Updated 2014 Nightingale island rock lobster assessment

Susan Johnston and Doug Butterworth

MARAM

Department of Mathematics and Applied Mathematics

University of Cape Town

Rondebosch, 7701

Summary

This paper provides an updated assessment of the rock lobster resource at Nightingale island. This assessment includes updated data from both the commercial fishery and biomass surveys. The 2014 assessment updates take into account both adult and juvenile mortality due to the OLIVA incident in 2011. The recent (2013) high nominal CPUE value at the island is unexpected, and suggests that the impact of the OLIVA may have been overestimated. A number of robustness trials are therefore run where alternate levels of both juvenile and adult mortality in 2011 due to the OLIVA incident are assumed. The implications of these assumptions for the future management of this resource are discussed. The recent high CPUE probably indicates that the adult mortality in 2011 due to the OLIVA incident was minimal. However, the effect of any juvenile mortality due to the OLIVA will only become evident from CPUE trends over the next few years; such mortality could result in a large drop in abundance over this period. In these circumstances it is recommended that the TAC for Nightingale for the 2014/15 season remain unchanged at 65 MT, and that modifications to this in subsequent seasons be based on future CPUE trends.

Introduction

The age-structured population model used for this assessment is described fully in Johnston and Butterworth (2013). The last assessment of the Nightingale resource was presented in 2012 (Johnston and Butterworth 2012) and did not include fitting to biomass survey data. The 2012 Nightingale assessment did not take into account any mortality due to the OLIVA incident which occurred in March 2011.

This 2014 assessment model is fit to the following data. New data are indicated in bold below:

1) Standardised longline CPUE data for 1997-2010[1].
2) **Biomass survey Leg1 CPUE data (2006-2013, with 2008 data absent).**
3) Catch-at-length data from the onboard observers (males and females separate) (1997-**2013**).
4) **Catch-at-length data from the Leg1 biomass survey (males and females separate) (2006-2013, with 2008 data absent).**

[1] The split season is referenced by the first year, i.e. 2010 refers to the 2010/2011 season.

5) Discard % (1997-**2012**).

Impact of the OLIVA on Nightingale

Reference case model assumptions

The impact that the OLIVA had on the resource at Nightingale is modelled by assuming the following:

i) an 80% once off mortality of lobsters aged 1, 2 and 3 years during the 2011 season, and
ii) a 50% once off mortality on adults (ages 4+) during the 2011 season.

These were previously considered the most reasonable assumptions[2].

The commercial fishery at Nightingale was closed for the 2011 season. A precautionary TAC of 40 MT was set for 2012, and of 65 MT for the 2013 season.

Robustness tests

A robustness test is run which assumes a lesser impact of mortality in 2011 on the **juvenile** lobsters due to the OLIVA incident:

ROB0: a 20% once off mortality on juveniles (ages 1-3) during the 2011 season (retaining the assumption of 50% adult mortality)

Two robustness tests are run which assume a lesser impact of mortality in 2011 on the **adult** lobsters due to the OLIVA incident:

ROB1: a 25% once off mortality on adults (ages 4+) during the 2011 season.

ROB2: a 10% once off mortality on adults (ages 4+) during the 2011 season.

A further robustness test is run which looks at a lesser mortalities for both the juvenile and adult lobsters in 2011:

ROBBOTH: a 20% once off mortality on **juveniles** (ages 1-3) and a 10% once-off mortality on **adults** (ages 4+) during the 2011 season.

[2] Cape Town Workshop held 16-18 November 2011.

The RC model forces F_{2009} = 0.3. Three further robustness tests explore the sensitivity of the model to this assumption.

ROB3: F_{2009} = 0.2.

ROB4: F_{2009} = 0.4.

ROB5: F_{2009} = 0.5.

