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Fitting a statistical catch at length model (NFT-SCALE) to Unit 1 + 2 redfish (*Sebastes mentella* and *Sebastes fasciatus*)

Daniel E. Duplisea[1], Hugo Bourdages[1], Claude Brassard[1], Johanne Gauthier[1], Yvan Lambert[1],
Paul Nitschke[2], Alexandra Valentin[1]

[1]Fisheries and Oceans Canada
850 route de la Mer
Mont-Joli, QC
G5H 3Z4

[2]NOAA Northeast Fisheries Center
Woods Hole, MA
USA

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

A statistical catch at length model (NFT-SCALE) was applied separately to the two species of redfish in the Units 1 and 2 stock area. The SCALE approach is considered advantageous over a previously applied production modelling approach in that it incorporates composition data from both surveys and the commercial fishery and as such it has an ability to show relative strength of specific cohorts both and pre-recruit and adult sizes but it remains to be seen if this approach can be usefully applied to Units 1 and 2 redfish.

The SCALE fitting to these stocks captures many of features of the stocks including adult abundance index trends, recruitment index trends and relative cohort strengths; however, the fit to survey and commercial composition data is not as good:

- There is an antagonistic relationship between fitting the important indices of adult and recruit abundance and fitting composition but more so with *Sebastes mentella* than *S. fasciatus*. The model does however capture composition data better in years when the stock was more abundant (pre 1992) and marginally better in commercial catch than in the main survey (Unit 1).
- For *S. mentella*, weighting the Unit 1 adult index more heavily forced the biomass to capture high survey biomass in the 1980s, which increased residuals for catch at length (CAL) and increased the q estimate of the Unit 2 survey. For *S. fasciatus*, a smaller weight was needed on the adult index to better follow the 1980s high biomass and this did not have a strong effect on fit to composition data.
- SCALE tends to overestimate proportion of small *S. mentella* and underestimate the proportion of larger *S. mentella*. Modifications of growth rate can change this to a small degree but not substantially but this composition misfit is less strong for *S. fasciatus*.

Retrospective runs from 2015-2005 for *S. fasciatus* show variation in the 1970s-1990s but settled down to a common trajectory after about 2006. When the U1 adult index was over-weighted (run2) the retrospective pattern was less unimportant after 1995.

The base run (run with fewest assumptions) for both species was quite good in capturing many of the stock features but there were better diagnostics and the better fit to the main survey index (e.g. Francis 2011) led to preferred runs which weighted the adult abundance index for Unit 1 by a factor of between 3 and 7 in the likelihood function.

The fittings for both species showed that the 2011 cohorts are amongst the largest ever produced by these stocks since 1960 and it is anticipated that in 3 years the exploitable biomass of both stocks will be much larger than it has been in decades.

Statistical catch at length approaches hold promise for reproducing the dynamics of these redfish stocks. The main issues in accepting this class of model for these stocks concerns the subjective choice of what data to fit best or if new mechanisms need to be introduced to better explain some residuals.

Ajustement d’un modèle statistique des captures à la longueur (NFT-SCALE) pour les sébastes (*Sebastes mentella* et *Sebastes fasciatus*) des unités 1 et 2

RÉSUMÉ

Un modèle statistique des prises selon la longueur (NFT – SCALE) a été appliqué séparément aux deux espèces de sébaste du stock des unités 1 et 2. L'approche SCALE est considérée comme avantageuse comparativement à l'approche de modélisation de la production appliquée antérieurement parce qu'elle intègre les données sur la composition tirées à la fois des relevés scientifiques et de la pêche commerciale. Elle peut ainsi montrer la force relative de cohortes spécifiques d'individus de la taille de pré-recrues et d'adultes. Cependant, il reste à vérifier si cette approche peut s'appliquer de façon pratique au sébaste des unités 1 et 2.

L'ajustement du modèle SCALE à ces stocks prend en compte la plupart des caractéristiques des stocks, y compris les tendances de l'indice d'abondance des adultes, les tendances de l'indice du recrutement et la force relative des cohortes; toutefois, l'ajustement aux données sur la composition des relevés et de la pêche commerciale n'est pas aussi bon :

- On observe une relation antagoniste entre l'ajustement des indices importants de l'abondance des adultes et des recrues et l'ajustement de la composition, davantage avec *Sebastes mentella* qu'avec *S. fasciatus*. Le modèle saisit mieux cependant les données sur la composition lors des années où le stock était plus abondant (avant 1992) et légèrement mieux celles de la récolte commerciale que du relevé principal (unité 1).
- En ce qui concerne *S. mentella*, une pondération plus élevée de l'indice des adultes de l'unité 1 a forcé les valeurs de la biomasse à tenir compte de la biomasse élevée des relevés menés dans les années 1980, ce qui a augmenté la valeur résiduelle de la capture à la longueur et a augmenté l'estimation de la valeur q pour le relevé de l'unité 2. En ce qui concerne *S. fasciatus*, l'indice des adultes nécessitait une pondération plus faible pour mieux suivre la biomasse élevée des années 1980, et cela n'a pas eu une forte incidence sur l'ajustement des données sur la composition.
- L'approche SCALE tend à surestimer la proportion de petits *S. mentella* et à sous-estimer la proportion de *S. mentella* de grande taille. La modification du taux de croissance peut modifier cela dans une certaine mesure seulement; ce problème d'ajustement de la composition est moins important pour *S. fasciatus*.

Les analyses rétrospectives de 2015 à 2005 pour *S. fasciatus* affichent une variation dans les années 1970-1990, mais finissent par atteindre une trajectoire commune après 2006. Lorsque l'indice des adultes de l'unité 1 était surpondéré (simulation 2), la tendance rétrospective était moins importante après 1995.

La simulation de base (simulation avec le moins d'hypothèses) pour les deux espèces a été assez bonne pour prendre en compte de nombreuses caractéristiques du stock, mais il y avait de meilleurs diagnostics et le meilleur ajustement aux indices du relevé (Francis 2011) ont donné les simulations préférées, lesquelles pondéraient l'indice d'abondance des adultes de l'unité 1 par un facteur de 3 à 7 dans la fonction de probabilité.

Les ajustements pour les deux espèces ont montré que les cohortes de 2011 figurent parmi les plus importantes jamais produites par ces stocks depuis 1960 et que, dans trois ans, la biomasse exploitable des deux stocks devrait être beaucoup plus élevée qu'elle l'a été depuis des décennies.

Les approches statistiques des prises à la longueur sont prometteuses pour reproduire la dynamique de ces stocks de sébaste. Les principales difficultés liées à l'acceptation de ce type de modèle pour ces stocks concernent le choix subjectif des données à inclure pour obtenir un ajustement optimal et la nécessité de déterminer si de nouveaux mécanismes doivent être mis en place afin de mieux expliquer certaines valeurs résiduelles.

INTRODUCTION

Units 1 + 2 redfish (*Sebastes* spp.) are distributed in the Gulf of St. Lawrence as well as the Laurentian Channel and Laurentian Fan areas off southern Newfoundland and Northeastern Nova Scotia. Both common redfish northwest Atlantic redfish species *S. fasciatus* and *S. mentella* are present in this area. A state-space Bayesian implementation of the Schafer surplus production model (BSP) was applied to these stocks in 2011 (McAllister and Duplisea 2011, 2012). Though BSP probably captured the magnitude of the real decline in biomass of these stocks, BSP does not make use of the length composition data and therefore it cannot include indices of pre-recruit abundance. Furthermore, both of these species display spasmodic recruitment characteristics and approaches which can more explicitly model recruitment should be advantageous.

Here we attempt to fit a statistical catch at length model, SCALE, which is publically available for download from the National Oceanographic and Atmospheric Administration (NOAA) of the United States (NOAA 2013). SCALE is a relatively simple implementation of this class of model and forces parsimony in the modelling approach, for example by only allowing a logistic selectivity curve. We therefore consider SCALE to be a good catch at length implementation to embark on the process of fitting more complicated models of this class as it can reveal the fundamental structure of the data and if it can be explained by these modelled processes without adding complicated mechanisms.

This modelling approach has good potential for these redfish stocks because it does not depend on age-based data but instead infers age structure from catch at length data combined with an estimate of the growth curve for a species. The output of such a model is age-based which can then be used in the same way as the output of any age-based model. Successful application of SCALE gives estimates pre-recruit year-class strength. This is a distinct advantage because since the last status evaluation of redfish in 2012, it has become apparent that the 2011 and 2012 year classes of *S. fasciatus* and especially *S. mentella* are very strong. These cohorts have not yet recruited to adult or fishery biomass but it is expected that when they do, stock status will change considerably. We therefore consider it important for projecting future biomass, catch and protecting future spawners that scenarios related to these two cohorts recruiting are considered.

DATA AND METHODS

SCALE description

The NOAA NFT Statistical Catch At LEngth model is a basic model of this type. The main inputs include a survey adult abundance index, a survey recruitment index, catch at length in a survey, total commercial catch, commercial catch at length as well as length at age and its variance and a value for natural mortality. Selectivity is constrained to be logistic and parameters can be bounded. The model can estimate missing years and can back-calculate population size given known catches. The output of a SCALE fitting is both length- and age-based and age-based output can be used as the basis for projections in more standard age-based methods. Furthermore, age-based yield per recruit estimates can be calculated from this output.

Input data and parameters

Because the purpose of the present document is to describe how this class of model can be fitted to these redfish stock and not to present an assessment, we do not present an analysis of the data inputs. The data have been presented in McAllister and Duplisea 2011, 2012. The main differences here are:

- Unit 1 survey index has been updated up to and including 2015
- Unit 1 survey has been extended back until 1984
- Catch data have been updated until 2014 and the 2015 catch is assumed to be the same as 2014

The main survey indices were the Unit 1 DFO summer survey (1984-2015) and the Unit 2 GEAC summer survey (2000, 2001, 2003, 2005, 2007, 2009, 2011). Annual adult indices for fish abundance ≥25 cm were used in the model. Maturity at length shows that for both species 50% maturity for females is in the 24-26 cm range therefore we used this index for adult abundance. Recruitment indices for four year olds were obtained by summing abundance of 15-17 cm fish in the survey each year and a three year old index for Unit 1 was obtained by summing abundance of 12-13 cm fish. Reported commercial catch including by-catch in other fisheries is available from 1960 – onwards. Estimates of total catch from 2014 are considered preliminary and 2015 not yet known and we have assumed that 2015 catch and composition is the same as 2014.

Natural mortality for *S. mentella* was considered 0.1 and for *S. fasciatus* 0.12 in accordance with previous modelling (McAllister and Duplisea 2011, 2012). This level of natural morality is likely on the high side for larger fish even if they are commonly living to only half of their longest life span, however, Gislason et al. 2012 suggests that fish with these Von Bertalanffy growth parameters should be much higher but it is not obvious that fish with much larger M could live to the ages that some individuals of these species are supposed to live. Some studies have shown M as low as 0.03 (Planque et al. 2012) but that study also showed increasing M with age, though the exact value is not known, M is probably on the low side compared to other groundfish.

Von Bertalanffy growth parameters for *S. mentella* can be found in the literature and values of Linfinity of 40-60, k of 0.04 to 0.12 and t0 of about -1.5 to -0.2 are common (Stransky et al. 2005, Mayo et al. 1990). Here we fitted a growth curve to sliced modes of the 1980/81 cohort up to about age 31. Two variations of this curve were also used in sensitivity runs: one that constrained Linfinity to a slightly larger size than observed in the data but for which there are still catch records, another curve where Linfinity was considerably larger (Figure 1). This allowed for the slower growth one might expect in a long lived fish achieving the largest sizes.

Splitting species in catch

The commercial fishery for redfish in Units 1 + 2 target both species while the surveys split the species based on AFR counts. In order to divide commercial catch between the two species, a loess smoother was fitted to the proportion of mature biomass of each species for each survey. Catches from these surveys area were then split based on the same proportions. Commercial catch length frequency was also split into species based on the survey species split in 1 cm length intervals (1984-2015). These survey proportions were logit transformed and a smoothing spline fitted to interpolate and extrapolate a proportion for each species from 5 to 57 cm. The antilogit smooths were then applied to the length frequency (1984-2015) (Fig. 2 at end). Commercial length frequency was available from 1981 and for the first three years when species split from surveys were not available then unspeciated catch composition data was applied to each species.

MODEL RESULTS

Sebastes mentella

The base run is not the preferred run, just the run which has the fewest explicit assumptions on weighting and other factors. All other runs come off this run for purposes of exploring the behaviour of this model with the present data set. The base run uses a growth curve fitted to the length frequency modes of the 1981 cohort. This includes fish up to 37 cm.

Characteristics of this model include fishery selectivity which is allowed to vary but which is effectively constrained in the fitting process with a 50% selectivity point at 23 cm and low selectivity for fish <20 cm. The abundance indices from the surveys are well followed in the 90s onward (collapsed period) but the teleost index highs in the 1980s are not well captured (Figure 2). The 2011 cohort is captured through the recruitment indices and shows it to be amongst the largest cohorts. Maximum biomass was estimated to be 876 kt and adult (age 10 and greater - 10+) biomass 760 kt (Figure 5). Because of the strength of the 2011 cohort, the current biomass is estimated at 77% of its maximum but adult biomass at 19% of its maximum as this cohort is currently only 5 years old (Table 2).

The *Teleost* index contains evidence of the rapid decline of biomass of early 1970s cohorts quickly followed by increasing biomass created by an incoming 1980/81 cohort thus we consider that capturing this period is important to properly capture the realised (adult) strength of known recruitment events in the 1970s and 80s (Parsons 1992, Morin and Bernier 1994). To capture this, the Unit 1 adult index was weighted by a factor of 7 in the likelihood function and this gave a much better fit to the 1980s peak biomass (Figure 7). The tradeoff with doing this is that the fit to composition data is not as good (Figure 8, Table 2).

