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Update of SURBA+ for 2J3KL cod

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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

SURBA+ is an age-based and survey-only stock assessment model that provides absolute estimates of total mortality rates (i.e., Z's) and relative estimates of stock size. However, SURBA+ requires external information about the catchability pattern of the age-based survey indices used for estimation, and SURBA+ estimates of Z's are sensitive to assumptions about catchability.

The data used in the model were the DFO 2J3KL RV survey indices for cod ages 2-12 during 1983-2012. Z's are modeled as a separable function of age and year effects in a standard SURBA model; however, this approach provided a poor fit to the 2J3KL cod survey index and a modification was used (i.e., SURBA+) in which Z's are modeled as a random walk over time for each age, and Z's are auto-correlated across ages. An update of this model is presented here.

Results indicated that 2J3KL cod increased in abundance (total and recruitment) and biomass (total and spawners) during 2004-09 and changed little since then. In 2012 the spawning stock biomass was 15 % (95 % confidence interval, 6-36 %) of the limit reference point. Average Z at ages 5-11 was low (about 0.15) during 2005-2008 but increased substantially to 0.84 in 2009 and then declined. In 2012 average Z was 0.27 (0.10, 0.73).

Mise à jour de SURBA+ pour la morue de 2J3KL

RÉSUMÉ

SURBA+ est un modèle d'évaluation du stock fondé sur l'âge et reposant uniquement sur des relevés. Il fournit des estimations absolues du taux total de mortalité (Z) et des estimations relatives de la taille des stocks. Cependant, SURBA+ requiert des données externes sur le patron de capturabilité des indices de relevés fondés sur l'âge utilisés pour les estimations; en outre, les estimations de Z faites à l'aide de SURBA+ sont sensibles aux hypothèses sur la capturabilité.

Pour le modèle, on a utilisé comme données les indices des relevés effectués par Pêches et Océans Canada à partir d'un navire de recherche dans 2J3KL pour les morues âgées de 2 à 12 ans, entre 1983 et 2012. Le taux de mortalité Z est modélisé comme une fonction séparable des effets de l'âge et de l'année dans un modèle SURBA standard; cependant, cette méthode s'accordait mal aux indices de relevés de la morue de 2J3KL et une modification a été utilisée (SURBA+), où Z est modélisé comme une marche aléatoire dans le temps pour chaque âge et autocorrélé à travers les âges. Une mise à jour de ce modèle est présentée ici.

Les résultats indiquent une augmentation en abondance de la morue de 2J3KL (total et recrutement) et en biomasse (total et reproducteurs) entre 2004 et 2009 et le stock a peu changé depuis. En 2012, la biomasse du stock de reproducteurs s'élevait à 15 % du point de référence limite (intervalle de confiance de 95 %, 6 à 36 %). La valeur moyenne de Z pour les morues âgées de 5 à 11 ans était faible (environ 0,15) entre 2005 et 2008, mais ce taux a augmenté substantiellement à 0,84 en 2009 avant de décliner. En 2012, la valeur moyenne de Z était de 0,27 (0,10, 0,73).

INTRODUCTION

A SURBA cohort analysis of autumn RV catch rates was used for the first time in the 2010 assessment of 2J3KL cod to infer trends in the status of cod in the offshore. The SURBA model was described by Cadigan (2010), and details of the 2J3KL cod application are given in Brattey et al. (2010). The model was applied to RV data from 1995-2009 and ages 2-8 to infer trends in total mortality rates (Z's) and recruitment rates. The model was not applied to ages greater than 8 because of the very low (i.e., many zero's) catch rates at these ages. The model was not applied to survey data prior to 1995 because of problems with the model fit. The model assumed that Z was a multiplicative function of age and year effects. This separable Z assumption did not seem appropriate over the entire 2J3KL survey time period (also see Fig. 15 in DFO 2011), as evidenced by the strong residual patterns (i.e., blocks of ages and years with positive or negative residuals).

The 2010 assessment model formulation was considered insufficient (DFO 2011) for determining a limit reference point because the short time frame of the model did not cover the 1980's when stock size and recruitment were much higher. Also, the limited age range in the 2010 SURBA model would produce partial and therefore biased estimates of SSB trends if the model was extended to the 1980's. Including more ages and years was considered necessary for limit reference point analyses. In DFO (2011) the SURBA model was extended to allow some variation in the *Z* age-pattern over time. This extension is referred to as the SURBA+ model.

In this paper the SURBA+ model is updated using survey data for the period 1983-2012 and a model formulation identical to DFO (2011). A more complete description of the method is also provided.

METHODS

The following description of SURBA+ expands on that in DFO (2011), with a few minor corrections added and additional text to describe survey data fitting.

The basis of SURBA+ is a standard cohort model in which the abundance at age *a* in year *y* ($N_{a,y}$) is equal to that cohort abundance in the previous year times the survival rate which is expressed in terms of total mortality rate (*Z*),

$$N_{a,y} = N_{a-1,y-1} \exp(-Z_{a-1,y-1}). \qquad (1)$$

Without loss of generality it is assumed that $a = 1,\dots,A$ and $y = 1,\dots,Y$. Equation (1) can be applied recursively to express $N_{a,y}$ in terms of recruitment at model age $a = 1$,

$$N_{a,y} = N_{1,y-a+1} \exp(-\sum_{i=1}^{a-1} Z_{i,y-a+i}). \qquad (2)$$

In equation (2), $N_{a,y}$ is modeled as cohort recruitment ($N_{1,y-a+1}$) times cumulative total mortality, $\exp(-\sum_{i=1}^{a-1} Z_{i,y-a+i})$.

In a standard SURBA model (Needle 2002; Beare et al. 2005) Zay is decomposed into age and year effects, $\log(Z_{ay}) = s_a + f_y$. However, a more flexible approach is used in SURBA+. Za,y's are assumed to be random effects that change smoothly over time. Let $\delta_{1y} = \log(Z_{1y})$. For a = 1, δ_{1y} is assumed to follow a random walk,

$$\delta_{1y} = \delta_{1y-1} + \varepsilon_{1y}, y = 2, \ldots Y. \tag{3}$$

where the ε_{1y}'s are independent and identically distributed (iid) normal random variables with zero mean and variance $\sigma^2_{1\varepsilon}$. Equation 3 defines a simple random walk for δ_1. Estimates of δ_1's, should differ between years only if these differences provide substantial improvement in fit to the survey indices. The fit is measured by the likelihood function which is described later in this Section. Between-year variation in δ_1's is controlled by $\sigma^2_{1\varepsilon}$ whose estimation is also described later.

The $Z_{a,y}$'s for other ages were also treated as random walks but correlated so that the age patterns in Z's varied more smoothly over years and ages,

$$\log(Z_{a,y}) = \log(Z_{a-1,y}) + \delta_{a,y},\ a = 2, \ldots, A \text{ and } \delta_{a,y} = \delta_{a,y-1} + \varepsilon_{a,y}, y = 2, \ldots Y. \tag{4}$$

where εa,y's are iid $N(0, \sigma^2_{a,\varepsilon})$. Estimation of $\sigma^2_{a,\varepsilon}$ is describe later.

The random walks in Equations (3) and (4) require some starting conditions. The random walks were started twice, once in the first year and also in 1994 to accommodate the potentially abrupt change in mortality pattern at that time (Fig. 15 in DFO 2011). In the first year (model year 1) and in 1994 (model year 12) the δ's were modeled as cubic polynomial functions of age, s(a),

$$\delta_{ak} = s_k(a) + \varepsilon_{ak},\ a = 1, \ldots, A;\ k = 1 \text{ or } 12, \tag{5}$$

where εa,y's are iid $N(0, \sigma^2_{a,\varepsilon})$. The cubic polynomials are used to roughly set the mean levels for the δ's, and fine tune adjustments are made by the εay's.