Nightingale model development

Similar changes as for Inaccessible and Gough, in the way time variance is modelled in the selectivity functions are applied here. Random variation in the μ parameter values are modelled as follows:

$$S_{y,l}^{m,comm} = \frac{e^{-(\mu^m + \varepsilon_y^m)l}}{1 + e^{-\delta^m (l - l_*^m)}} \tag{1}$$

$$S_{y,l}^{f,comm} = P \frac{e^{-(\mu^f + \varepsilon_y^f)l}}{1 + e^{-\delta^f (l - l_*^f)}} \tag{2}$$

where

$$\varepsilon_y^m \sim N(\,0, (\sigma_\mu^2)\ \ ) \tag{3}$$

$$\varepsilon_y^f \sim N(\,0, (\sigma_\mu^2)\ \ ) \tag{4}$$

Consequently a penalty term is added to the likelihood:

$$-lnL \rightarrow -lnL + \frac{1}{2\sigma_\mu^2} \sum_{1997}^{2012} [(\varepsilon_y^m)^2 + (\varepsilon_y^f)^2] \tag{5}$$

Furthermore, the –lnL contribution was modified in order to prevent the model from giving too much weight to the CPUE data (i.e. fitting the CPUE data perfectly by allowing for the ε_y values to vary sufficiently. The contribution of the abundance data to the negative of the log-likelihood function (after removal of constants) is given by:

$$-\ln L = \sum_y \left[(\varepsilon_y)^2 / 2(\sigma^2 + c^2) + \frac{1}{2} \ln(\sigma^2 + c^2) \right] \tag{6}$$

where

σ is the residual CPUE standard deviation estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma} = \sqrt{1/n \sum_{y} \left(\ln CPUE_y - \ln \hat{q}\ \hat{B}_y \right)^2} \tag{7}$$

and *c* is a constant used to prevent the CPUE data receiving too much weight in the likelihood.

In order to keep the realised CPUE residual standard deviation to a reasonable value ~ 0.10-0.15, the following values were selected:

σ_μ=0.02

c = 0.6.

As for the Gough assessment, it was found that allowing the female scaling parameter "P" to vary over time also produced better fits of the model to the CAL data. Thus equation (2) was further modified to:

$$S_{y,l}^{f,comm} = (P + \varepsilon_y^P)\frac{e^{-(\mu_y^f + \varepsilon_y^f)l}}{1 + e^{-\delta^f (l - l_*^f)}} \tag{8}$$

where

$$\varepsilon_y^P \sim N(\,0, (\sigma_P^2)\ \ ) \tag{9}$$

Consequently, a further penalty term was added to the likelihood:

$$-lnL = -lnL + \frac{1}{2\sigma_p^2}\sum_{1997}^{2012}\ (\varepsilon_y^P)^2 \tag{10}$$

and σ_P was fixed at 0.2.

Somatic growth rate model

Previously, two alternate somatic growth rate models have been used to model the growth at Nightingale. Here the "James Glass" somatic growth model is used, as this has since been shown to produce better fits to the observed data (Johnston and Butterworth 2012).

Projections

The resource is projected forwards to 2030 under a constant catch of 65 MT, 75 MT and 85 MT. The future (2011+) stock-recruit residuals are modelled as follows:

The model estimates residuals for 1992-2010. For 2011+ recruitment is set equal to its expected values given the fitted stock-recruit relationship. The relationship itself is $R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{\varepsilon_y - \sigma_R^2/2}$ where $\varepsilon_y \sim N(0, \sigma_R^2)$ and $\sigma_R = 0.4$. This means that the expected recruitment $E[R_y] = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}}$.

Deterministic projections are carried out for the RC model, as well as for all seven robustness tests.

Results and Discussion

The recent (2013) high nominal CPUE value reported at Nightingale (Johnston 2014) is unexpected, and suggests that the impact of the OLIVA incident on the resource may have been overestimated. Consideration of this is a primary focus of this section.

Table 1 compares the 2014 updated RC Nightingale assessment with the previous assessment reported in 2012. Table 1 also reports results of ROB0 for which a lesser amount of *juvenile* mortality is assumed due to the OLIVA incident in 2011, ROB1 and ROB2 where lesser amounts of *adult* mortality due to the OLIVA incident in 2011 are assumed, and for ROBBOTH where lesser amounts of *both* juvenile and adult mortality in 2011 due to the OLIVA are assumed. Estimates of *K* are similar for the assessments (~430 MT) reported in Table 1, with *K* for ROBBOTH being the lowest at 418 MT. Estimates of current spawning biomass relative to pristine for the RC 2014 assessment are less optimistic (~0.40*K*) than estimated in the 2012 assessment (~0.80*K*). The main reason for this is the assumption in the RC that both adults and juveniles were affected by the OLIVA incident (the 2012 assessment results assumed no such OLIVA impacts). The four robustness tests reported for which lesser amounts of juvenile and/or adult mortality is assumed to have occurred in 2011 due to the OLIVA incident estimate the current spawning biomass to be higher at between 0.52*K* and 0.80*K*.