Composition was not well fitted for surveys and only marginally better for catch with most model runs (Figures 3, 4, 8, 9, Table 2). The model tended to systematically overestimate the proportion of small fish (<30) and under estimate proportion of large fish. The more heavily the main adult index was weighted, the greater the residuals from composition data. Fitting to composition data was better in the 1980s when the stock was abundant than in the post collapse period from the mid 1990s to present.

Most runs showed peak biomass in the late 1960s and 1980s and usually less than a million tonnes. Since 1995 biomass were at low levels but the strength of 2011 put current estimates of total biomass much higher than in the past 20 years but still very low adult/exploitable biomass (Figures 5, 10). If the 2011 and 2012 cohorts recruit to adult sizes, we expect the adult stock biomass to increase considerably in the next five years.

The base run had a retrospective problem (Figure 6) which tended to follow a high biomass trajectory or low biomass trajectory depending on the estimated strength of the 1960 year class. Increased weighting on the main survey index (U1 adult) reduced retrospective issues and there was no retrospective issue for the preferred run (Figure 11).

Sebastes fasciatus

The growth of *S. fasciatus* was considered to the be same as *S. mentella* for present purposes (Figure 1) and most of the sensitivity and model behaviour insights found for *S. mentella* are transferable to *S. fasciatus* even if the specific results cannot.

The base model produced similar characteristics as *S. mentella* with differences in timing and strength of a few year classes but not that many. On the whole *fasciatus* dynamics have followed those of *mentella*. Contrary to *mentella*, over-weighting the main survey adult index for *fasciatus* did not produce a strong tradeoff with fitting composition (Figures 12, 13, 14, 17, 18, 19, Table 3). Putting more weight on the adult index gave a more stable retrospective view of the stock though there was not a worrying retrospective pattern even with the base run (Figures 16, 21).

Current biomass of the stock is increasing (Figures 15, 20) but not at the same rate as *S. mentella* since the 2011 cohort was not as strong in *fasciatus* as *mentella*. *S. Fasciatus* is known to have two disappearing cohorts (1988 and 2003). That is, these abundant cohorts were observed in the survey for 2-3 years and then disappeared from the system. Genetic analyses have shown that these cohorts were likely more closely rated to the Grand Banks stock than Unit 1 and 2. Because SCALE does not attempt to fit survey composition a sizes smaller than 19 cm these disappearing cohorts have less influence in the fit but they do still appear in the recruitment index. However, because they do not appear as adults later, SCALE produces a negative residual for these year classes which is actually good behaviour. Therefore, SCALE, even without the best fit to composition data has an internal consistency which makes sense for this stock area which occasionally acts as a nursery area for other stocks.

CONCLUSIONS

The fitting of this statistical catch at length model can capture many of the known features of the stock such as adult abundance indices, recruitment indices and the years and relative strength of important cohorts.

The main issue with the model and especially for *S. mentella* is the difficulty of fitting both the survey adult and growth indices well while also fitting the composition data. The model tends to over-estimate the proportion of small fish and under-estimate the proportion of large.

The model fitting is quite sensitive to natural mortality and in certain aspects to growth, particularly in composition. Data weighting can be used as a tool to resolve some of these issues. Previous catch history can be quite important but recent changes in proportion of catch allocated to *S. fasciatus* is not very import for determining current stock state. An important observation in fitting was the number of age classes allowed in the model. If only 31 age classes were used the model produced extremely high historical biomass estimates while if 45 or 70 age classes were allowed, results were very similar. This interplay between growth, longevity and mortality is an important consideration for setting up a model of this nature.

SCALE has advantages over production modelling in that it shows the large recruitment of 2011 and 2012 and this can be projected into adult/exploitable biomass. On the other hand, we are still not certain how strong this cohort is or how strong it will be when it recruits.

The model was examined during a stock assessment framework peer review meeting held in December 2015 (DFO 2016). It was considered that further developments and a better understanding of various model fits were required before the model could be used as basis for an assessment of the stock. In particular, the main issue in considering the statistical catch at length approach is how to trade-off quality of fit of composition vs adult index through data weighting. Other biological mechanisms can be introduced to try to resolve this problem but the issue then turns to how plausible and well informed are these mechanisms by data or other studies. With a data weighting approach, the model will produce residuals and the question for the analysis should consider if these residuals can be explained by other processes, by how much, and if those residuals are acceptable or not.

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TABLES

Table 1: Description of model fits (runs) undertaken for S. mentella using SCALE, including the purpose and which outputs are shown in the present document.

Run number	Run description	Purpose	Outputs shown
Run 0	Fewest assumptions, not species-split in commercial CAL	Compare to base if splitting commercial CAL makes important difference	Likelihood, state indicators
Run 1	Base run, fewest assumptions but species-split commercial catch composition data	Base	Likelihood, state indicators; Figures: fits to indices, composition, estimated biomass, age 1 recruitment, retrospective
Run 2	Teleost adult index weight 3 in likelihood	To Better follow main survey index, especially in 1980s, consider tradeoffs with composition fit	Likelihood, state indicators; Figures: fits to teleost adult index
Run 3	Teleost adult index weight 5 in likelihood	To Better follow main survey index, especially in 1980s, consider tradeoffs with composition fit	Likelihood, state indicators
Run 3.1	Teleost adult index weight 6 in likelihood	To Better follow main survey index, especially in 1980s, consider tradeoffs with composition fit	Likelihood, state indicators
Run 4	Teleost adult index weight 10 in likelihood	To Better follow main survey index, especially in 1980s, consider tradeoffs with composition fit	Likelihood, state indicators;
Run 5	Teleost adult index weight 7 in likelihood	To Better follow main survey index, especially in 1980s, consider tradeoffs with composition fit	Likelihood, state indicators; Figures: fits to indices, composition, estimated biomass, age 1 recruitment, retrospective
Run 6	-50% on CAL surveys and catch	To determine how weighting of CAL affects fit, consider tradeoff with adult indices	Likelihood, state indicators
Run 7	+50% on CAL surveys and catch	To determine how weighting of CAL affects fit, consider tradeoff with adult indices	Likelihood, state indicators
Run 8	+500% on CAL surveys and catch	To determine how weighting of CAL affects fit, consider tradeoff with adult indices	Likelihood, state indicators
Run 9	+500% ESS on CAL surveys + catch, Teleost adult index weight =10	To determine how upweighting of CAL and the main adult index affects fit	Likelihood, state indicators
Run 10	M=0.06	Impact of natural mortality assumption	Likelihood, state indicators

Run number	Run description	Purpose	Outputs shown
Run 11	M=0.14	Impact of natural mortality assumption	Likelihood, state indicators
Run 12	VB Linf=42, k=0.086, to=-1.57	Sensitivity to growth rate parameters especially in regards to fitting composition	Likelihood, state indicators
Run 13	VB Linf=57, k=0.04, to=-4.08	Sensitivity to growth rate parameters especially in regards to fitting composition	Likelihood, state indicators
Run 14	Catch 1960-1977 20% higher	Potential under-reporting before 200 mile limit	Likelihood, state indicators
Run 15	Catch 1985-1992 40% higher	Explanation for discarding in this period for which there is some anecdotal evidence	Likelihood, state indicators
Run 16	Impact of an alternative extraction of Unit 2 catch since 1995 by Bruce Atkinson	There are a few differences with DFO ziff primarily because of fishing season vs calendar year in the assignment of catch to years, this is an exploration of the impact of this difference.	Likelihood, state indicators
Run 17	Increase the proportion of fasciatus in the catch since 2011 by 10% and decrease proportion of mentella accordingly to keep total catch at reported levels.	Impact of increased proportion of fasciatus in redfish catch since about 2011 due to active efforts by industry in Unit 2 to target effort in southeast in a more fasciatus rich area.	Likelihood, state indicators
Run 18	Increase the proportion of fasciatus in the catch since 2011 by 50% and decrease proportion of mentella accordingly to keep total catch at reported levels.	Impact of increased proportion of fasciatus in redfish catch since about 2011 due to active efforts by industry in Unit 2 to target effort in southeast in a more fasciatus rich area.	Likelihood, state indicators
Run 19	truncate age classes to 45 and lengths to 42 cm	explore the impact of the most basic structural aspect of setting up the model: number of age classes and how many length classes to include in the model	Likelihood, state indicators
Run 20	truncate age classes to 31 and lengths to 42 cm	explore the impact of the most basic structural aspect of setting up the model: number of age classes and how many length classes to include in the model	Likelihood, state indicators
Run 21	fit commercial CAL from 22 cm	explore the impact of allowing fit of CAL to smallest commercial sizes	Likelihood, state indicators

Table 2: Likelihoods, parameter values and state indicators for various fits (runs) of SCALE to Units 1 and 2 Sebastes mentella. Runs numbers correspond to detailed descriptions in Table 1.

	Data weighting										
	Catch LF not species split	**Base run**	**Teleost adult 3**	**Teleost adult 5**	**Teleost adult 6**	**Teleost adult 10**	**Teleost adult 7**	**ESS -50%**	**ESS +50%**	**ESS +500%**	**ESS +500%, Teleost adult 10**
	Run 0	**Run 1**	**Run 2**	**Run 3**	**Run 3.1**	**Run 4**	**Run 5**	**Run 6**	**Run 7**	**Run 8**	**Run 9**
Total Objective Function	47.0	48.7	69.2	87.4	96.2	117.6	106.8	42.9	54.2	85.5	180.0
Resid from Catch Weight	5.86	5.80	9.22	9.62	10.09	21.95	18.83	6.43	5.44	4.90	13.74
Resid Catch Length Frequency	3.09	4.67	4.93	4.98	4.95	20.02	12.67	2.32	6.89	19.55	19.92
Resid R Index - U1.15to17.age4	7.57	7.60	7.86	8.14	8.49	8.43	8.27	7.61	7.71	8.82	10.34
Resid R Index - U2.15to17.age4	1.02	1.02	0.94	0.91	0.91	1.07	1.02	0.98	1.05	1.24	1.15
Resid R Index - U1.12to13.age3	10.16	10.16	11.10	11.69	12.08	11.88	13.36	10.03	10.30	11.71	14.51
Resid Adult.U1.teleost	13.08	13.38	9.34	8.92	8.65	2.93	4.83	12.02	14.18	15.98	8.80
Resid Adult.U2	0.28	0.28	0.33	0.35	0.35	1.44	0.82	0.31	0.27	0.29	0.29
Resid CAL U1 survey	5.04	4.97	5.87	6.15	6.37	19.48	14.84	2.72	7.07	19.37	26.96
Resid CAL U2 survey	0.86	0.85	0.97	1.02	1.07	4.01	3.13	0.45	1.25	3.61	5.07
Q R Index U1.15to17.age4	0.00011	0.00011	0.00011	0.00012	0.00012	0.00011	0.00012	0.00011	0.00010	0.00010	0.00007
Q R Index - U2.15to17.age4	0.00034	0.00034	0.00037	0.00038	0.00039	0.00034	0.00038	0.00035	0.00034	0.00034	0.00024
Q R Index - U1.12to13.age3	0.00007	0.00007	0.00008	0.00008	0.00008	0.00007	0.00008	0.00007	0.00007	0.00007	0.00005
Q Adult.U1.teleost	0.22	0.21	0.26	0.29	0.33	1.89	1.19	0.25	0.20	0.20	0.22
Q Adult.U2	0.54	0.53	0.75	0.88	0.99	6.30	3.98	0.63	0.49	0.46	0.69
Alpha Selectivity	23	23	23	23	23	23	23	23	23	23	23

Data weighting

	Catch LF not species split	Base run	Teleost adult 3	Teleost adult 5	Teleost adult 6	Teleost adult 10	Teleost adult 7	ESS -50%	ESS +50%	ESS +500%	ESS +500%, Teleost adult 10
	Run 0	**Run 1**	**Run 2**	**Run 3**	**Run 3.1**	**Run 4**	**Run 5**	**Run 6**	**Run 7**	**Run 8**	**Run 9**
Parameter											
Beta Selectivity Parameter	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
B2015	688	674	603	570	547	507	469	632	695	778	924
B.10plus.2015	142	144	109	95	84	8	15	129	150	152	96
Bmax	1053	876	1056	1004	940	667	688	861	877	836	1516
B.10plus.max	1009	761	868	811	744	588	611	807	741	684	1265
Bmin	26.7	26.7	26.7	26.7	26.7	15.3	21.8	26.7	26.7	27.0	25.8
B.10plus.min	0.004	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.009
B2015/Bmax	0.65	0.77	0.57	0.57	0.58	0.76	0.68	0.73	0.79	0.93	0.61
B.10plus2015 /B.10plus.max	0.14	0.19	0.13	0.12	0.11	0.01	0.02	0.16	0.20	0.22	0.08
Nage1.2012	9.6E+09	9.6E+09	9.1E+09	8.7E+09	8.5E+09	9.1E+09	8.3E+09	9.2E+09	1.0E+10	1.2E+10	1.7E+10
Nage4.2015	7.1E+09	7.1E+09	6.7E+09	6.4E+09	6.3E+09	6.8E+09	6.1E+09	6.8E+09	7.5E+09	8.9E+09	1.1E+10

