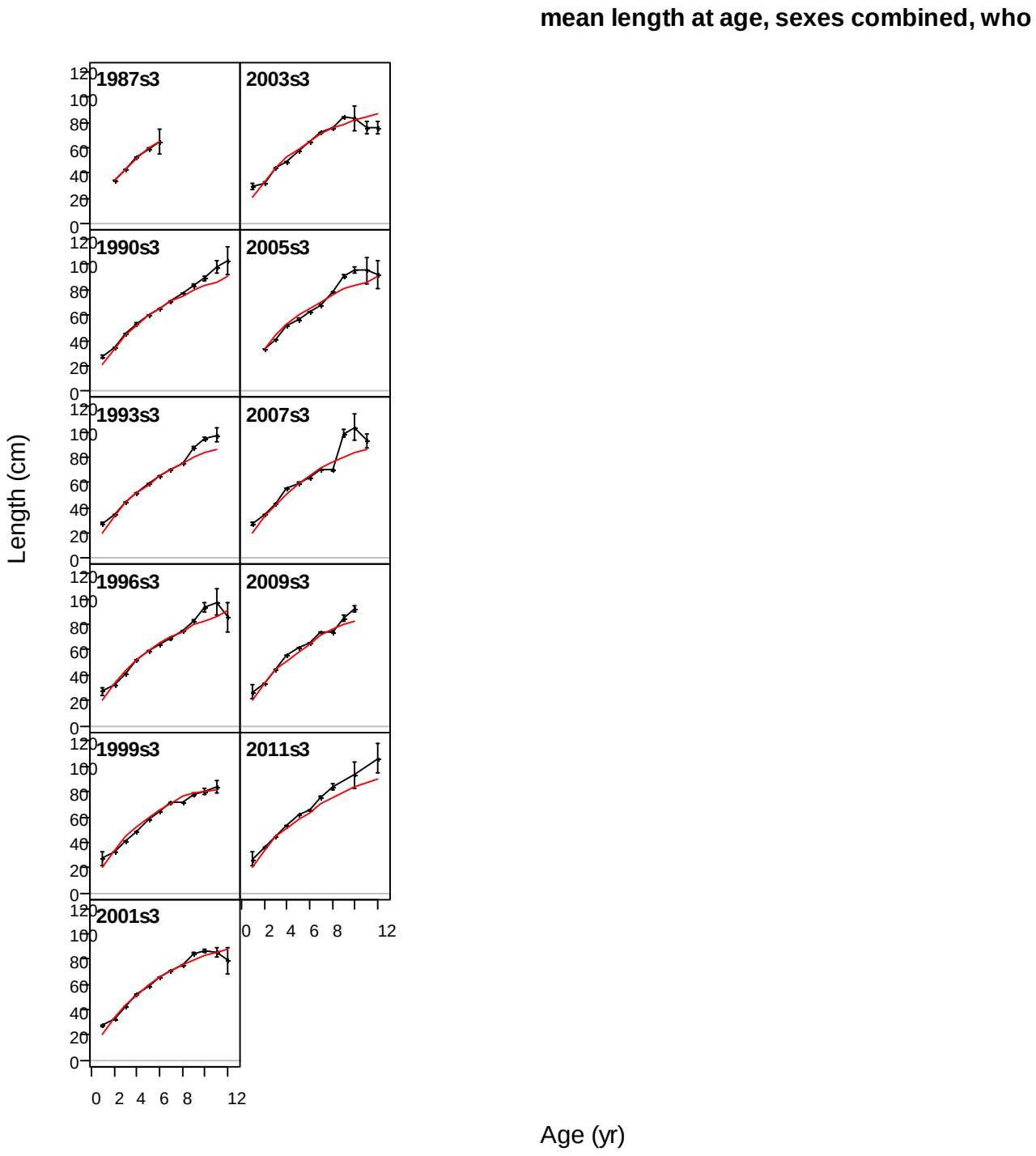
DRAFT

Figure 14 – Age comps for the sub-27 survey for Model 1



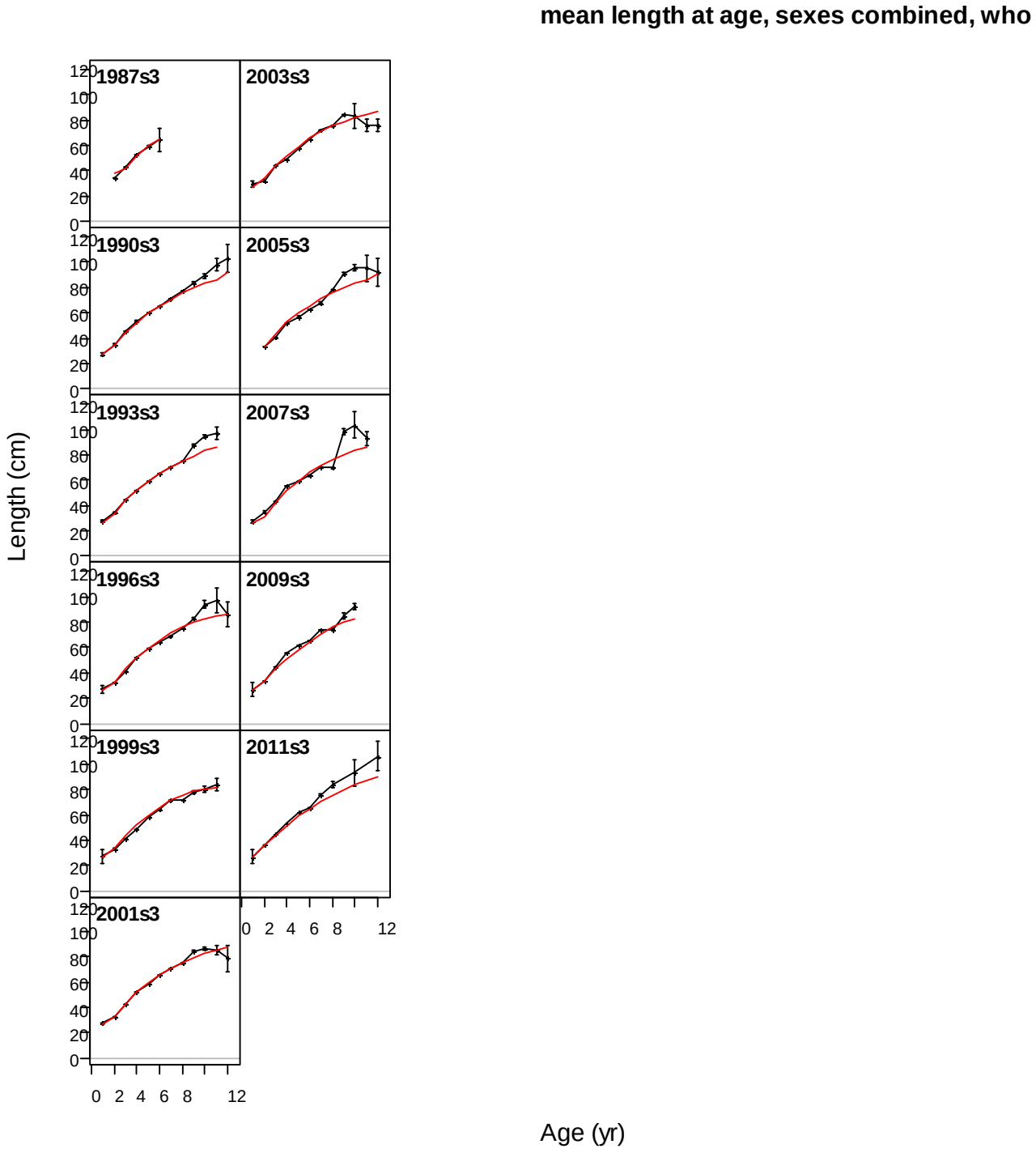