Figure 1 contains plots of the 2014 RC assessment fits to both the longline CPUE and biomass survey CPUE data. The model fits the longline CPUE data well. Note that the Biomass survey CPUE series has data from the 2011-2013 period which are not available for the longline GLM data series. The model does not fit the recent biomass survey CPUE data particularly well (though this could simply reflect that this survey has high variance). Fits to the discard proportion data are not good – this is similar to the situation for Inaccessible and Gough 2014 assessments. The spawning biomass declines even after the impact of the assumed OLIVA adult mortality has taken effect. This is a consequence of the assumed OLIVA-related juvenile mortality.

Figure 2a reports the various selectivity functions estimated. Note that effectively a separate function is estimated for each year CAL data are available. Figure 2b plots the RC selectivity μ residuals (these indicate how fast the right hand limb of the selectivity function decreases). Figure 2c plots the female scalar residuals which indicate how the relative selectivity for females has changed over time, e.g. for the period 2002-2004 there was a reduced female selectivity (compared with the "norm").

The RC fits to the commercial longline catch-at-length (CAL) data are good (Figure 3a), though it there is a consistent overestimation of males in size classes 100mm CL and larger. Future work will explore improving this lack of fit. Figure 3b reports the RC model fit to the average biomass survey CAL data. Again, the fits are reasonably good. Figures 4a and 4b report the RC CAL residuals. Here one can detect where there are consistent patterns of "mis-fitting". Again one can see the mis-fit of the commercial longline male CAL data at larger sizes.

Figure 5a compares the estimated biomass trends for the RC, ROB0, ROB1, ROB2 and ROBBOTH (which explore "lesser" amounts of adult mortality due to the OLVIA in 2011). These plots show clearly that the post-2011 biomass trends are heavily dependent on the assumptions one makes regarding the extent of juvenile and adult mortality due to the OLIVA in 2011. The RC which assumes the most extreme case of mortalities in 2011 produces the most pessimistic estimated 2011+ biomass trajectory.

It is also interesting to note the best model fits to the data are achieved for ROB2 (compared with ROB0, ROB1, ROBBOTH or the RC), as evidenced in the total –lnL values reported in Table 1. The fits to the CPUE data (Figure 5b) show little distinction, but the model estimates of Bexp and *Bsp* post 2010 are very different (clearly as a result of the different levels of OLIVA induced mortality assumed). ROBBOTH, which assumes the least amount of OLIVA induced juvenile and adult mortality in 2011 (only 20% and 10% respectively) predicts a sharp increase in Bexp (and hence also CPUE) post 2010. In Johnston (2014) the more recent CPUE values for both the commercial longline and the biomass survey series are compared for Nightingale. In this document it is shown that both these series show much improved CPUE values for 2012 and 2013 (compared with previous years). Figure 5b plots the 2012 and 2013 nominal longline CPUE values (solid black circles). From the various model biomass estimates, it is clear that the ROBBOTH 2013 estimated value is the closest to the observed values – but still falls way short. All this suggests that the adult mortality in 2011 due to the OLIVA is likely to have been negligible.

Table 2 compares the model results of the RC with the three robustness tests that explore alternate F_{2009} values. The lowest –lnL values (ie best fit to the data) is for ROB5 (F_{2009}=0.5). The trend observed from these results is that the higher the F_{2009} is forced, the smaller K is estimated to be, but the θ (the proportion of K at which the stock is estimated to be in 1990) estimates increase accordingly. Figure 6a plots the estimated *Bsp*/*K* trends for the RC and ROB3, ROB4 and ROB5. Here it is clear that these trends are very similar across all models. Figure 6b reports the fits to CPUE for these robustness tests.

Projections

Projections under three alternate future constant catch levels (65 MT, 75 MT and 85 MT) have been run. Table 2 reports the *Bsp/K* value in 2033 for each of the three CC scenarios for the RC and the seven robustness trials. Figures 7a-c report resultant CR and *Bsp/K* trajectories for the RC, ROB2 and ROBBOTH respectively. The results indicate that w.r.t. the final *Bsp/K* statistic, there is little difference between the three CC scenarios and across the various robustness trials. *Bsp/K* in 2033 remains high at over 0.90 for all scenarios. There are however very different estimated future CR and *Bsp* trends between the RC, ROB2 and ROBBOTH, particularly over the 2011-2020 period. The large decline in *Bsp* seen for the RC (and to a lesser degree in ROB2) is due to the assumption that 80% of all juvenile lobsters died in 2011 due to the OLIVA event. If one reduces this amount to only 20% (see Figure 7c) one can immediately see that the predicted spawning biomass will hardly be affected in the future. Catch rates are similarly dependent on the levels of mortality assumed.