The difference between Za,y and Za,y-1 depends on $\sigma^2_{a,\varepsilon}$ which may differ by age. $\sigma^2_{a,\varepsilon}$ was constrained to be equal for ages 2-3 (young), 4-8 (medium), and ages 9-12 (old). Hence, only three parameters for the $\sigma^2_{a,\varepsilon}$'s were estimated.

There are a large number of effects (parameters and random terms) to estimate in this model. There are A initial numbers at age (Na1's), Y-1 other recruitments (N1y's), eight parameters in the two cubic polynomials (s1(a) and s2(a), Equation 5), the AxY ε random effects in Za,y's (Equations 3-5), and the three variance parameters $\sigma^2_{young,\varepsilon}$, $\sigma^2_{medium,\varepsilon}$ and $\sigma^2_{old,\varepsilon}$. However, the random effects are not freely estimated. Fixed effects parameters, denoted collectively as the parameter vector θ, are estimated via maximum likelihood (MLE) based on the marginal likelihood, L(θ), in which random effects are "integrated out". Let Ψ denote the AxY matrix of random walk error terms εay's. The marginal likelihood is

$$L(\theta). = \iiint_{\Psi} f_\theta(I_{11}, \ldots, I_{AY} \mid \Psi) g_\theta(\Psi) \partial\Psi, \tag{6}$$

where $f_\theta(I_{11},...,I_{AY} \mid \Psi)$ is the joint probability distribution function (pdf) for the RV indices and $g_\theta(\Psi)$ is the joint pdf for the random effects (Ψ). AD Model Builder (ADMB Project 2009) and the random effects module were used to implement the model. The high dimensional integral (Eqn. 6) is numerically evaluated using the Laplace approximation in ADMB. The MLE's of θ maximize L(θ). The random effects Ψ can be predicted by maximizing the joint likelihood, $f_\theta(I_{11},...,I_{AY} \mid \Psi) g_\theta(\Psi).$ Additional information on these procedures is provided by Skaug and Fournier (2006).

Surveys provide the data to estimate model parameters. Let Iay denote the DFO autumn RV survey index for age a fish in year y. Let t be the midpoint of the survey dates, which is expressed in a fraction of the year and fixed at t = 0.8 for all years for the DFO autumn RV survey. Indices for ages 2-12 and years 1983-2012 were used for model estimation. Indices for age 1 are not used because catch rates of age 1 cod in the Engels portion of the time-series (1983-94) were low and are not comparable to recent catch rates in the Campelen trawl that has a smaller mesh size.

The observation equation is

$$E(I_{ay}) = q_a N_{ay} \exp(-tZ_{ay}). \qquad (7)$$

The $\exp(-tZ_{ay})$ term projects beginning-of-year stock abundance (Na,y) to the time of the survey. The qa's are catchability parameters that adjust stock abundance to the scale of the surveys. If the survey indices are estimated totals for the entire survey area then the q's may be close to one. However, if the indices are in mean numbers per tow, as is the case in this application, then the q's will be much less than one.

In a SURBA model, q's cannot be estimated in addition to the N's. Hence, the q's are fixed at user-specified values and SURBA+ estimates of stock size are relative to these q-assumptions. The fully recruited q's (age 4+) were fixed at one for 2J3KL cod so that both the SURBA estimates and the index are scaled as number per tow. For ages 2 and 3 the q's were set at smaller values (0.2 and 0.5, respectively) to remove residual patterns. There is some information about catchability at younger ages, because this is the only mechanism in the model that could allow catch rates to increase with age; however, the SURBA model cannot estimate how small q's may be at young ages because this is confounded with how large Z's may be. Hence, the approach taken was to set q's at ages 2 and 3 to large values that also remove residual patterns. The values for q's are shown in Fig. 1. These are the same values used in DFO (2011 and Figure 14 in that document).

The indices are assumed to have a lognormal distribution with mean $E\{\log(I_{a,y})\} = \log(q_a) + \log(N_{a,y}) - tZ_{a,y}$ and standard deviation $\sigma_I = Var\{\log(I_{a,y})\}^{1/2}$ which is also estimated. Parameters are estimated using Equation (6). The lognormal distribution requires survey indices to be positive (i.e., no zero's), and any zero index is given an arbitrary value of one and an estimation weight of zero so that this arbitrary value does not contribute to the likelihood in (6). 19 % of indices had zero values, although the zeros were mostly at older ages (see Fig. 13). In addition, the 2004 survey was incomplete and not used for estimation.

Other model inputs are estimates of maturity-at-age and beginning-of-year weight-at-age. The maturity data were provided by the stock assessment lead, and are estimates of the proportion mature-at-age (ages 0-25, 1983-2016) obtained from a Binomial logistic regression analysis applied by cohort. Cadigan (2013) investigated a few model-based approaches to predict beginning-of-year stock weights based on average weight-at-age sampled in the fall autumn RV survey. Preliminary analyses indicated that the modified-Gompertz model fit the survey weight data best and these were used in the SURBA model presented at the 2013 RAP. However, subsequent analyses indicated that the more standard Von Bertalanffy model fit slightly better (Cadigan 2013). The reason for this change seems to have been an error in fitting the Von Bertalanffy model before the RAP. The sensitivity of assessment results to these different weights will be presented at the end of this document.

RESULTS

Estimates of beginning-of-year stock size (total biomass, SSB, and recruitment) increased during 2004-09 and changed little since then (Table 1; Fig. 2). In 2012 the spawning stock biomass was 15 % (95 % confidence interval, 6-36%) of the limit reference point (Table 2; Fig. 3).

The age patterns in SURBA+ Z's (Fig. 4) indicate a change over time. Total mortality rates were at times very high for 2J3Kl cod (Figs. 5 and 6) during 1990-2005. Average Z at ages 5-11 was low (about 0.15) during 2005-2008 but increased substantially to 0.84 in 2009 and then declined. In 2012 average Z was 0.27 (95 % CI: 0.10, 0.73).

SURBA+ predictions correspond well with survey mean numbers per tow (Figs. 7-9). The largest discrepancies were in 1985 and 1986, and this could be caused by the high survey estimates in 1986 which are generally thought to be year effects. There are also discrepancies for the 2000-06 cohorts.

SSB was derived from SURBA+ by projecting beginning-of-year numbers at age to mid-year by applying 50% of the estimated Z, and then multiplying by survey weight-at-age and maturities, and summing over ages. SSB was also derived directly from the survey. Both sets of results were adjusted up by the survey swept area. The survey estimates differed from the SURBA+ estimates (Figs. 10 and 11) because additional mortality occurs between mid-year when the SURBA+ SSB was computed and the fall survey. Mid-year SSB is thought to be a more reliable indicator of the true SSB.

There were no major patterns in SURBA+ residuals (Figs. 12-14) to indicate important model misspecifications. Within-model retrospective variation, which can also indicate misspecification, was not large and did not have a consistent trend (Fig. 15). The retrospective differences in 2009 are consistent with a year-effect in that year.

Abundance estimates for 1983-2010 (Fig. 16) were very similar to the results in DFO (2011), and differences in biomass estimates are related to the different weights-at-age used in the 2013 RAP and in DFO (2011) and Cadigan (2013). These differences are shown in Fig. 17. However, using updated weight at age data had little impact on estimates of SSB relative to Blim (Fig. 18).