		Natural mortality		Growth		Historical catch			Recent species split
	Base run	0.06	0.14	constraints: Linf>42	constraints: Linf>57, K<0.1	Catch +20% before 1977	+40%, 85-92	Atkinson	+10% fasc
	Run 1	**Run 10**	**Run 11**	**Run 12**	**Run 13**	**Run 14**	**Run 15**	**Run 16**	**Run 17**
Total Objective Function	48.7	52.5	43.5	51.0	53.7	46.5	45.3	47.0	47.0
Resid from Catch Weight	5.80	7.78	0.02	7.38	7.41	0.05	5.34	5.85	5.86
Resid Catch Length Frequency	4.67	4.99	5.44	5.27	6.13	5.19	3.11	3.09	3.09
Resid R Index - U1.15to17.age4	7.60	7.62	7.30	7.44	7.40	7.13	7.51	7.57	7.57
Resid R Index - U2.15to17.age4	1.02	0.94	1.01	1.04	1.06	1.04	1.06	1.02	1.02
Resid R Index - U1.12to13.age3	10.16	11.14	8.43	10.40	10.52	8.53	9.94	10.17	10.16
Resid Adult.U1.teleost	13.38	13.42	15.50	12.10	11.50	18.57	12.08	13.06	13.08
Resid Adult.U2	0.28	0.58	0.25	0.29	0.34	0.30	0.29	0.28	0.28
Resid CAL U1 survey	4.97	5.18	4.63	6.19	8.32	4.77	5.14	5.05	5.04
Resid CAL U2 survey	0.85	0.81	0.90	0.85	1.06	0.93	0.87	0.86	0.86
Q R Index U1.15to17.age4	0.00011	0.00010	0.00002	0.00011	0.00011	0.00003	0.00010	0.00011	0.00011
Q R Index - U2.15to17.age4	0.00034	0.00032	0.00006	0.00034	0.00034	0.00008	0.00033	0.00034	0.00034
Q R Index - U1.12to13.age3	0.00007	0.00007	0.00001	0.00007	0.00007	0.00002	0.00007	0.00007	0.00007
Q Adult.U1.teleost	0.21	0.16	0.02	0.24	0.27	0.02	0.20	0.22	0.22
Q Adult.U2	0.53	0.38	0.06	0.61	0.68	0.05	0.51	0.54	0.54
Alpha Selectivity Parameter	23	23	23	23	23	23	23	23	23
Beta Selectivity Parameter	0.75	0.75	1.19	0.75	0.75	1.03	0.75	0.75	0.75
B2015	674	853	4123	639	652	3677	832	665	669
B.10plus.2015	144	272	868	148	161	1413	151	141	143
Bmax	876	1197	8248	905	890	7304	1146	1052	1053
B.10plus.max	761	1085	7579	727	768	6658	1106	1007	1009
Bmin	26.7	51.8	70.7	26.8	28.1	79.1	27.5	26.7	26.7
B.10plus.min	0.002	0.004	0.008	0.012	0.051	0.008	0.005	0.004	0.004
B2015/Bmax	0.77	0.71	0.50	0.71	0.73	0.50	0.73	0.63	0.64
B.10plus2015/B.10plus.max	0.19	0.25	0.11	0.20	0.21	0.21	0.14	0.14	0.14
Nage1.2012	9.6E+09	9.5E+09	6.7E+10	5.1E+10	1.0E+10	4.1E+10	1.0E+10	9.6E+09	9.6E+09
Nage4.2015	7.1E+09	8.0E+09	4.4E+10	6.6E+09	7.4E+09	3.1E+10	7.6E+09	7.1E+09	7.1E+09

Table 3: Likelihoods, parameter values and state indicators for various fits (runs) of SCALE to Unit 1&2 Sebastes fasciatus.

		Data weighting	
	base run	**Teleost adult 3**	**Teleost adult 5**
	Run 1	**Run 2**	**Run 3**
Total Objective Function	47.7001	65.978	79.8776
Resid from Catch Weight	10.8111	13.6746	14.0706
Resid Catch Length Frequency	5.86879	8.30931	10.1676
Resid R Index - U1.15to17.age4	9.5753	11.4228	12.9336
Resid R Index - U2.15to17.age4	2.72735	3.30833	3.66807
Resid Adult.U1.teleost	11.9959	7.59508	6.43305
Resid Adult.U2	0.89594	0.977405	1.05429
Resid CAL U1 survey	4.5828	4.5324	4.85256
Resid CAL U2 survey	1.24288	0.967863	0.965637
Q R Index U1.12to13.age3	0.000178761	0.00020615	0.00022076
Q R Index - U2.12to13.age3	0.000170445	0.000210164	0.000236692
Q Adult.U1.teleost	0.199457	0.307154	0.38409
Q Adult.U2	1.15E+00	1.95298	2.43958
Alpha Selectivity Parameter	23	23	23
Beta Selectivity Parameter	0.75	0.75	0.75
B2015	674.124	506.639	547.253
B.10plus.2015	144.371	7.844	84.469
Bmax	876.288	666.931	939.989
B.10plus.max	760.536	587.698	744.326
Bmin	26.697	15.273	26.697
B.10plus.min	0.002	0.002	0.002
B2015/Bmax	0.769	0.760	0.582
B.10plus2015/B.10plus.max	0.190	0.013	0.113
Nage1.2012	9.6E+09	9.1E+09	8.5E+09
Nage4.2015	7.1E+09	6.8E+09	6.3E+09

FIGURES

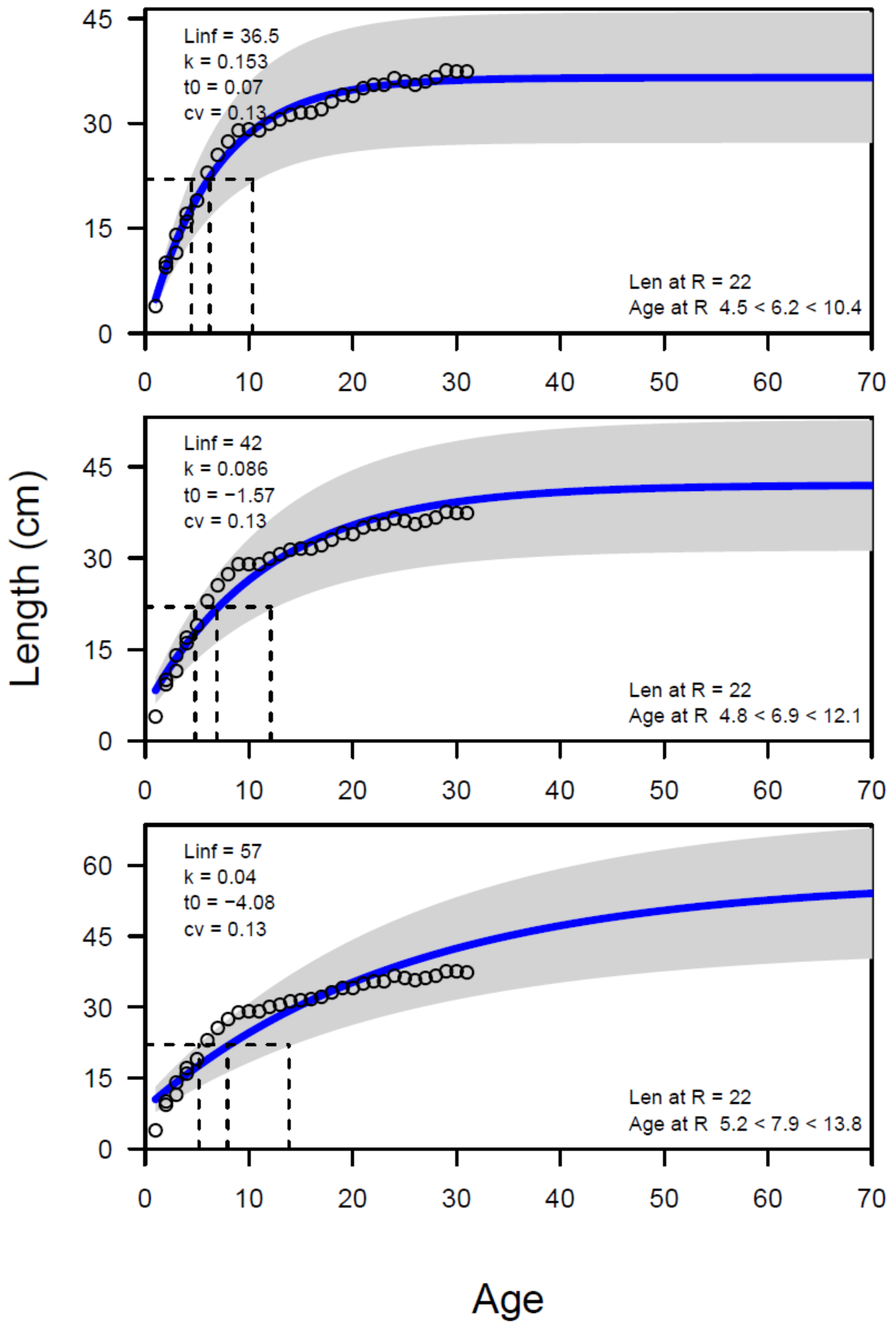

Figure 1: Von Bertalanffy growth curves used for both species in the SCALE model fitting. The top panel is the base run curve where all parameters were uncontrained. The middle panel is the Linf constrained curve (Linf≥42 cm) and is only used in S. mentella run 12. The bottom panel is the curve when k and Linf were constrained to ≤0.1 and ≥57 cm, respectively (used in mentella run 13). Parameter values and approximate age of recruitment to 22 cm is shown on each plot.

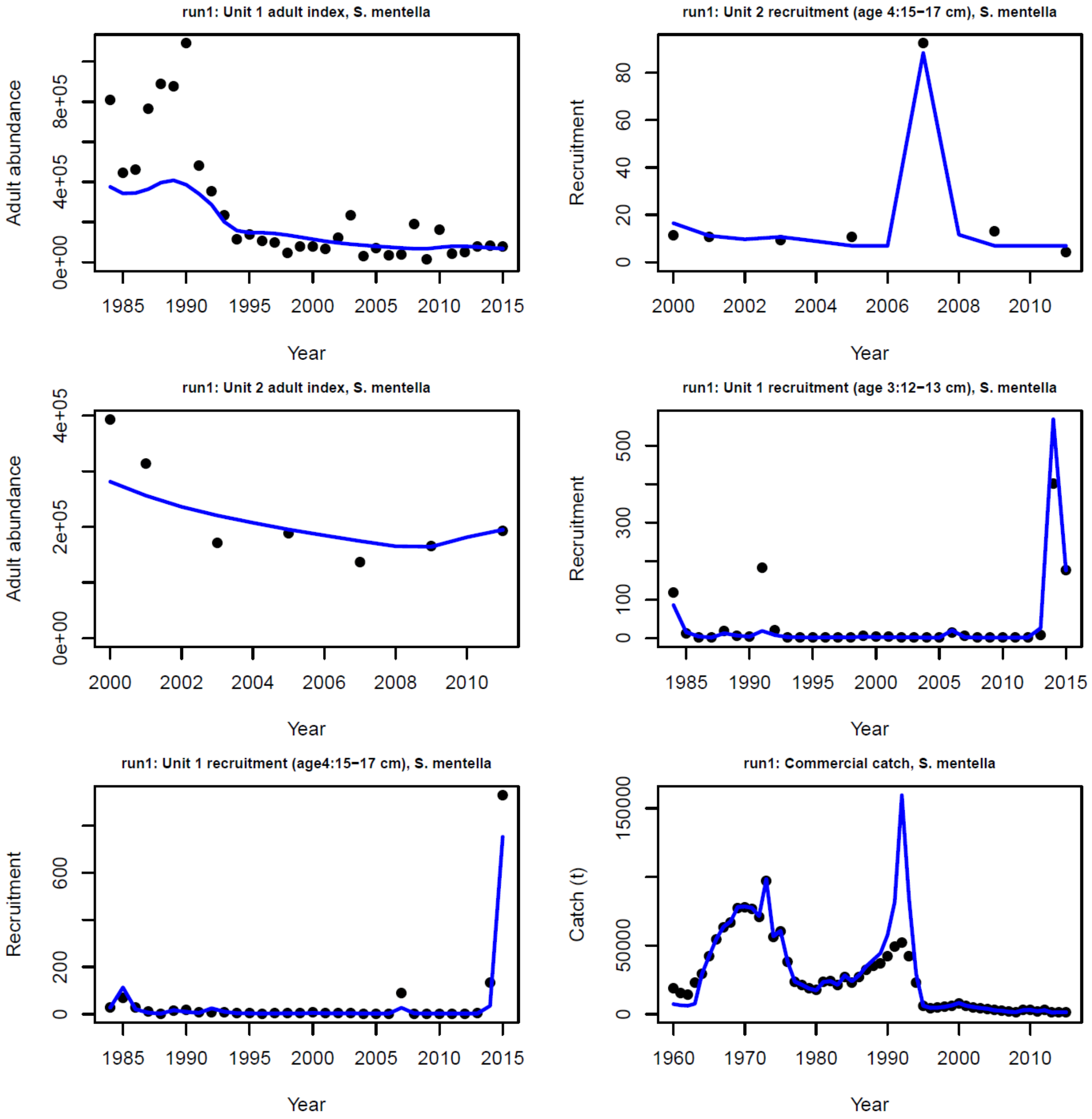

Figure 2: Sebastes mentella, base run (run 1) fits to data. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