The future catch rates do differ somewhat between the three CC scenarios. For both the RC and ROB2 (see Figures 7a and b) the CR is predicted to decline to very low levels (< 2 kg/trap/day) from around 2016. This is due to the assumption of oil induced mortality on the juveniles in 2011 due to the OLIVA feeding through the population into the “legal sized” portion of the stock. Figure 8 compares CR and *Bsp* trajectories for a future CC = 65 MT between the RC (80% juvenile and 50% adult mortality in 2011 due to OLIVA), ROB0 (20% juvenile and 50% adult mortality in 2011 due to OLIVA), ROB2 (80% juvenile 10% adult mortality in 2011 due to OLIVA) and ROBBOTH (20% juvenile and 10% adult mortality in 2011 due to the OLIVA). Management will need to monitor catch rates carefully in the future, as these will inform which of the various mortality scenarios considered here is most likely, as this in turn has important implications for TACs in the short to medium term.

Management Advice

Results in this paper indicate that in the longer term, Nightingale can sustain annual catches in excess of 65 MT. However, in the shorter term, biomass projections are heavily dependent on magnitudes of possible impacts on survival rates arising from the OLIVA incident. The very high CPUE at present suggests that the OLIVA did not give rise to high adult mortality. However, it is too early to know whether there was a large impact on juvenile survival, which if it occurred would mean sharply reduced abundance over the next few years. In these circumstances it is recommended that the TAC for Nightingale for the 2014/15 season remain unchanged at 65 MT, and that modifications to this in subsequent seasons be based on future CPUE trends.

References

Johnston, 2013. 2014. Comparative plots of commercial CPUE and biomass survey index data (Leg1) for the Tristan da Cunha group of islands. MARAM/TRISTAN/2014/MAR/05. 3pp.

Johnston, S.J. and Butterworth, D.S. 2012. Updated 2012 rock lobster assessment of the Tristan da Cunha group of islands. MARAM/Tristan/2012/Jul/10. 20pp

Johnston, S.J. and Butterworth, D.S. 2013a. The age structured population modeling approach for the assessment of the rock lobster resources at the Tristan da Cunha group of islands. MARAM/Tristan/2013/Mar/07. 15pp.

Table 1a: Nightingale 2014 assessment results for the "James Glass" growth model. The 2012 assessment results are reported to allow comparison. The shaded values are fixed on input. Values in parentheses are estimated σ values. (The –lnL values are not comparable between the 2012 and 2014 assessments.) Results shown for the RC, ROB0, ROB1, ROB2 and ROB3 robustness tests.