For the 2013 RAP, Cadigan (2013) proposed a modified Gompertz growth model to infer beginning-of-year weight-at-age for SSB and reference point calculations. However, subsequent analyses suggested that the more standard Von Bertalanffy growth model seems to provide slightly better results (Cadigan 2013). However, both modelling choices result in very similar conclusions about stock status relative to Blim (Fig. 19).

DISCUSSION

In summary, the SURBA+ model results indicate that:

- 2J3KL cod increased in abundance (total and recruitment) and biomass (total ages 2-12 and SSB) during 2004-09 and changed little since then.
- In 2012 the SSB was 15 % (95 % confidence interval, 6-36%) of the limit reference point.
- Average Z at ages 5-11 was low (about 0.15) during 2005-08 but increased substantially to 0.84 in 2009 and then declined.
- In 2012 average Z was 0.27 (0.10, 0.73).

SSB was projected to midyear when determining stock status relative to Blim. However, beginning-of-year weights-at-age were used to calculate midyear SSB. In the future it would be more consistent to use midyear weights which can be easily obtained using a growth model (Cadigan 2013). Alternatively, stock status could be evaluated at the beginning of the year.

Stock status relative to Blim was not sensitive to the choice of model used to infer beginning-of-year stock weights; however, the Von Bertalanffy model fit the survey weights slightly better (Cadigan 2013) and in future assessments this model may be a better choice than the modified-Gompetz model.

There is a slight residual pattern at ages 3-5 (Fig. 13) which suggests that further refinement to the values of catchability (q) assumed at these ages may be warranted.

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Table 1. Estimates of beginning-of-year stock size (total biomass, SSB, and recruitment at age 2) with 95 % confidence intervals (L,U). Units are per tow and corrected for survey catchability (see Figure 1).

	Recruits (# per tow)			Total biomass (Kg per tow)			SSB (Kg per tow)		
Year	**Estim.**	**L**	**U**	**Estim.**	**L**	**U**	**Estim.**	**L**	**U**
1983	109.62	58.01	207.14	139.97	91.72	213.58	36.54	18.03	74.02
1984	233.50	68.53	795.57	187.88	86.01	410.42	36.56	15.79	84.64
1985	158.25	45.94	545.09	162.89	66.92	396.53	38.03	16.97	85.24
1986	50.50	15.18	167.98	145.01	59.71	352.14	46.58	19.62	110.58
1987	53.67	20.94	137.55	176.64	70.19	444.54	46.11	18.19	116.90
1988	49.70	13.19	187.30	115.78	49.32	271.79	46.39	17.09	125.93
1989	97.72	35.81	266.67	142.28	62.49	323.98	54.59	19.70	151.25
1990	211.79	82.15	546.05	172.28	72.07	411.81	39.42	14.70	105.74
1991	74.83	24.76	226.13	143.94	56.55	366.38	16.70	6.39	43.67
1992	44.01	11.81	164.01	75.19	27.24	207.55	6.56	2.41	17.88
1993	13.24	2.75	63.73	19.76	6.80	57.41	1.52	0.55	4.21
1994	9.82	2.13	45.21	6.84	1.95	23.94	0.46	0.16	1.38
1995	2.52	0.61	10.46	1.96	0.84	4.59	0.28	0.09	0.87
1996	3.86	1.38	10.81	2.71	1.19	6.17	0.34	0.10	1.09
1997	5.37	2.05	14.08	3.16	1.36	7.38	0.38	0.13	1.07
1998	2.91	1.00	8.45	2.51	1.16	5.45	0.43	0.17	1.09
1999	3.60	1.49	8.72	3.01	1.49	6.07	0.56	0.24	1.31
2000	6.71	3.23	13.96	4.91	2.47	9.76	0.57	0.24	1.37
2001	7.91	3.51	17.84	6.10	3.04	12.24	0.55	0.23	1.32
2002	8.03	3.37	19.13	5.62	2.73	11.55	0.49	0.22	1.11
2003	7.37	2.91	18.63	3.98	1.83	8.69	0.39	0.18	0.81
2004	3.58	1.17	10.98	2.34	1.05	5.19	0.36	0.17	0.76
2005	4.66	1.96	11.08	3.08	1.38	6.86	0.49	0.23	1.03
2006	3.64	1.98	6.71	5.07	2.23	11.52	1.01	0.43	2.38
2007	5.56	3.15	9.81	7.93	3.61	17.42	2.90	1.09	7.73
2008	9.73	5.60	16.90	12.03	5.91	24.48	5.19	1.94	13.87
2009	11.44	6.42	20.41	17.15	8.61	34.14	5.38	2.16	13.37
2010	10.65	5.11	22.23	14.68	7.88	27.37	4.87	2.16	11.00
2011	8.86	4.11	19.06	14.46	7.65	27.35	5.30	2.58	10.93
2012	11.72	5.42	25.36	14.79	8.03	27.23	6.48	3.31	12.70

Table 2. Estimates of midyear SSB relative to Blim which is average SSB during 1983-1989. 95 % confidence intervals are indicated as L for lower and U for upper.

				SSB/Blim							
Year	**Estim.**	**L**	**U**	**Year**	**Estim.**	**L**	**U**	**Year**	**Estim.**	**L**	**U**
1983	0.84	0.48	1.47	1993	0.03	0.01	0.10	2003	0.01	0.00	0.02
1984	0.84	0.50	1.41	1994	0.01	0.00	0.03	2004	0.01	0.00	0.02
1985	0.87	0.59	1.29	1995	0.01	0.00	0.02	2005	0.01	0.00	0.03
1986	1.07	0.77	1.49	1996	0.01	0.00	0.03	2006	0.02	0.01	0.06
1987	1.06	0.80	1.41	1997	0.01	0.00	0.03	2007	0.07	0.02	0.19
1988	1.07	0.66	1.72	1998	0.01	0.00	0.03	2008	0.12	0.04	0.35
1989	1.25	0.67	2.35	1999	0.01	0.00	0.03	2009	0.12	0.04	0.34
1990	0.91	0.44	1.86	2000	0.01	0.01	0.03	2010	0.11	0.04	0.29
1991	0.38	0.16	0.90	2001	0.01	0.00	0.03	2011	0.12	0.05	0.30
1992	0.15	0.05	0.41	2002	0.01	0.00	0.03	2012	0.15	0.06	0.36

Figure 1. SURBA catchability (q) versus age.