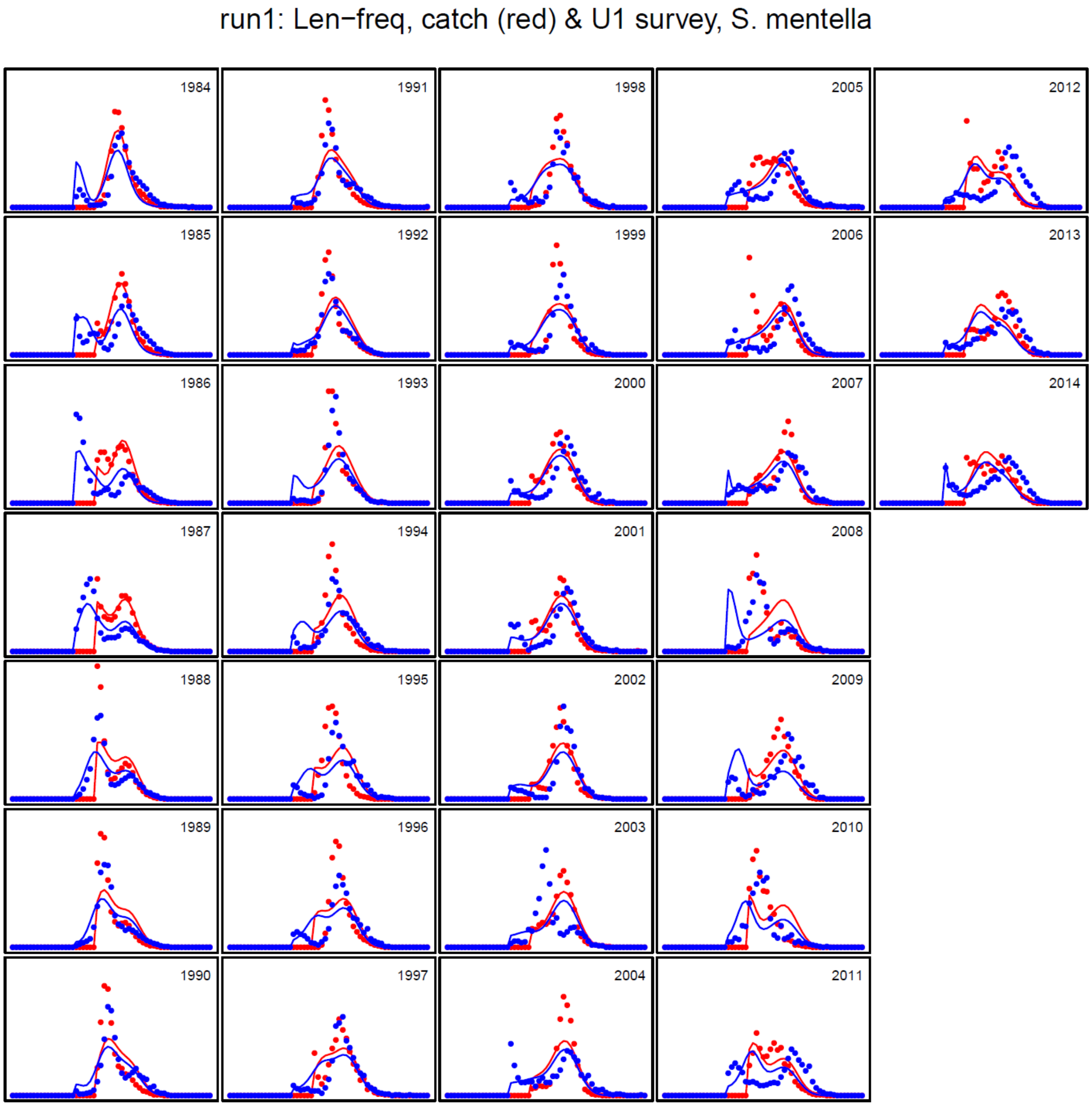

Figure 3: Sebastes mentella, base run (run 1) fits to length frequency data. The lines are the fits while points are the data. Blue points and lines are the Unit 1 survey and red are the commercial catch. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

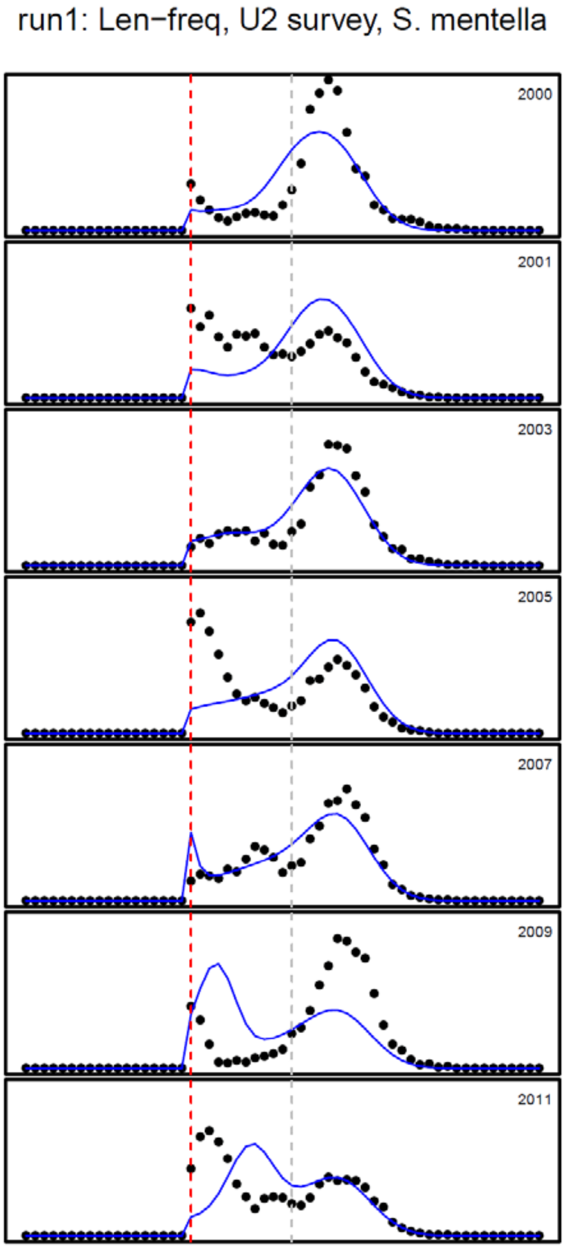

Figure 4: Sebastes mentella, base run (run 1) fits to Unit 1 survey length frequency data. The lines are the fits while points are the data. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

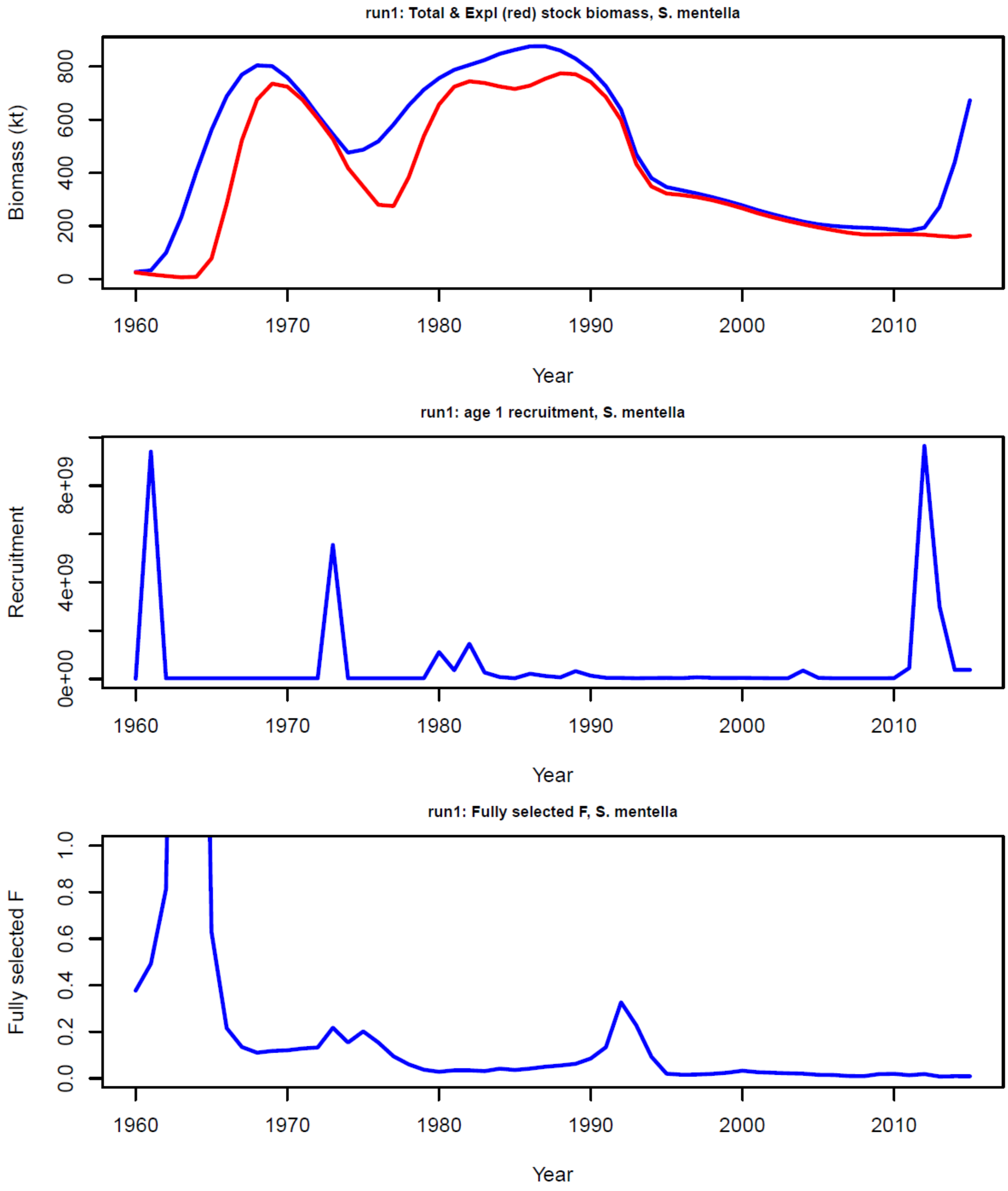

Figure 5: Sebastes mentella, base run (run 1) model fitting predictions of stock biomass, recruitment and fishing mortality. On the top panel, exploitable biomass is in red and total biomass is blue (and always larger). The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

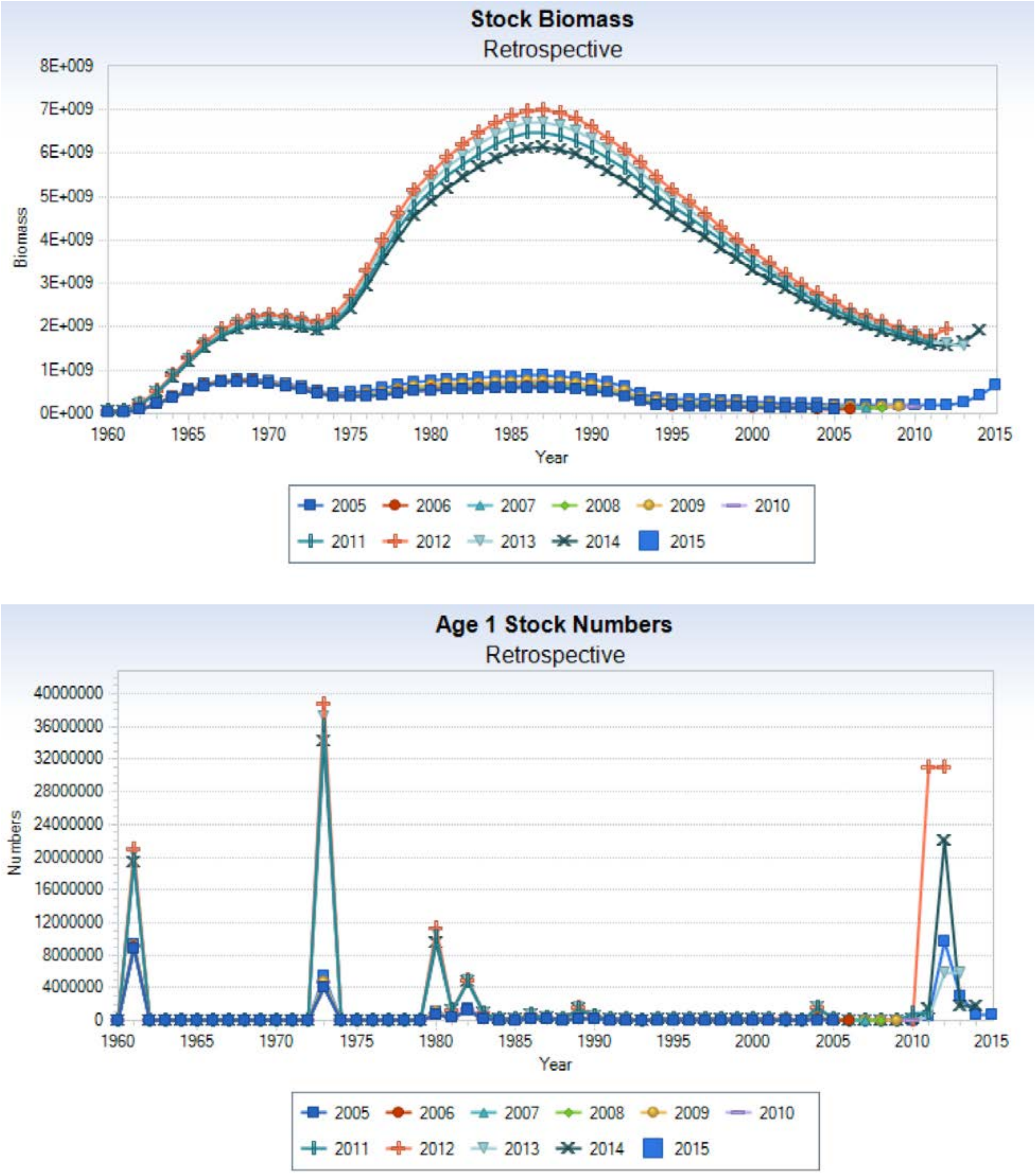

Figure 6: Sebastes mentella, base run (run 1) retrospective runs truncating data from 2015 back to 2005. The top panel is the prediction of total stock biomass (kg), the bottom panel is the prediction of recruitment (number of individuals at age 1 (x103)). The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