	2012 (No mortality due to OLIVA incident)	**2014 assessment RC (2011 adult mortality due to OLIVA = 50% and juvenile mortality = 80%)**	**2014 assessment ROB0 (2011 juvenile mortality due to OLIVA = 20%)**	**2014 assessment ROB1 (2011 adult mortality due to OLIVA = 25%)**	**2014 assessment ROB2 (2011 adult mortality due to OLIVA = 10%)**	**2014 assessment ROBBOTH (2011 adult mortality due to OLIVA = 10%; juvenile mortality=20%)**
# parameters	41	85	85	85	85	85
σ_R	0.4	0.4	0.4	0.4	0.4	0.4
K	435	433	431	427	422	418
h	1.00	0.88	0.88	0.90	0.91	0.92
F_{2009} fixed at	0.3	0.3	0.3	0.3	0.3	0.3
Male selectivity μ 90-99	0.013	All μ and female selectivity scalar values estimated separately for male and females for years for which CAL data are available	All μ and female selectivity scalar values estimated separately for male and females for years for which CAL data are available	All μ and female selectivity scalar values estimated separately for male and females for years for which CAL data are available	All μ and female selectivity scalar values estimated separately for male and females for years for which CAL data are available	All μ and female selectivity scalar values estimated separately for male and females for years for which CAL data are available
Male selectivity μ 00-06	0.017					
Male selectivity μ 07+	0.038					
Female selectivity μ 90-099	0.072					
Female selectivity μ 00-06	0.101					
Female selectivity μ 07+	0.100					
θ	0.285	0.312	0.314	0.317	0.321	0.324
-lnL total	-18.87	-13.45	-12.69	-15.09	-15.28	-14.66
-lnL CPUE T	-20.14	-15.96	-16.72	-17.16	-17.21	-17.49
-lnL CPUE longline	-20.14	-13.30 (0.116)	-13.27 (0.118)	-13.31 (0.115)	-13.35 (0.113)	-13.34 (0.113)
-lnL CPUE Survey Leg1	-	-2.66 (0.456)	-3.44 (0.424)	-3.85 (0.449)	-3.86 (0.465)	-4.14 (0.454)
-lnL CAL T	-19.82	-46.78	-39.06	-43.03	-40.29	-33.95
-lnL CAL onboard observer	-19.82	-46.37 (0.071)	-42.47 (0.072)	-44.59 (0.071)	-43.08 (0.072)	-39.84 (0.072)
-lnL CAL Survey Leg 1	-	-0.41 (0.103)	3.45 (0.107)	1.56 (0.105)	2.79 (0.106)	5.89 (0.109)
SR1 pen	1.28	3.05	3.43	2.33	1.97	1.99
-lnL discard	2.64	3.30	3.61	3.18	3.14	3.37
Bsp(1990)/Ksp	0.25	0.29	0.29	0.30	0.30	0.30
Bsp(2012)/Ksp	0.75	0.48	0.55	0.67	0.77	0.83
Bsp(2013)/Ksp	0.88	0.43	0.58	0.60	0.68	0.82
Bsp(2014)/Ksp	-	**0.39**	**0.62**	**0.52**	**0.58**	**0.80**
Bsp(2012)/Bsp(1990)	2.95	1.64	1.88	2.27	2.57	2.75
Bsp(2013)/Bsp(1990)	-	1.48	1.98	2.02	2.26	2.71
Bsp(2014)/Bsp(1990)	-	1.33	2.11	1.75	1.94	2.65
Bexp(2012)/Bexp(1990)	-	1.58	1.65	2.25	2.57	2.59
Bexp(2013)/Bexp(1990)	-	1.43	1.65	2.14	2.45	2.60
Programs		Nightjg.tpl	Nightj20.tpl	Nightjg25.tpl	Nightjg10.tpl	Nightb.tpl

Table 1b: Nightingale 2014 assessment results comparing the RC (F_{2009}=0.2) with ROB3 (F_{2009}=0.2), ROB4 (F_{2009}=0.4) and ROB5 (F_{2009}=0.5). Values in parentheses are estimated σ values.

	2014 assessment ROB3 (F_{2009}=0.2)	**2014 assessment RC (F_{2009}=0.3)**	**2014 assessment ROB4 (F_{2009}=0.4)**	**2014 assessment ROB5 (F_{2009}=0.5)**
# parameters	85	85	85	85
σ_R	0.4	0.4	0.4	0.4
K	647	433	385	371
h	0.88	0.88	0.84	0.83
F_{2009} fixed at	**0.2**	**0.3**	**0.4**	**0.5**
θ	0.210	0.312	0.353	0.373
-lnL total	-12.21	-13.45	-14.20	-14.28
-lnL CPUE T	-15.28	-15.96	-16.87	-17.60
-lnL CPUE longline	-12.79 (0.144)	-13.30 (0.116)	-13.50 (0.104)	-13.70 (0.089)
-lnL CPUE Survey Leg1	-2.48 (0.467)	-2.66 (0.456)	-3.37 (0.430)	-3.90 (0.414)
-lnL CAL T	-43.48	-46.78	-57.41	-59.89
-lnL CAL onboard observer	-45.12 (0.071)	-46.37 (0.071)	-54.37 (0.070)	-54.95 (0.069)
-lnL CAL Survey Leg 1	1.63 (0.105)	-0.41 (0.103)	-3.05 (0.101)	-4.94 (0.100)
SR1 pen	2.67	3.05	4.05	4.82
-lnL discard	2.83	3.30	3.22	3.37
Bsp(1990)/Ksp	0.20	0.29	0.33	0.35
Bsp(2012)/Ksp	0.48	0.48	0.50	0.52
Bsp(2013)/Ksp	0.44	0.43	0.45	0.47
Bsp(2014)/Ksp	0.40	0.39	0.41	0.43
Bsp(2012)/Bsp(1990)	2.47	1.64	1.52	1.49
Bsp(2013)/Bsp(1990)	2.23	1.48	1.38	1.36
Bsp(2014)/Bsp(1990)	2.02	1.33	1.25	1.24
Bexp(2012)/Bexp(1990)	2.76	1.58	1.38	1.20
Bexp(2013)/Bexp(1990)	2.38	1.43	1.27	1.24
Programs	Nrob3.tpl	Nightjg.tpl	Nrob4.tpl	Nrob5.tpl