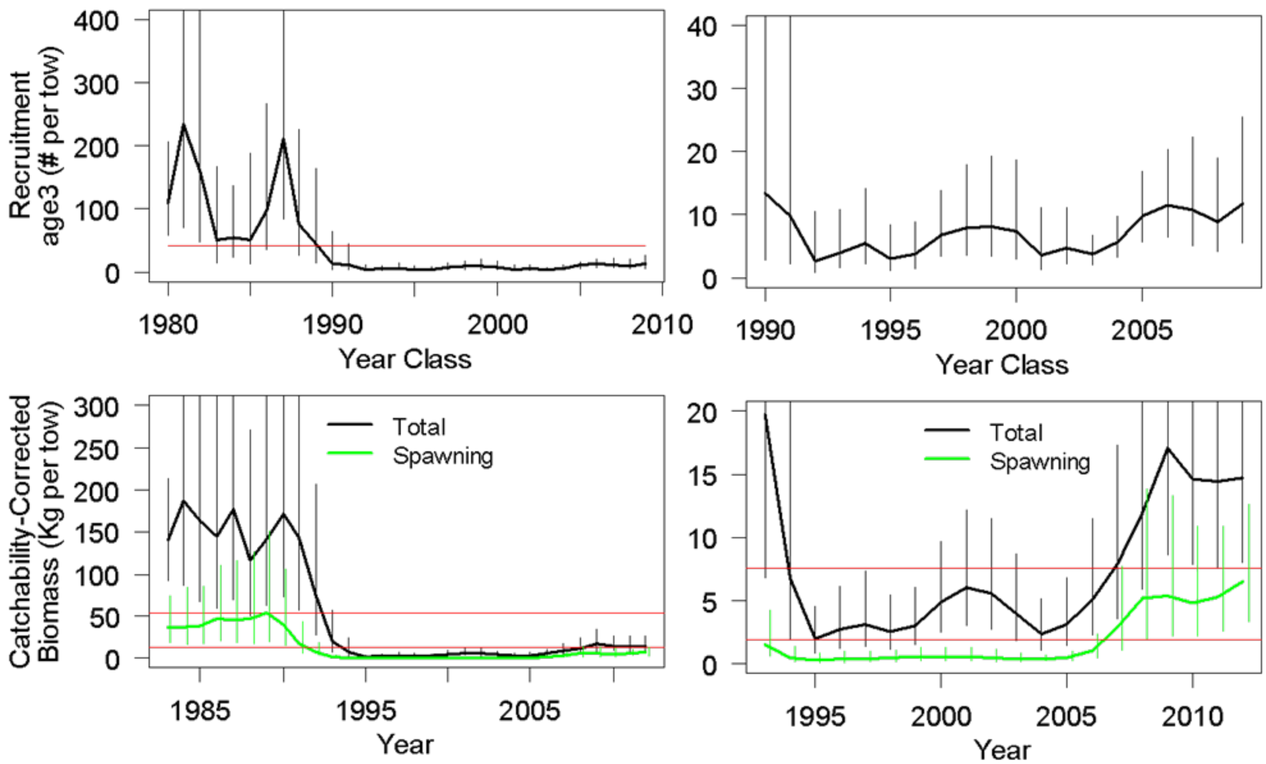

Figure 2. Estimates of recruitment from SURBA+ (number per tow at age two) for 1983-2012 (top right panel) and 1992-2012 (top left panel). The red line indicates the mean of the time series. Bottom panel: Catchability corrected trends in stock biomass for the same periods below. The red lines indicate the means of the time series. Vertical lines indicate 95 % confidence intervals.

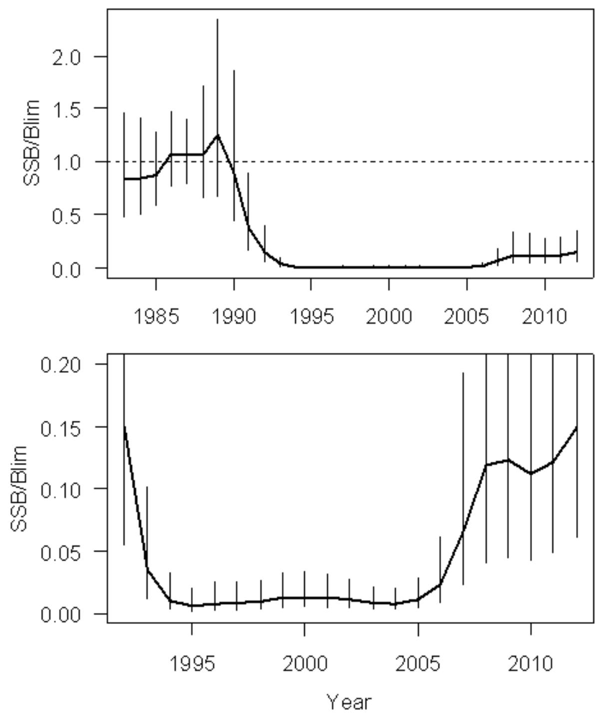

Figure 3. Trends in SSB during 1983-2012 (top panel) and 1992-2012 (bottom panel) relative to Blim. The dashed line in the top panel is for reference. Vertical lines are 95% confidence intervals.

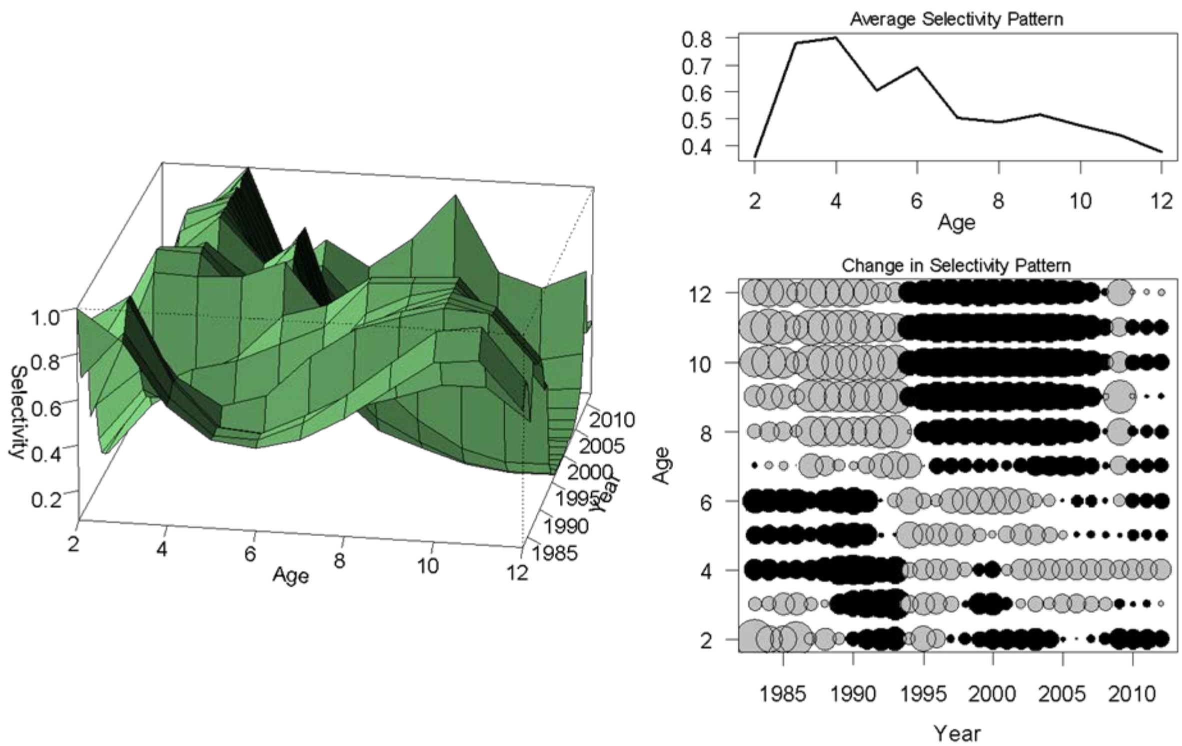

Figure 4. Left panel: Three dimensional graph of the age pattern in SURBA+ Z's (called selectivity), scaled to a maximum of one each year. Top right panel: Average selectivity at age over all years. Bottom right panel: Selectivity deviations from the average. Black indicates negative (i.e. less than average) and grey indicates positive.