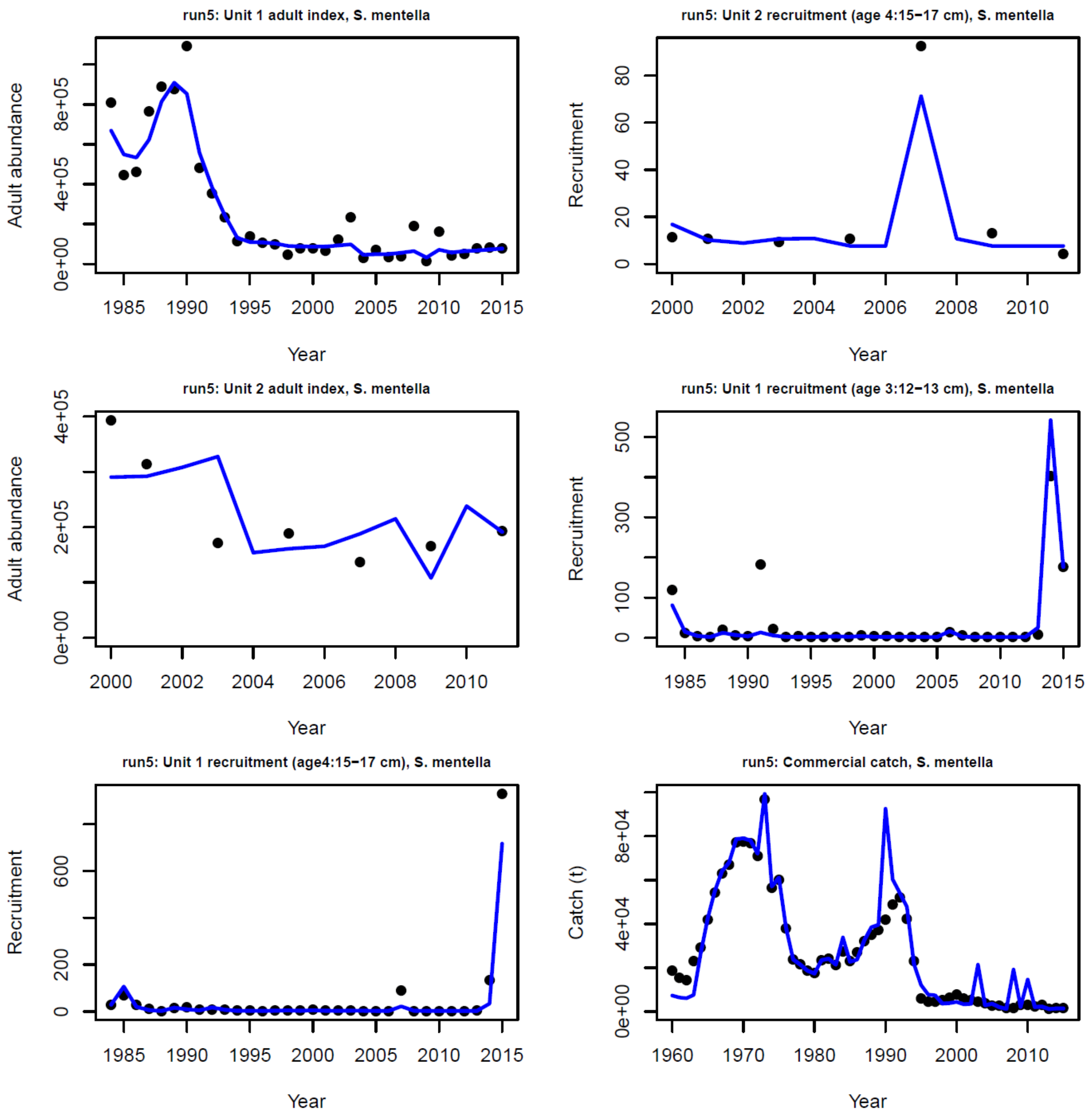

Figure 7: Sebastes mentella, preferred run (run 5) fits to data. It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

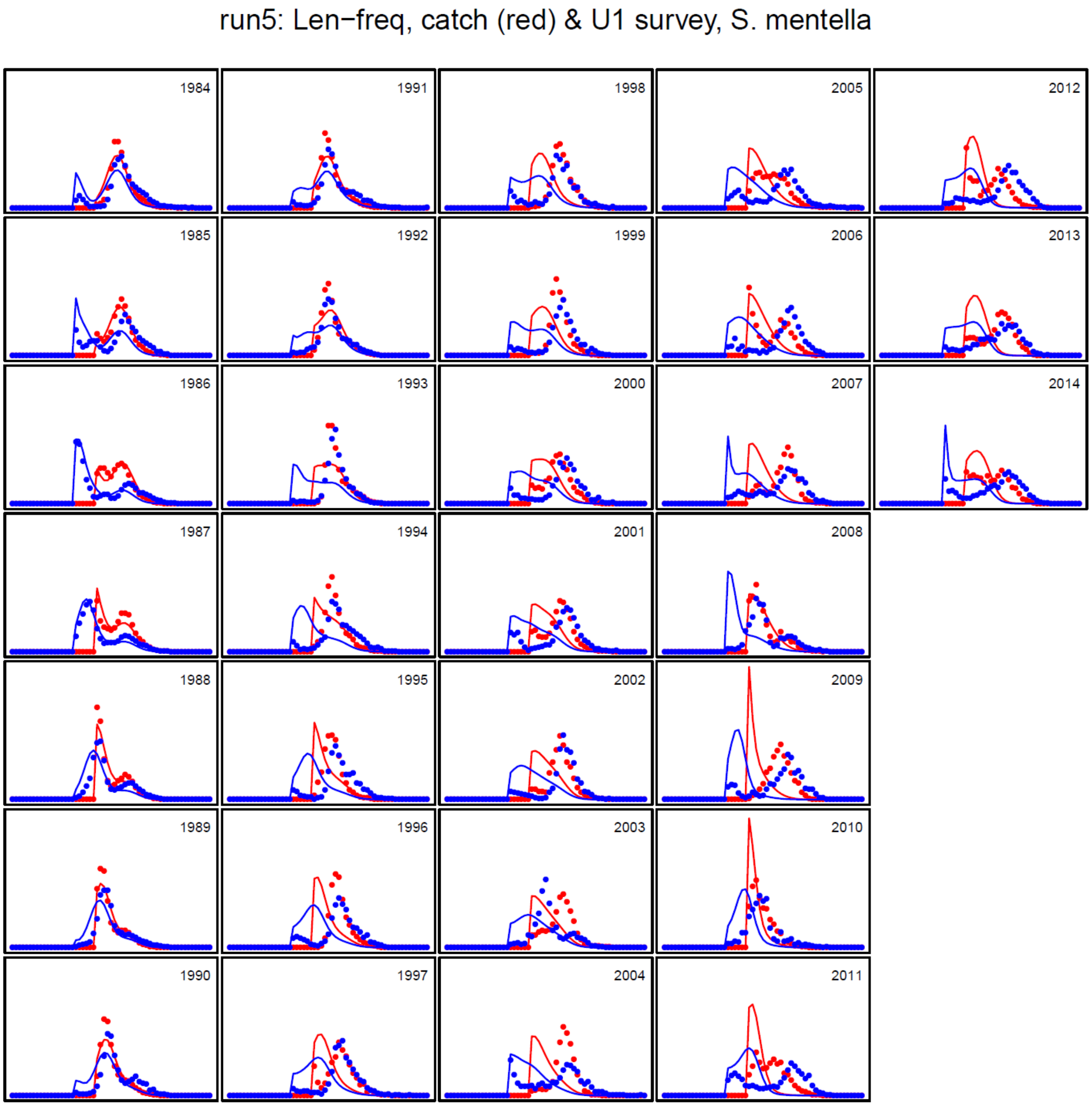

Figure 8: Sebastes mentella, preferred run (run 5) fits to length frequency data. The lines are the fits while points are the data. Blue points and lines are the Unit 1 survey and red are the commercial catch. It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

run5: Len−freq, U2 survey, S. mentella

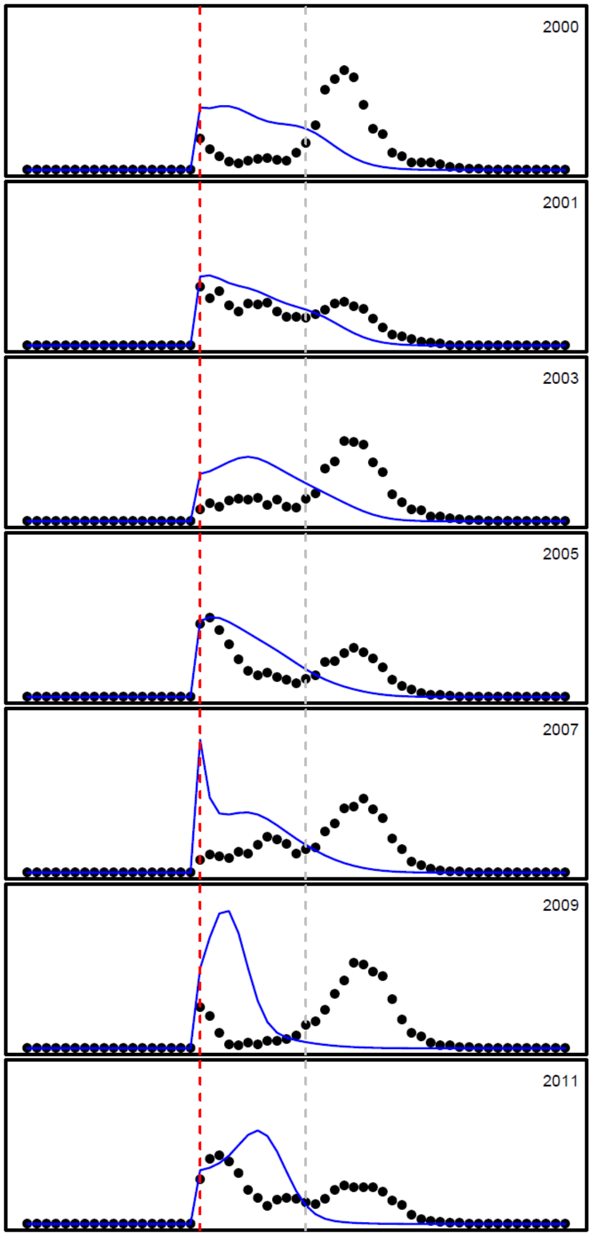

Figure 9: Sebastes mentella, preferred run (run 5) fits to Unit 1 survey length frequency data. The lines are the fits while points are the data. It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

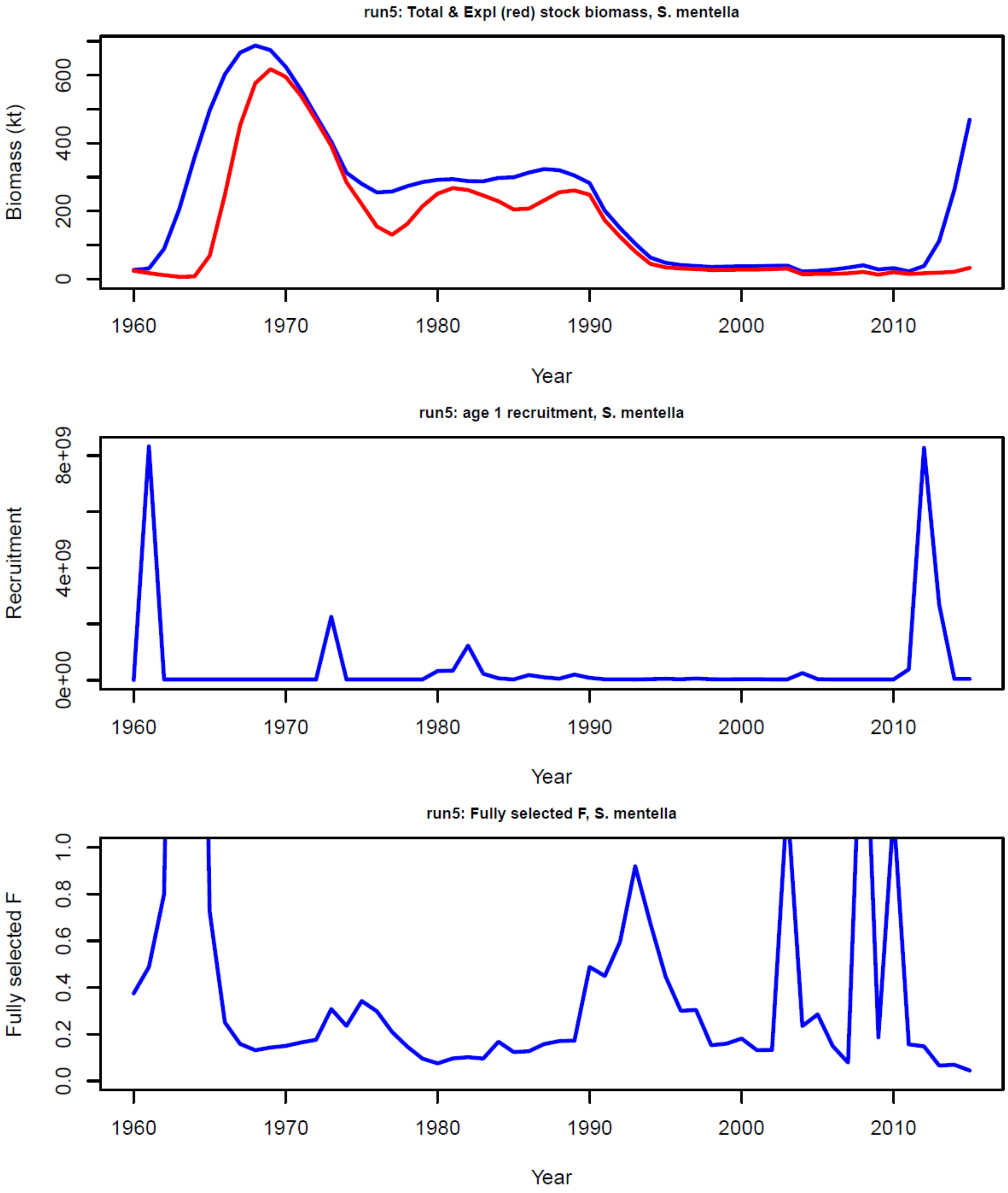

Figure 10: Sebastes mentella, preferred run (run 5) model fitting predictions of stock biomass, recruitment and fishing mortality. On the top panel, exploitable biomass is in red and total biomass is blue (and always larger). It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