Table 2: Model estimated Bsp/K values in 2033 under three alternate levels of future constant catch (CC = 65 MT, CC = 75 MT and CC = 85 MT). Values are reported for the RC and six robustness trials.

	Juvenile mortality in 2011 due to OLIVA	**Adult mortality in 2011 due to OLIVA**	**CC = 65 MT**	**CC = 75 MT**	**CC = 85 MT**
RC	80%	50%	0.95	0.94	0.93
ROB0	**20%**	50%	0.95	0.94	0.93
ROB1	80%	**25%**	0.95	0.94	0.94
ROB2	80%	**10%**	0.95	0.94	0.93
ROBBOTH	**20%**	**10%**	0.95	0.95	0.93
ROB3 (F_{2009}=0.2)	80%	50%	0.96	0.96	0.95
ROB4 (F_{2009}=0.4)	80%	50%	0.94	0.93	0.91
ROB5 (F_{2009}=0.5)	80%	50%	0.94	0.93	0.91

Figure 1: Nightingale 2014 **RC** assessment results. In the top LHS plot of longline CPUE, the 2012 and 2013 nominal CPUE values are indicated (triangles).

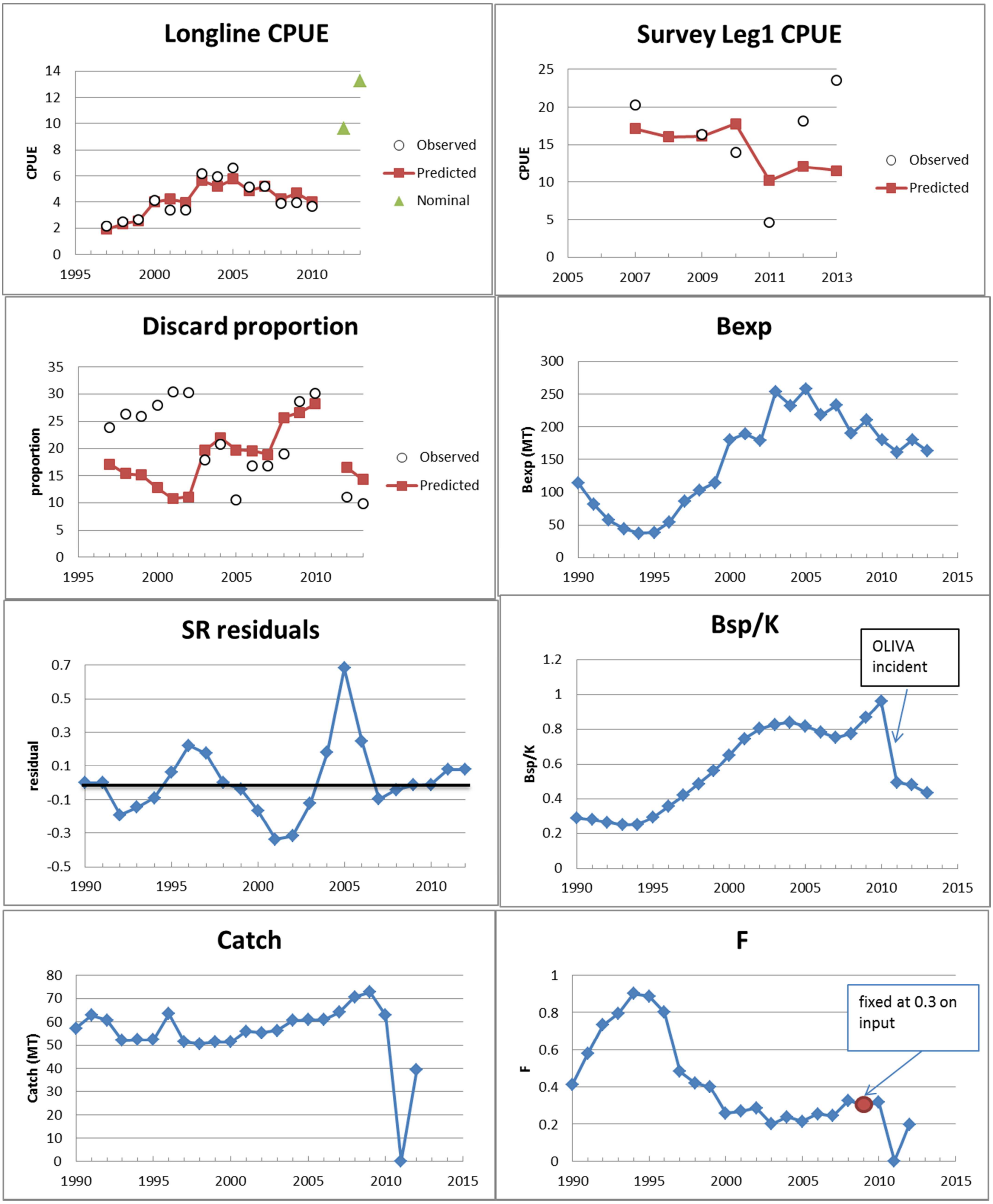


Figure 2a: Nightingale **RC** selectivity functions.