DRAFT

Figure 15 – Mean size-at-age for the 27-plus survey for Model 1



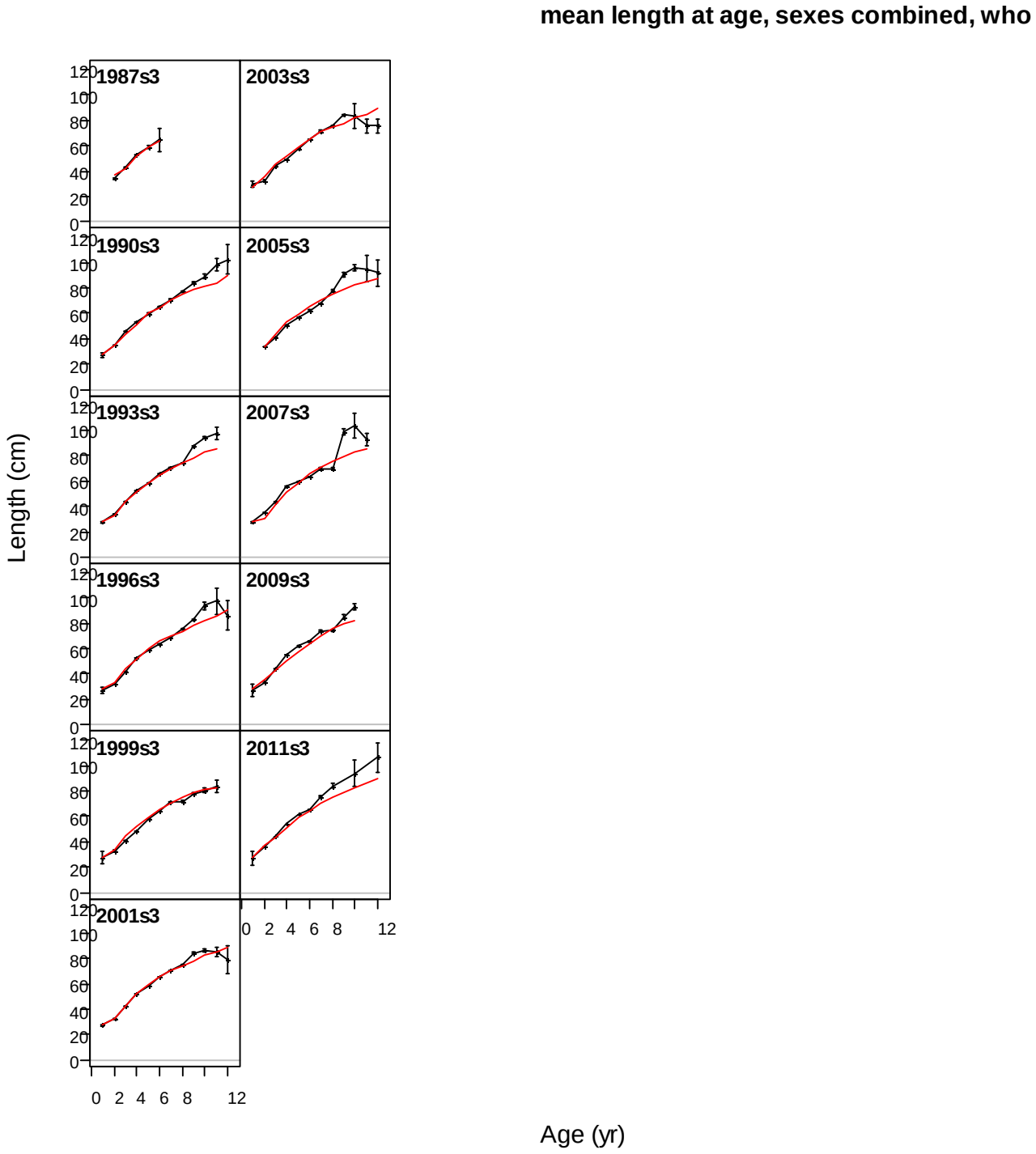