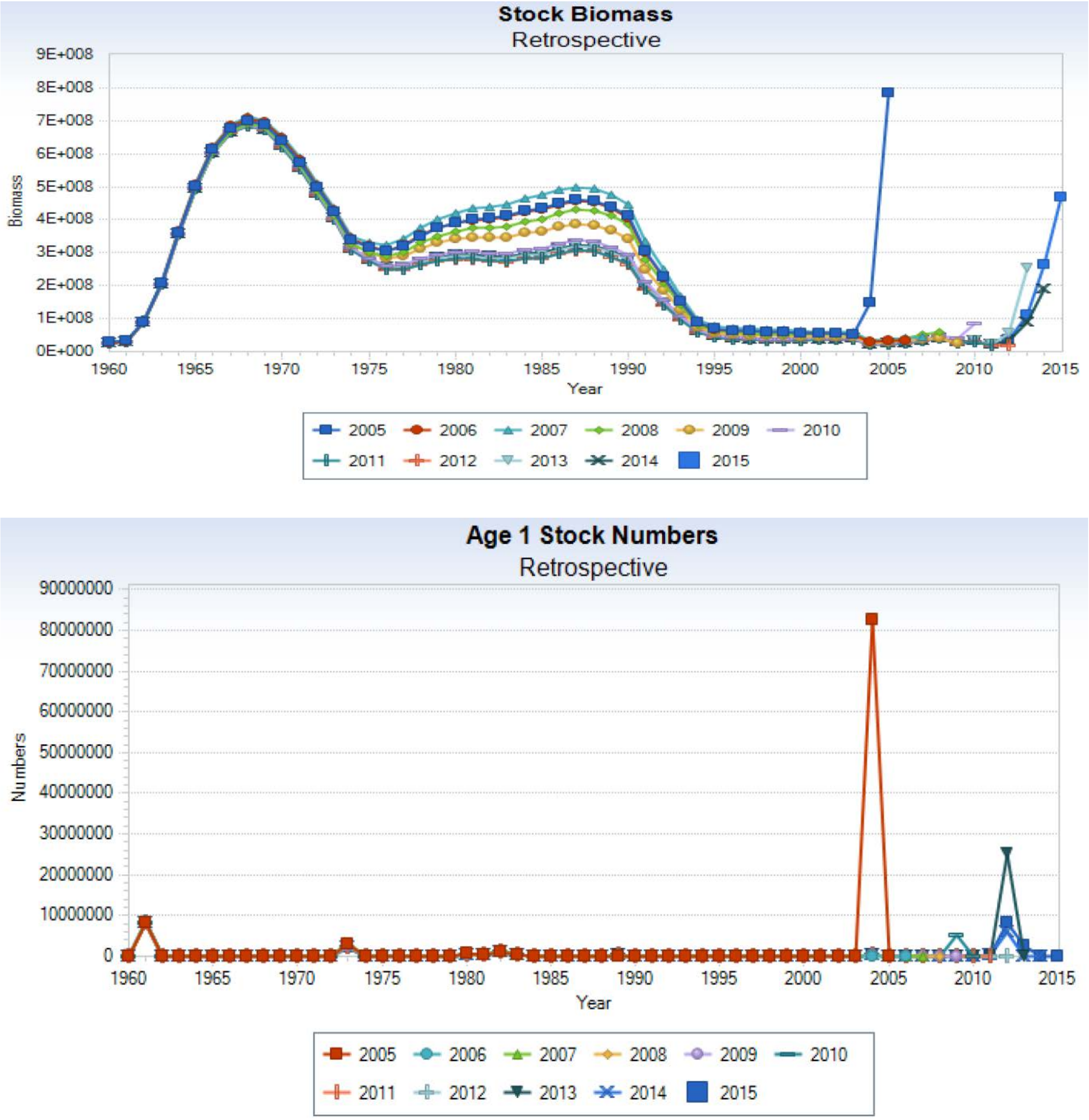

Figure 11: Sebastes mentella, preferred run (run 5) retrospective runs truncating data from 2015 back to 2005. The top panel is the prediction of total stock biomass (kg), the bottom panel is the prediction of recruitment (number of individuals at age 1 (x103)). It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

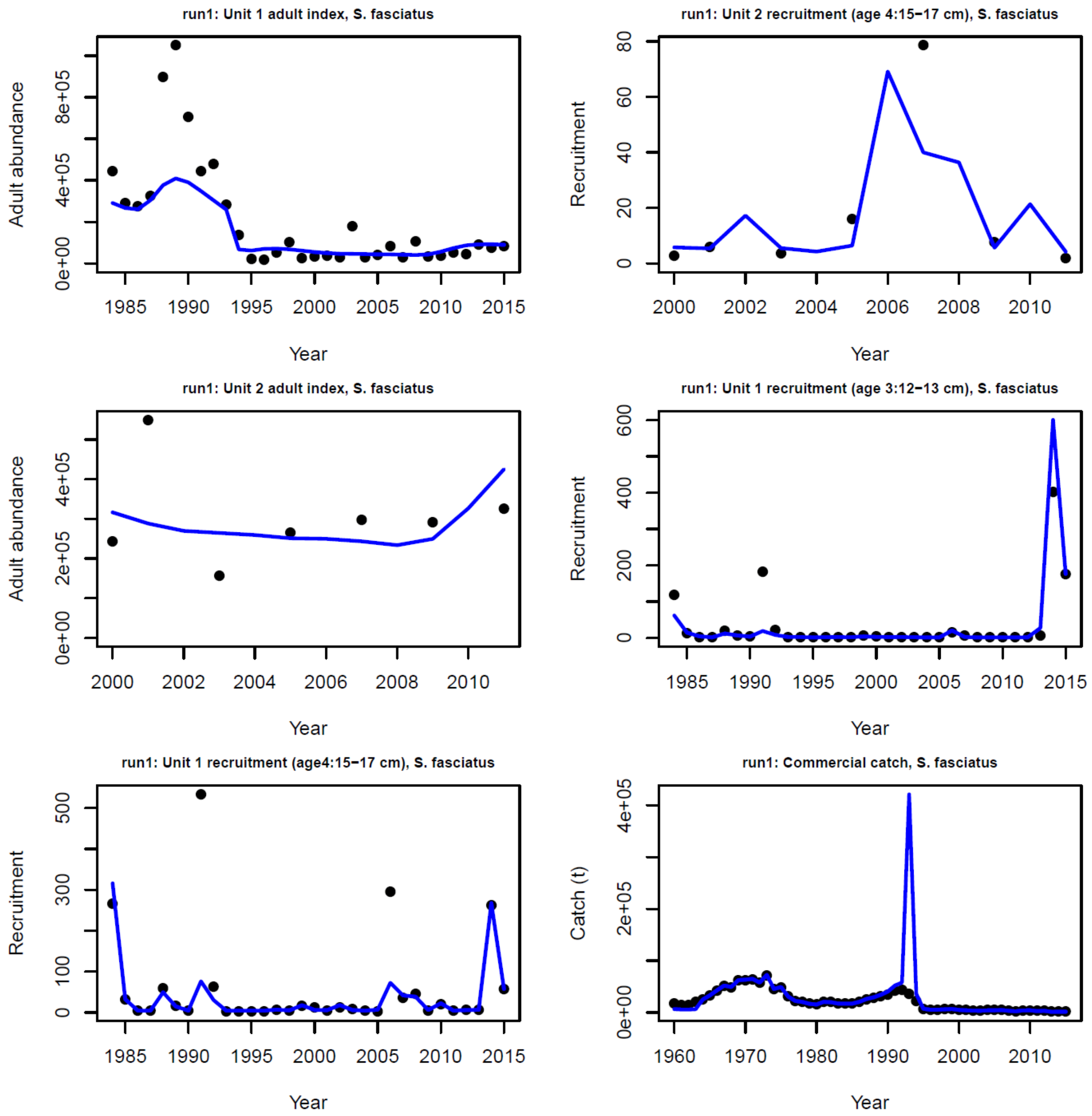

Figure 12: Sebastes fasciatus, base run (run 1) fits to data. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

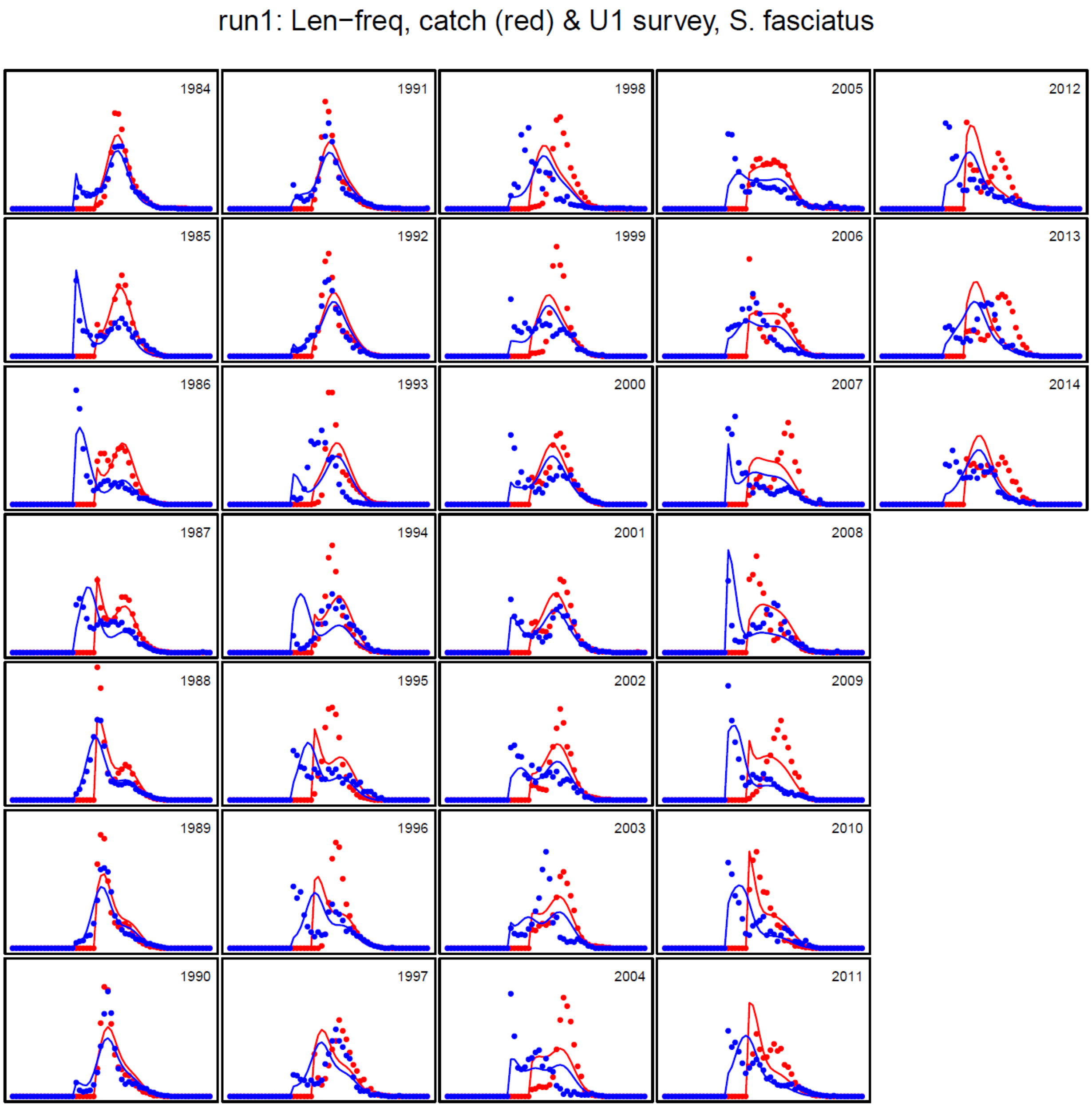

Figure 13: Sebastes fasciatus, base run (run 1) fits to length frequency data. The lines are the fits while points are the data. Blue points and lines are the Unit 1 survey and red are the commercial catch. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