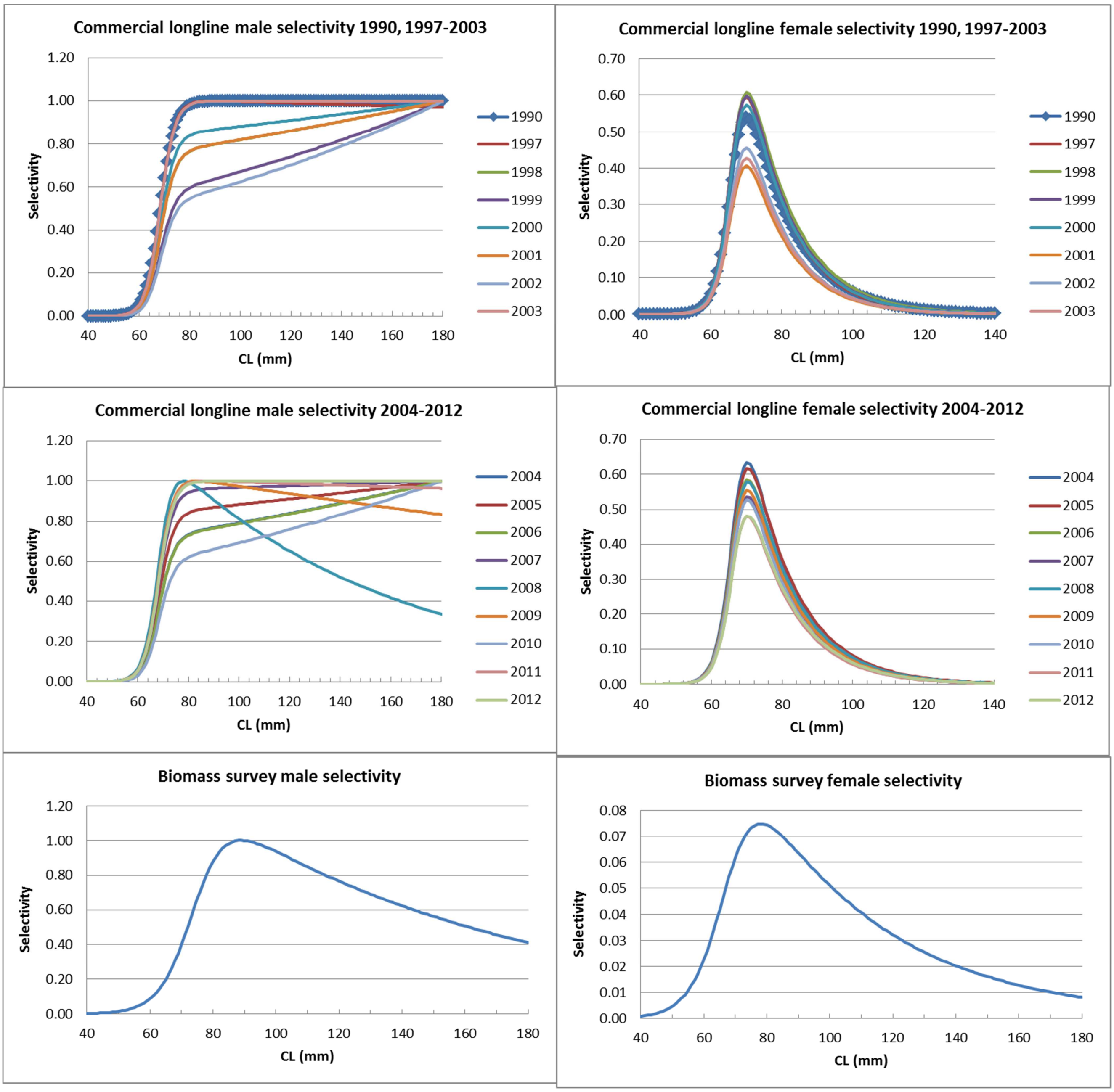


Figure 2b: Nightingale **RC** estimated μ residuals (used for selectivity function variability).