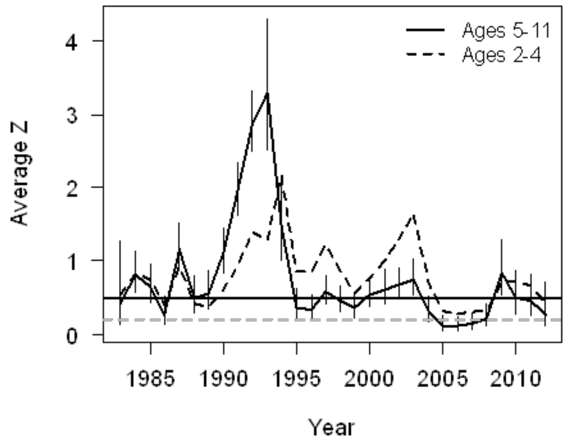

Figure 5. SURBA+ estimates of average total mortality rates (Z's) for young (ages 2-4) and old (ages 5-11) cod. Horizontal lines indicate Z=0.2 (grey dashed) and z=0.5 (black). Vertical lines indicate 95% confidence intervals.

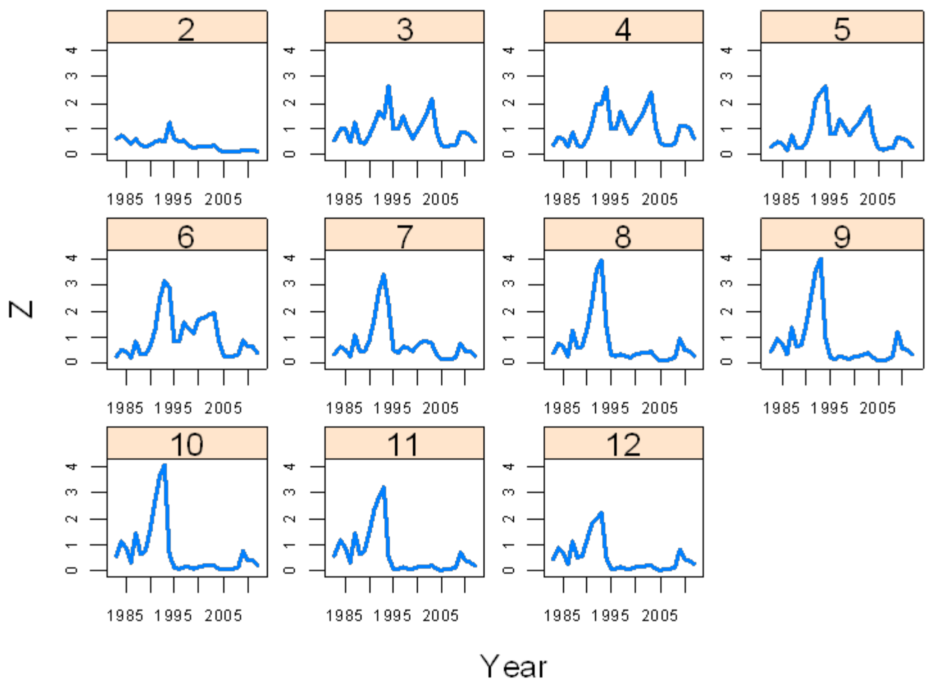

Figure 6. SURBA+ estimates of age-specific (panels) total mortality rates (Z's).

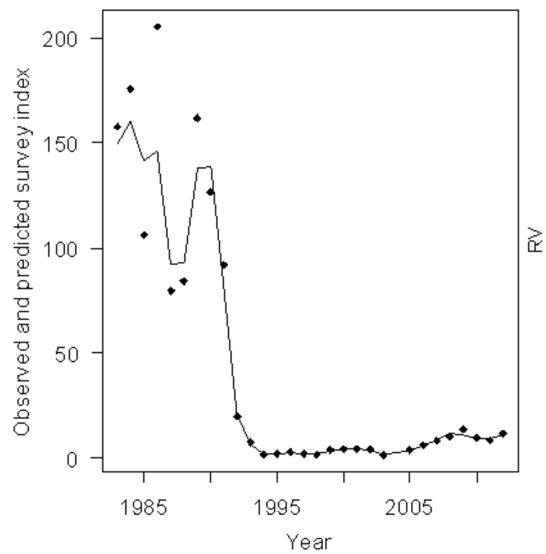

Figure 7. Observed versus predicted total (ages 2-12) survey indices with positive estimation weights.

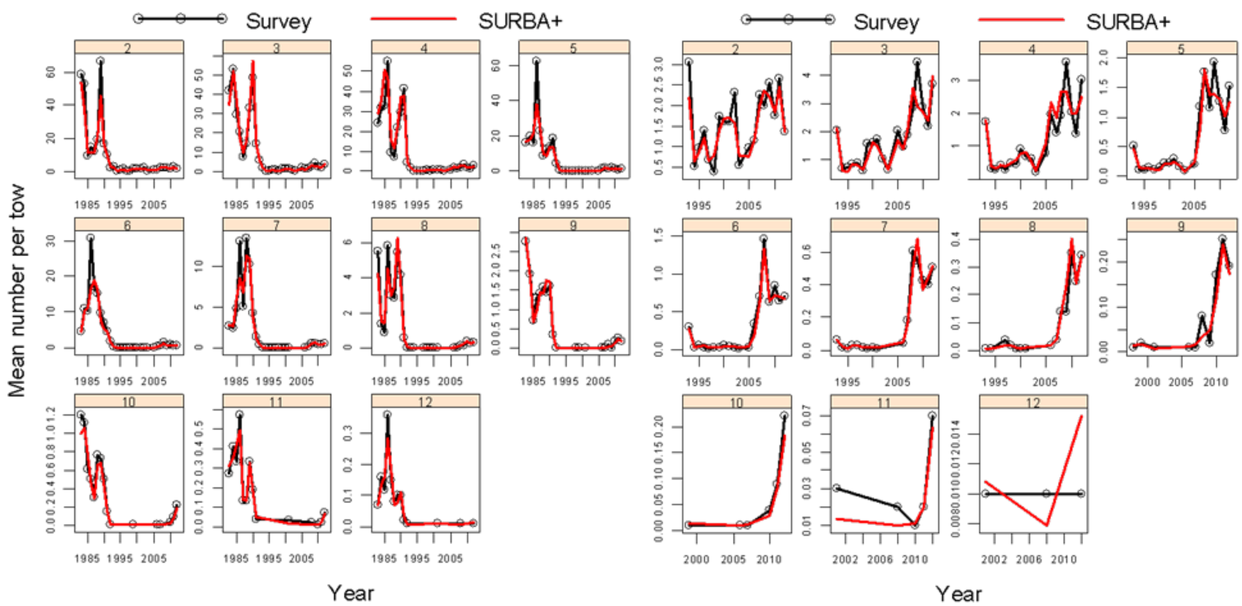

Figure 8. Survey indices (points connected by black lines) versus SURBA+ predicted values (red lines) by age class. Left side: entire series. Right side: since 1992. Only non-zero indices are shown which is why the series are truncated in some panels.

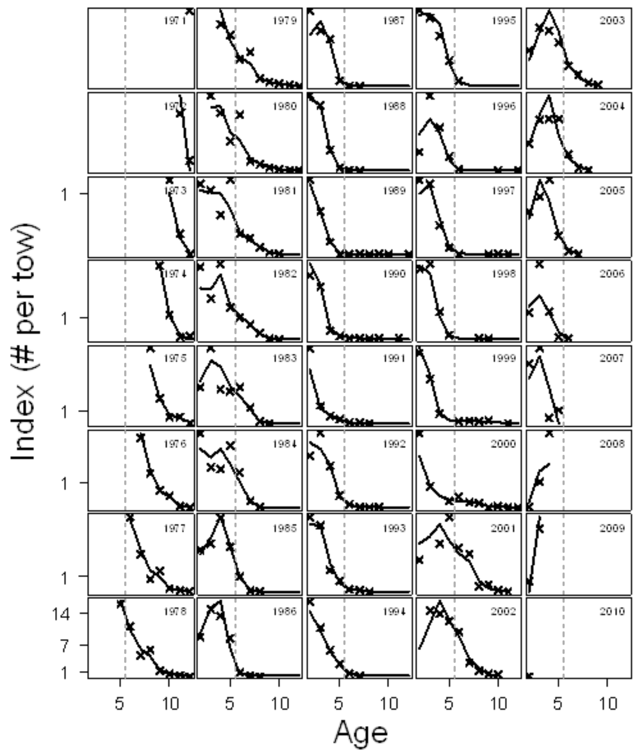

Figure 9. Survey indices (points) versus SURBA+ predicted values (lines) for the 1971 to 2010 cohorts. Each panel shows the results for a cohort.