run1: Len−freq, U2 survey, S. fasciatus

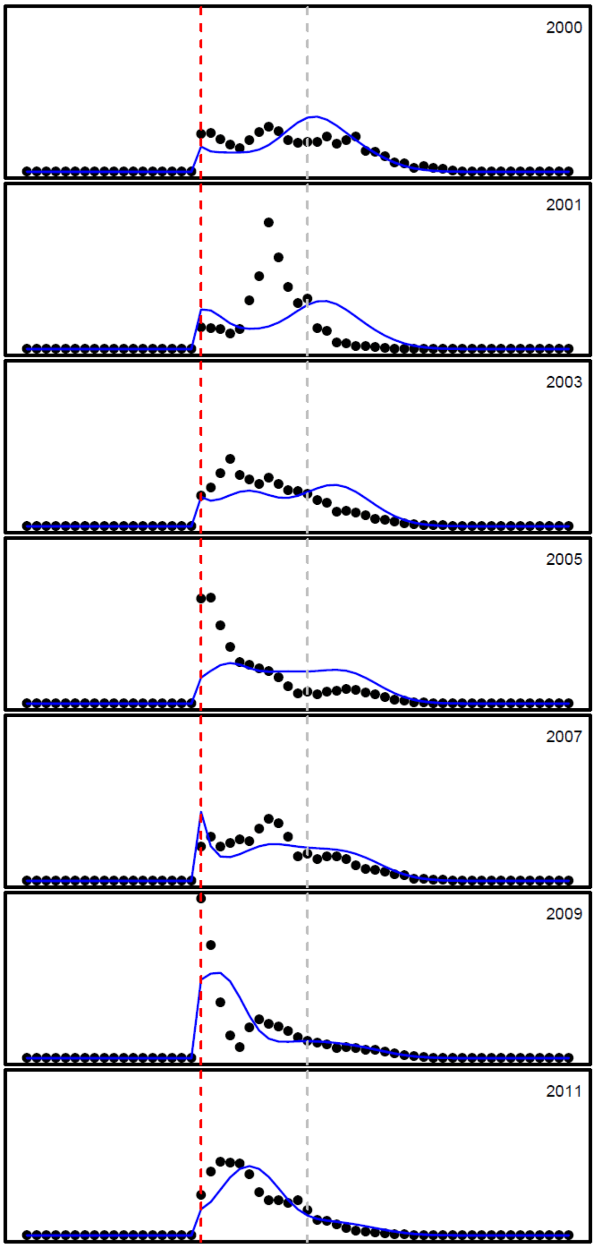

Figure 14: Sebastes fasciatus, base run (run 1) fits to Unit 1 survey length frequency data. The lines are the fits while points are the data. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

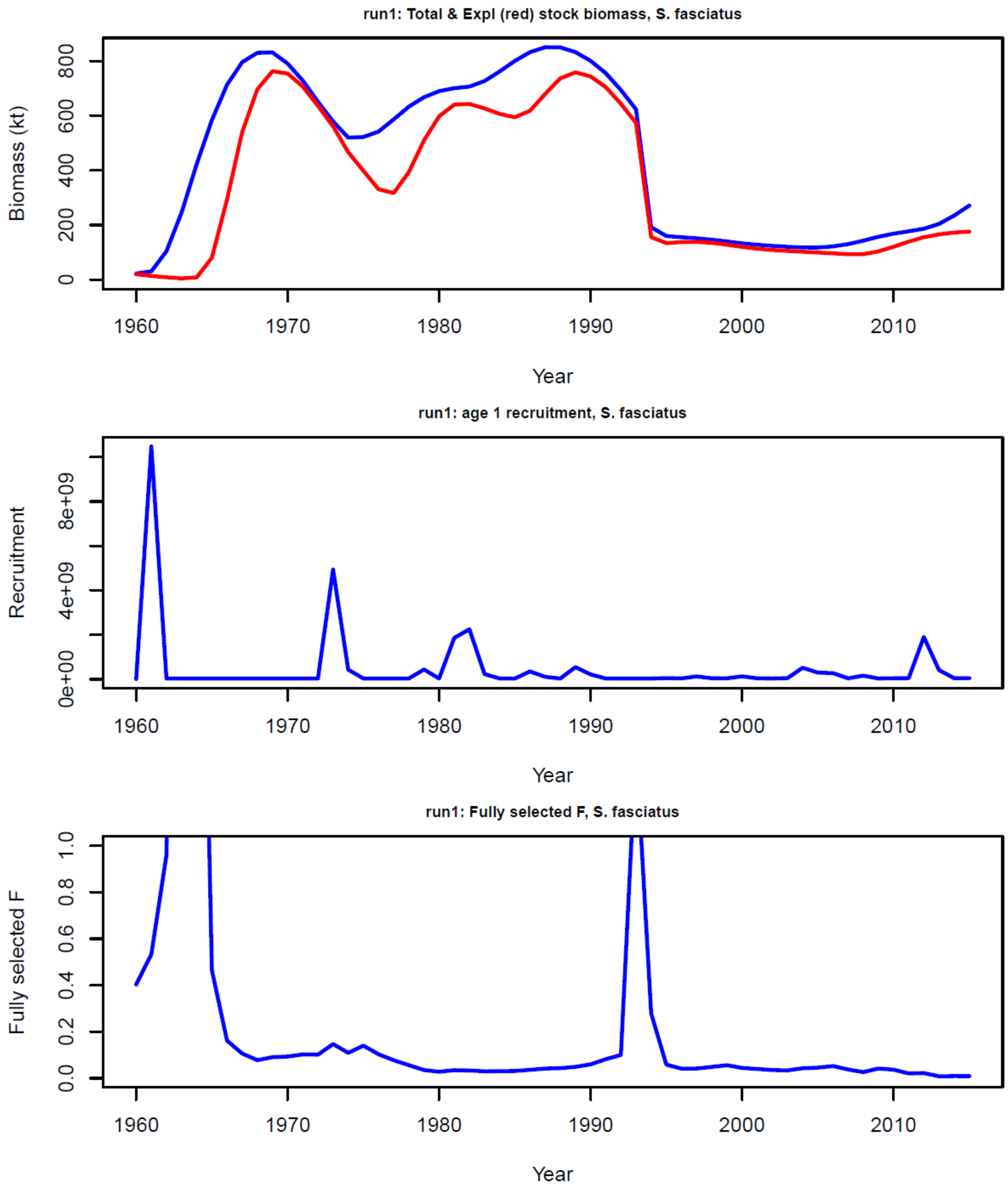

Figure 15: Sebastes fasciatus, base run (run 1) model fitting predictions of stock biomass, recruitment and fishing mortality. On the top panel, exploitable biomass is in red and total biomass is blue (and always larger). The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

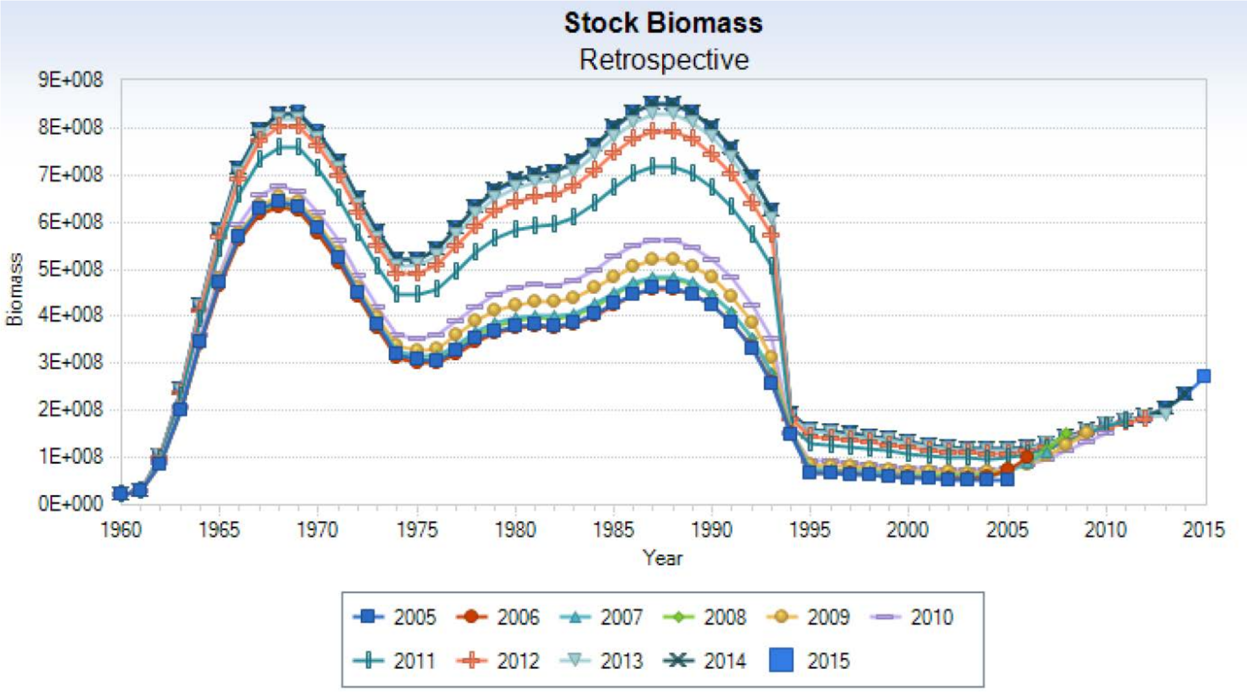

Figure 16: Sebastes fasciatus, base run (run 1) retrospective runs of total stock biomass (kg) truncating data from 2015 back to 2005. The base run is not the preferred run but the fitting with the fewest subjective assumptions (e.g. data weighting, growth constraints).

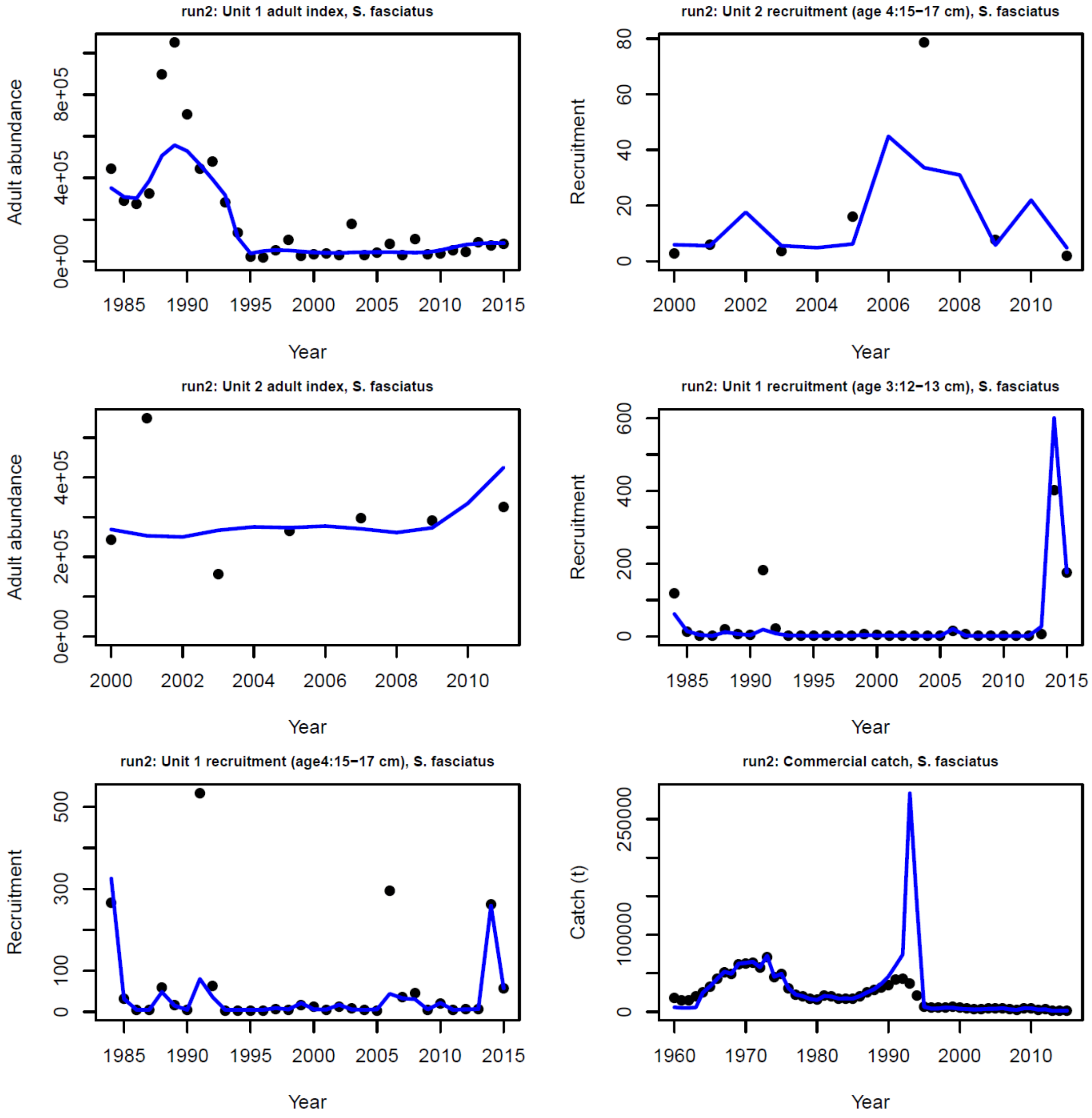

Figure 17: Sebastes fasciatus, preferred run (run 2) fits to data. It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