DRAFT

Figure 16 – Mean size-at-age for the 27-plus survey for Model 4



DRAFT

Figure 17 – Mean size-at-age for the 27-plus survey for Model 9N



DRAFT

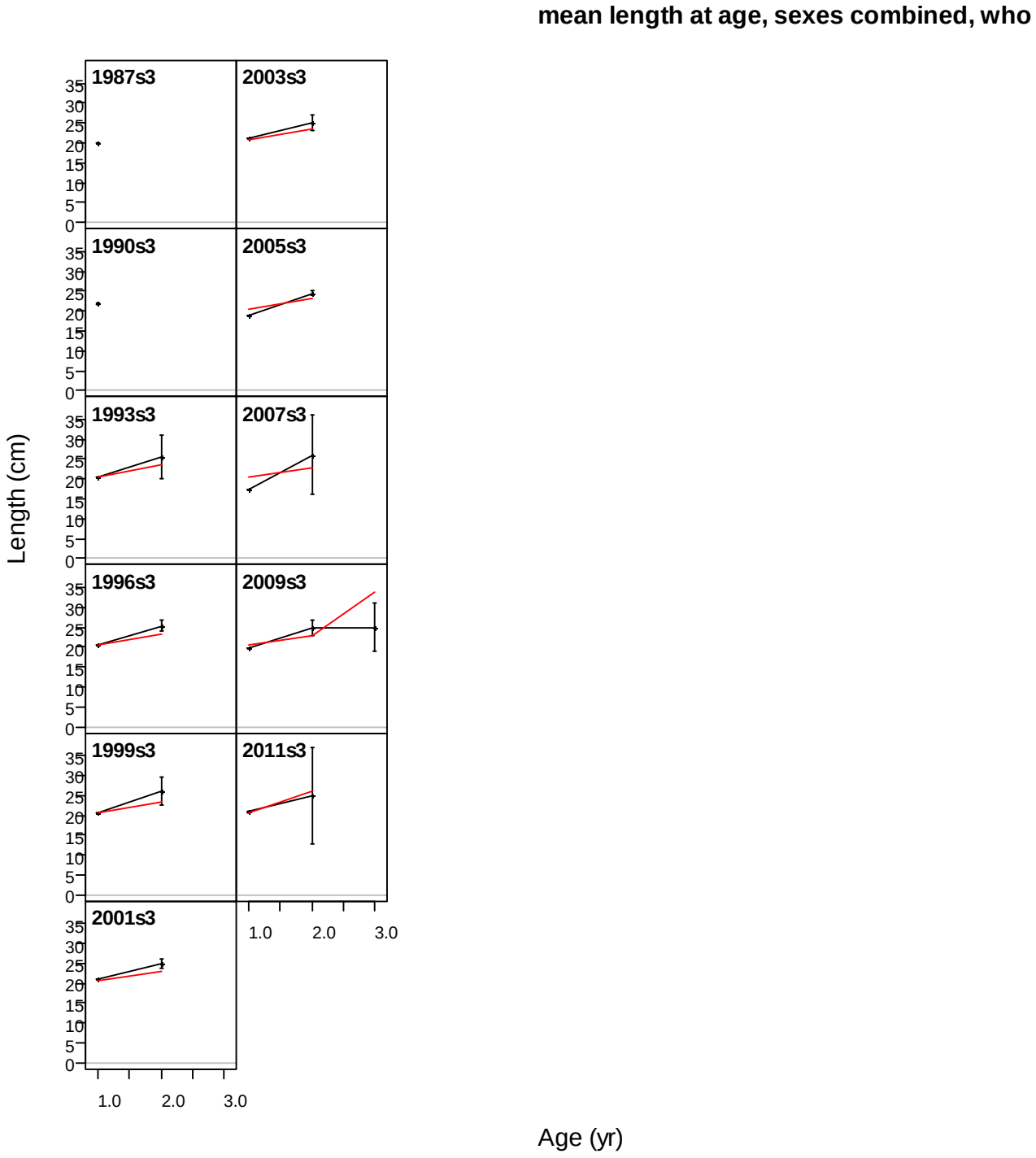



Figure 18 – Mean size-at-age for the sub-27 survey for Model 1