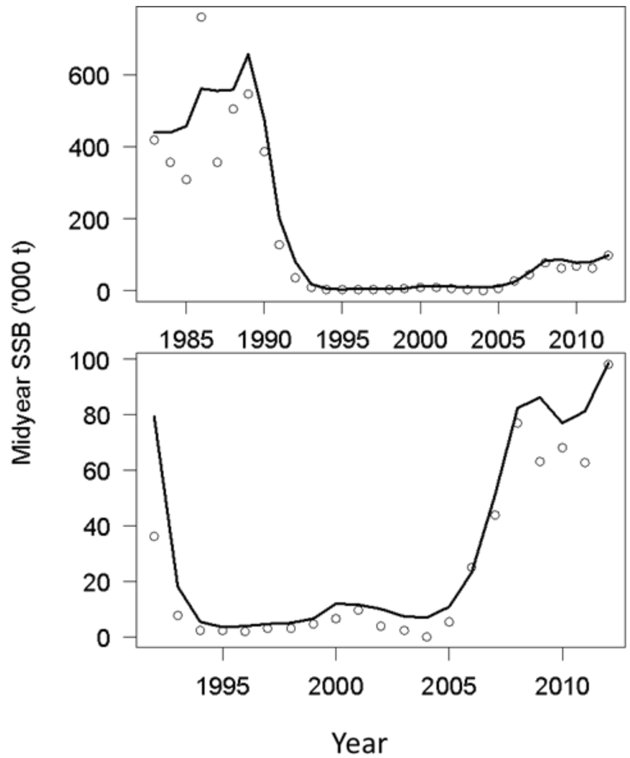

Figure 10. Raw survey estimates of SSB (points) versus SURBA+ estimates (lines). The top panel shows the results for the entire time-series, and the bottom panel gives results since 1992.

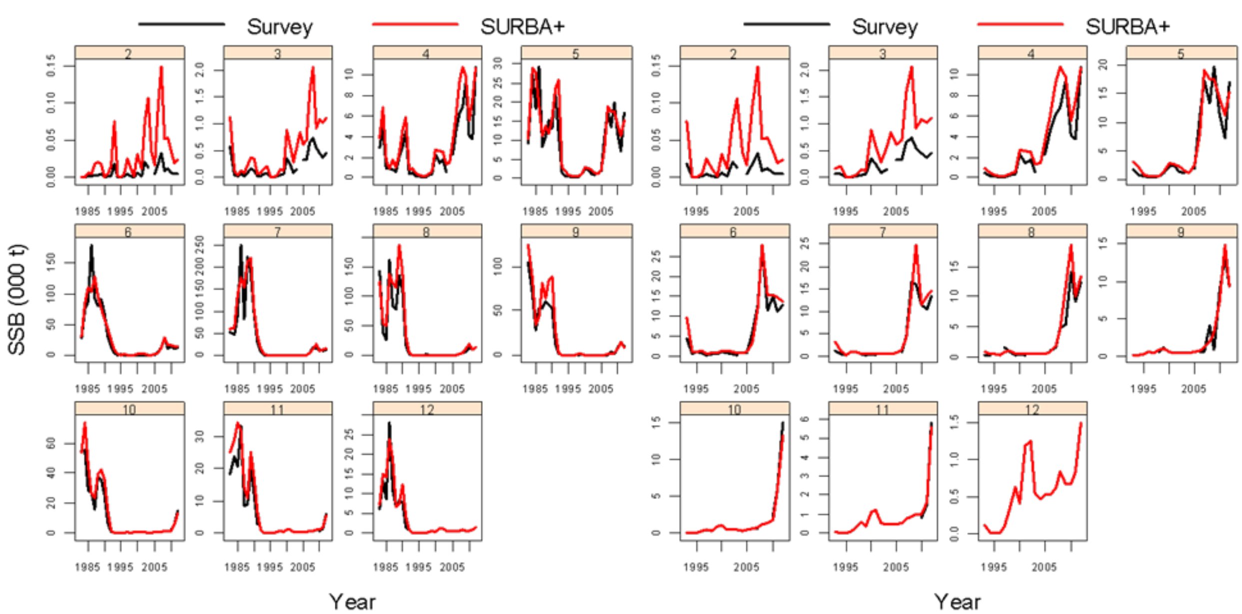

Figure 11. Survey swept-area SSB indices (black lines) versus SURBA+ predicted values (red lines). Left side: entire series. Right side: since 1992. Only non-zero indices are shown which is why the series are truncated in some panels.

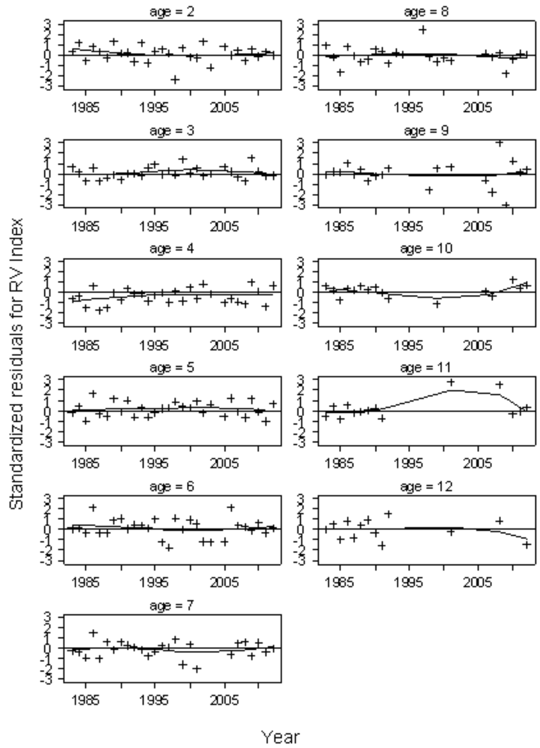

Figure 12. SURBA+ standardized residuals for each age (panels).