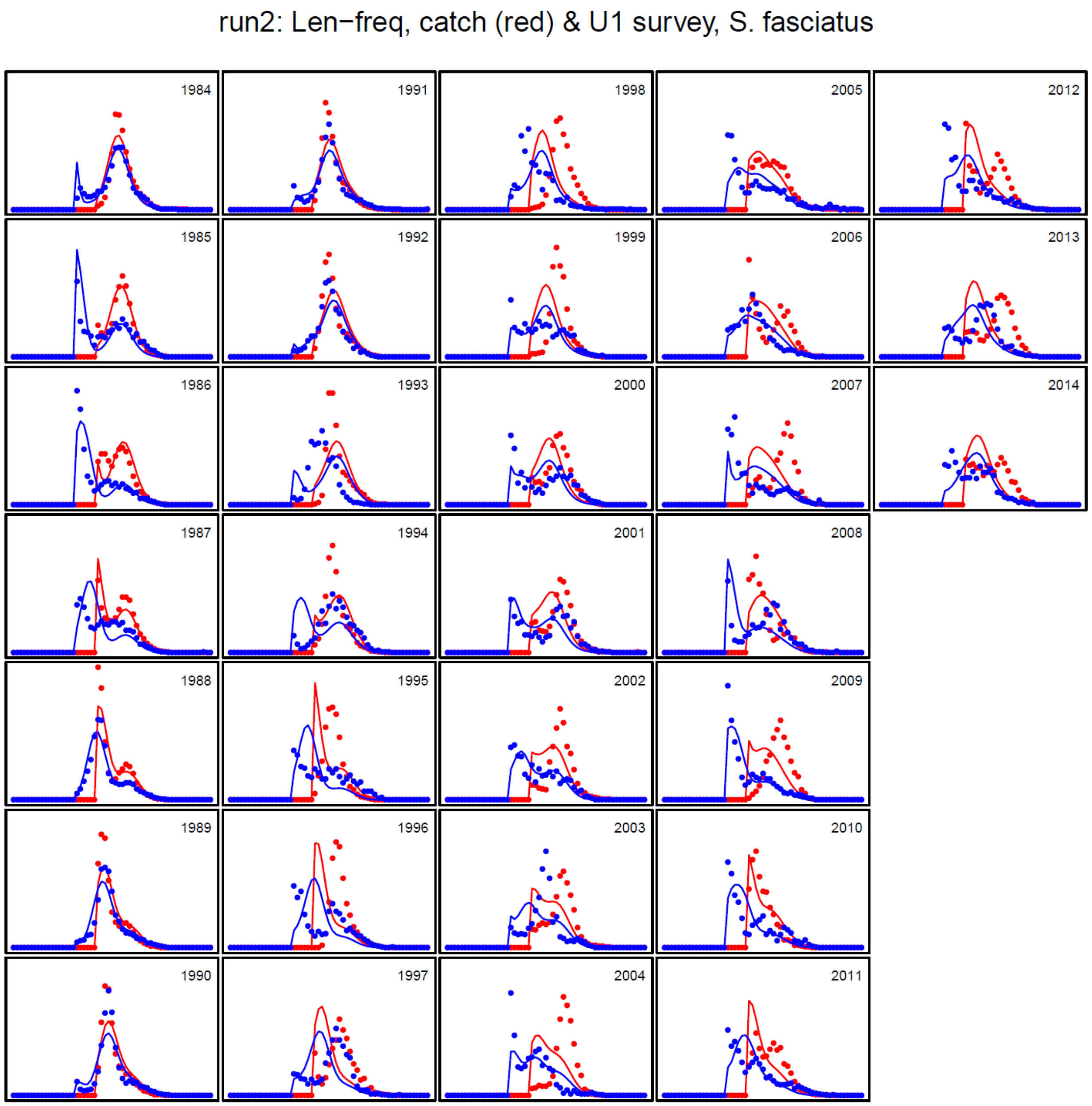

Figure 18: Sebastes fasciatus, preferred run (run 2) fits to length frequency data. The lines are the fits while points are the data. Blue points and lines are the Unit 1 survey and red are the commercial catch. It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

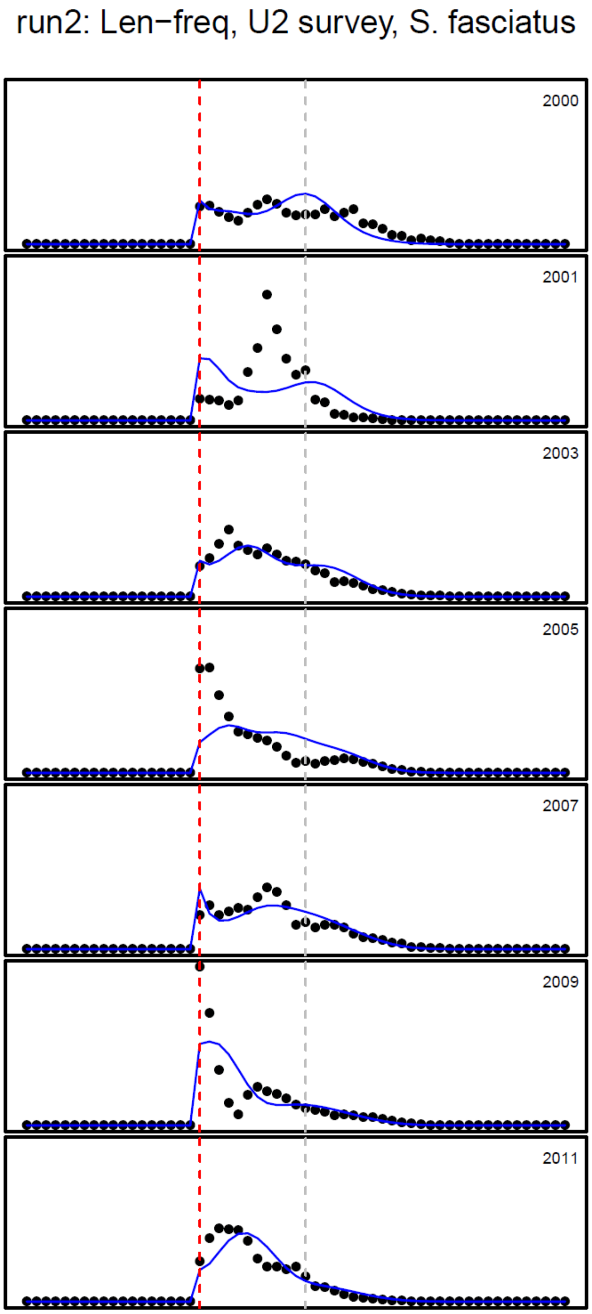

Figure 19: Sebastes fasciatus, preferred run (run 2) fits to Unit 1 survey length frequency data. The lines are the fits while points are the data. It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

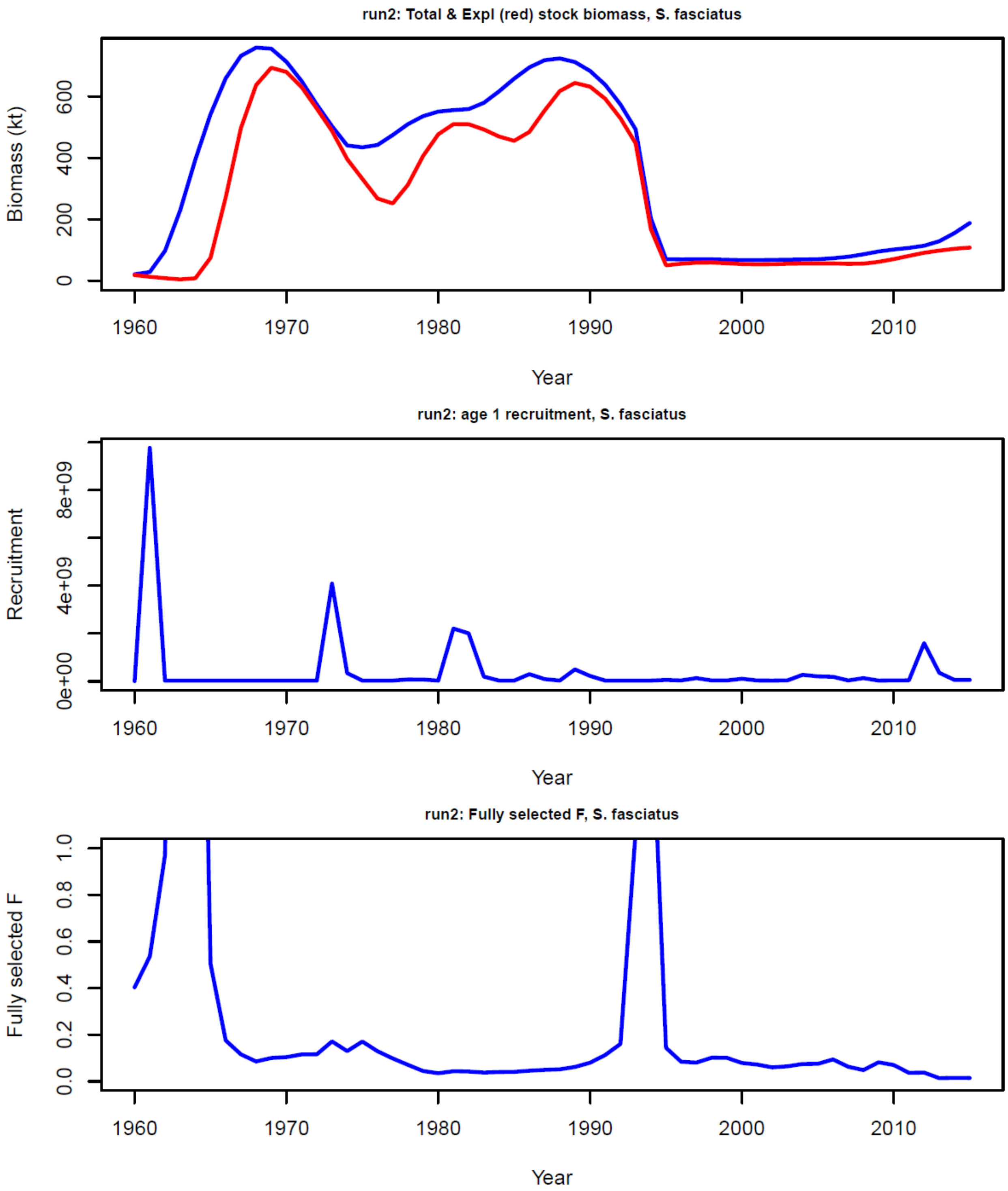

Figure 20: Sebastes fasciatus, preferred run (run 2) model fitting predictions of stock biomass, recruitment and fishing mortality. On the top panel, exploitable biomass is in red and total biomass is blue (and always larger). It is preferred for its better fits to data (especially Unit 1 survey adults) and no retrospective problem in the past 10 years.

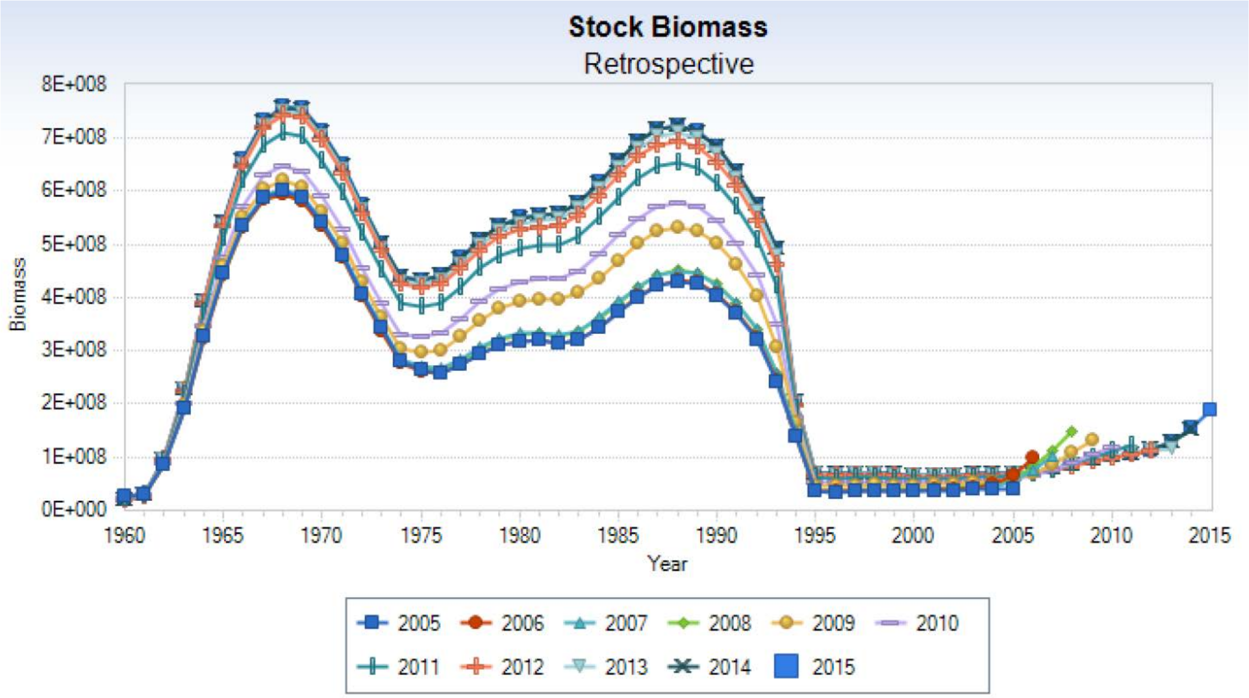

Figure 21: Sebastes fasciatus, preferred run (run 2) retrospective runs of total stock biomass (kg) truncating data from 2015 back to 2005. It is preferred for its better fits to data (especially Unit 1 survey adults).