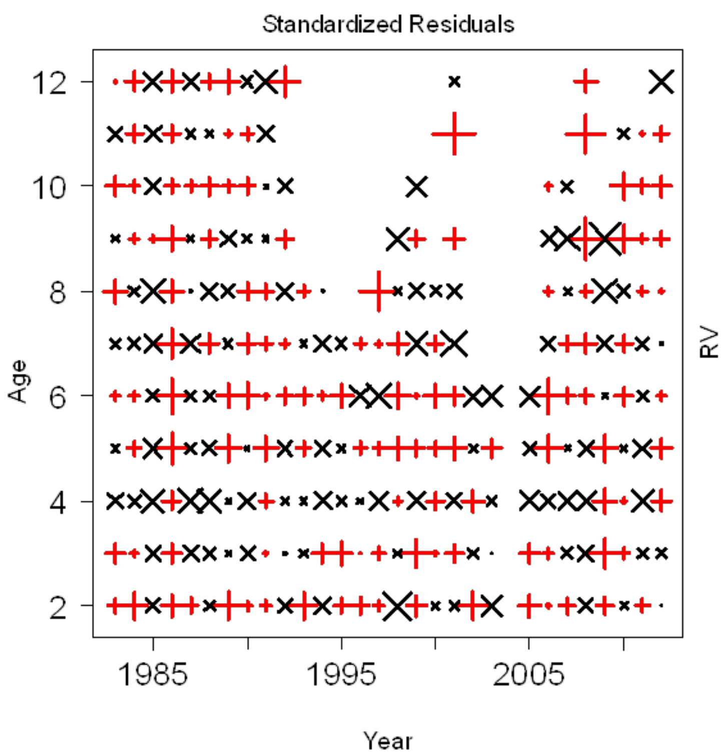

Figure 13. Matrix plot of SURBA+ residuals. Red +'s are positive and black ×'s are negative. The sizes of plotting symbols are proportional to the absolute value of the residuals. Blanks indicate values with zero estimation weights.

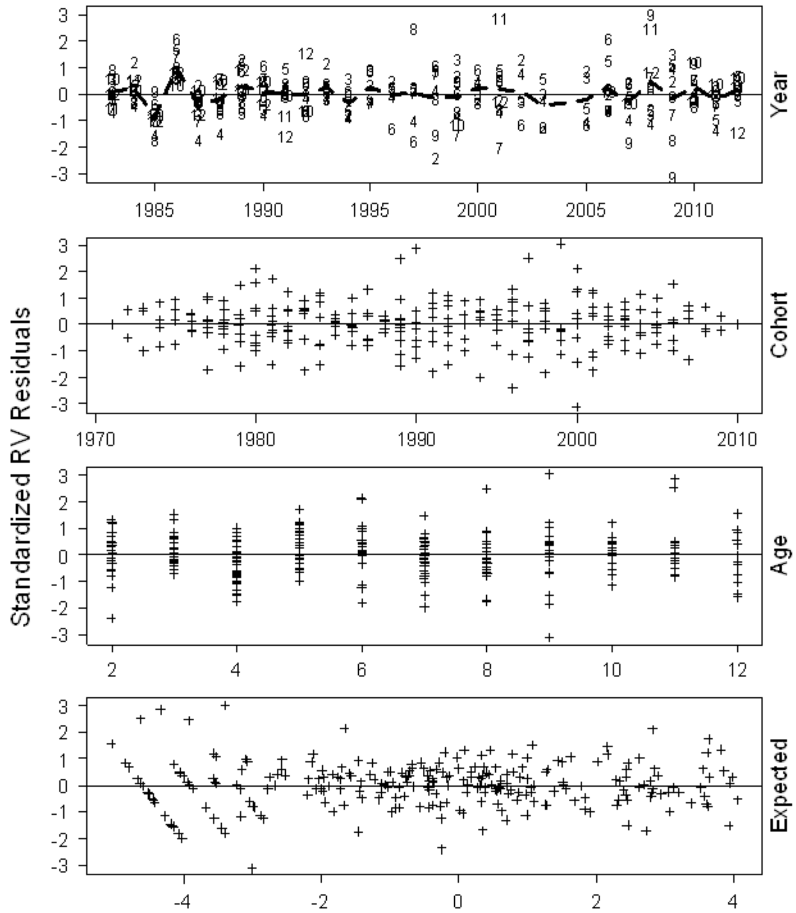

Figure 14. Standard residuals versus year, age, cohort, and predicted value. The dashed line in the top panel indicates the average residual each year, where the plotting symbols indicate age.

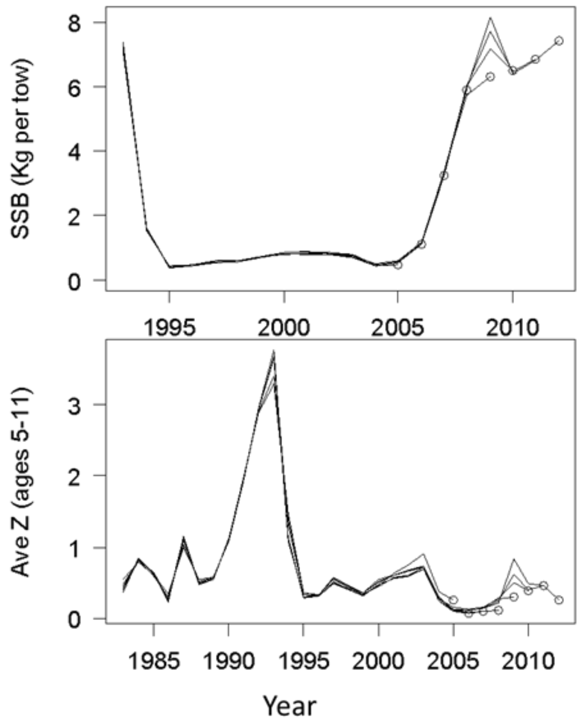

Figure 15. SURBA+ model retrospective patterns in SSB (top panel) and average Z (bottom panel).

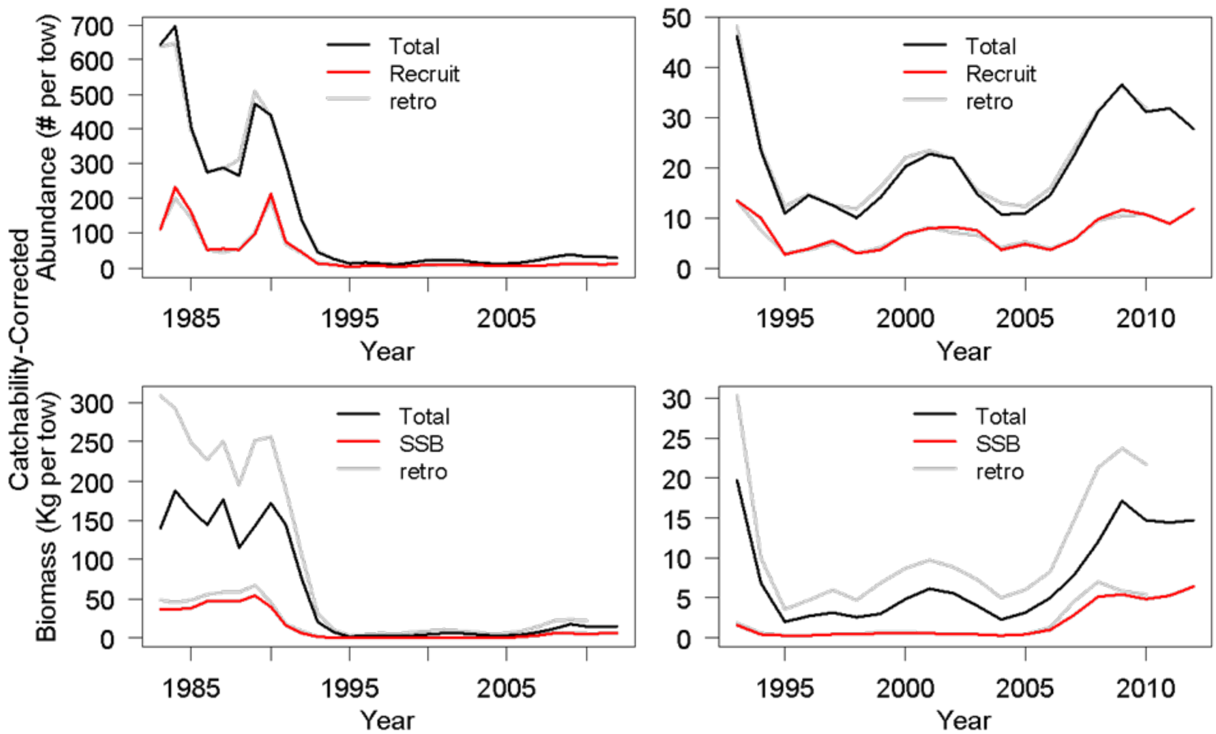

Figure 16. A comparison of 2013 (black and red lines) and 2011 (grey lines) SURBA+ assessment results. Left side: entire series. Right side: since 1992.

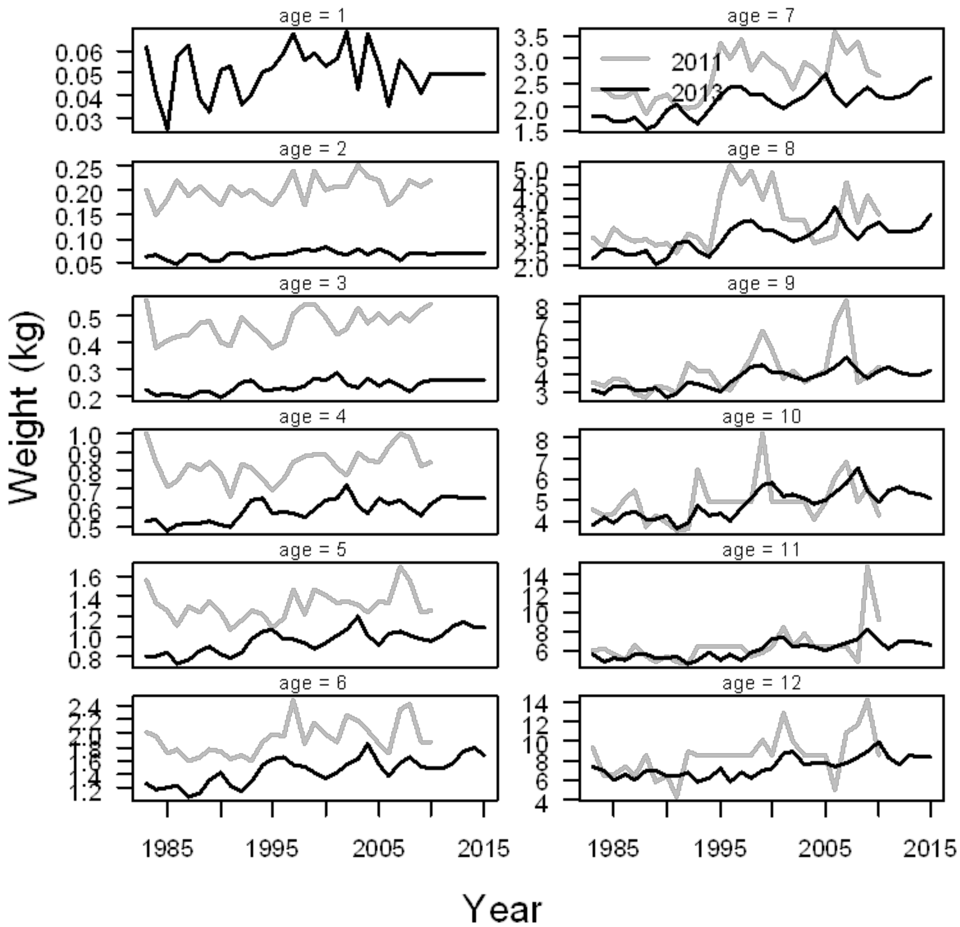

Figure 17. A comparison of modified Gompertz model predicted beginning-of-year weights (labeled 2013) versus the stock weights used in the 2011 SURBA+ assessment of 2J3KL cod. Each panel shows the results for an age class.

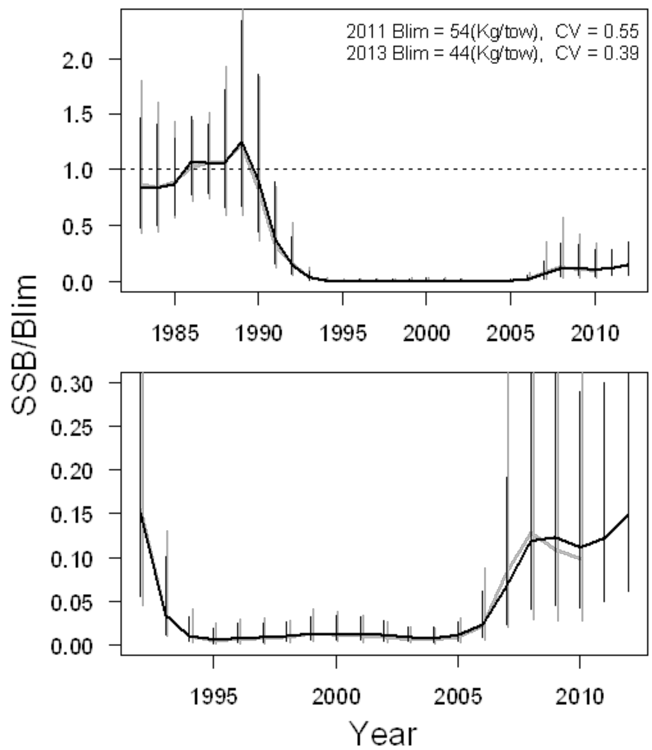

Figure 18. A comparison a 2013 (black lines) and 2011 (grey lines) SURBA+ estimates of SSB relative to Blim. Right side: entire series. Left side: since 1992. Vertical lines indicate 95 % confidence intervals.

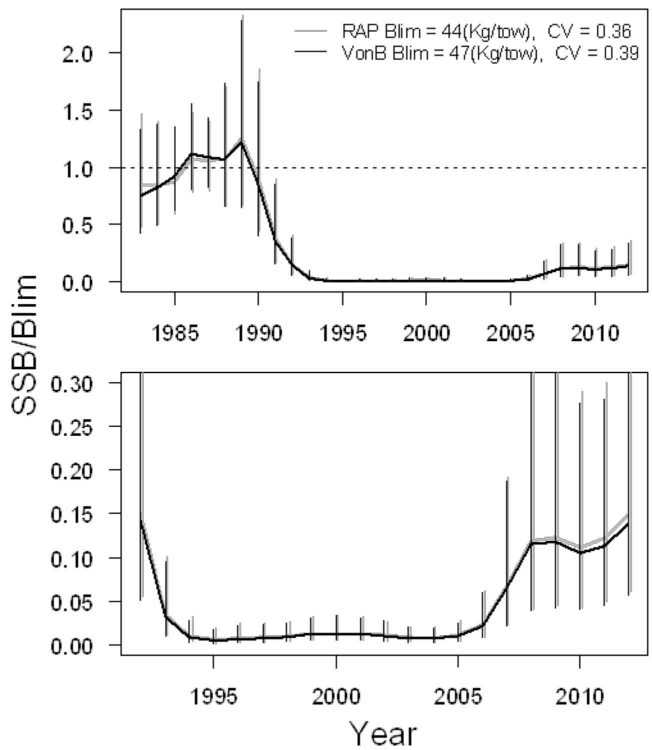

Figure 19. A comparison a SURBA+ estimates of SSB relative to Blim based on beginning-of-year weight-at-age predicted using a modified Gompertz (grey lines) and Von Bertalanffy (black lines) models. Right side: entire series. Left side: since 1992. Vertical lines indicate 95 % confidence intervals.