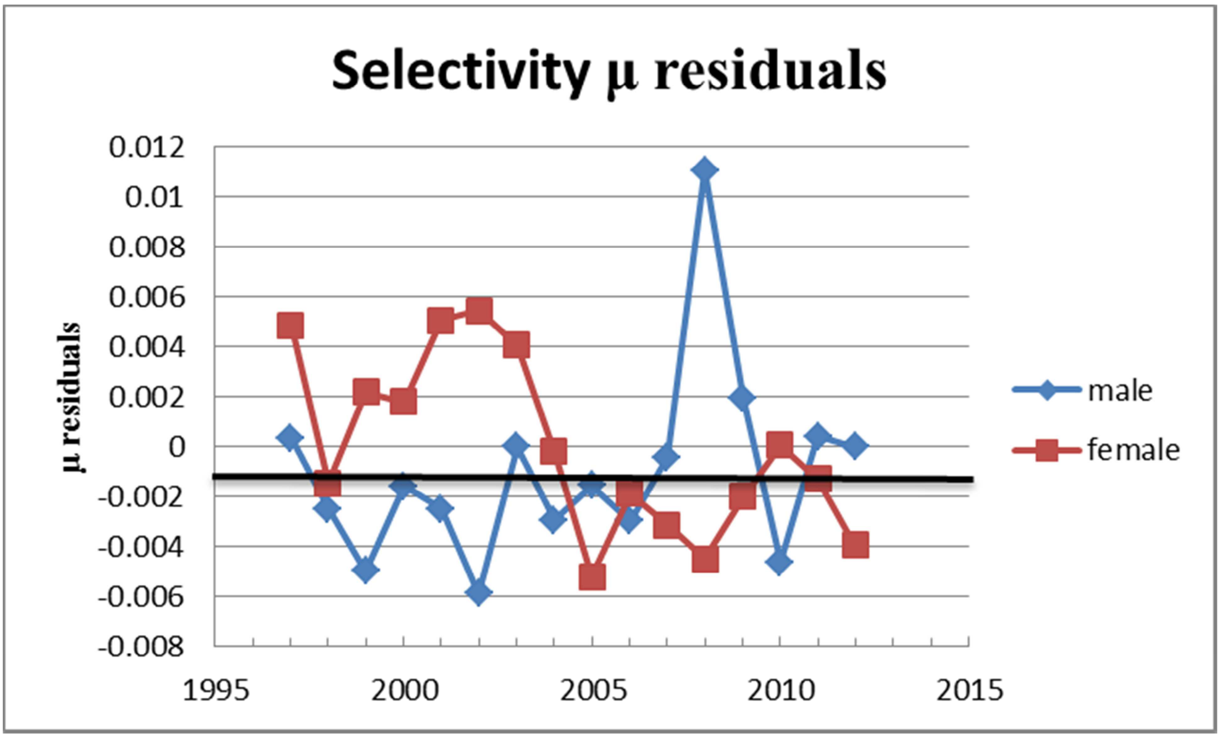


Figure 2c: Nightingale **RC** estimated female scalar variability (used for selectivity function variability).

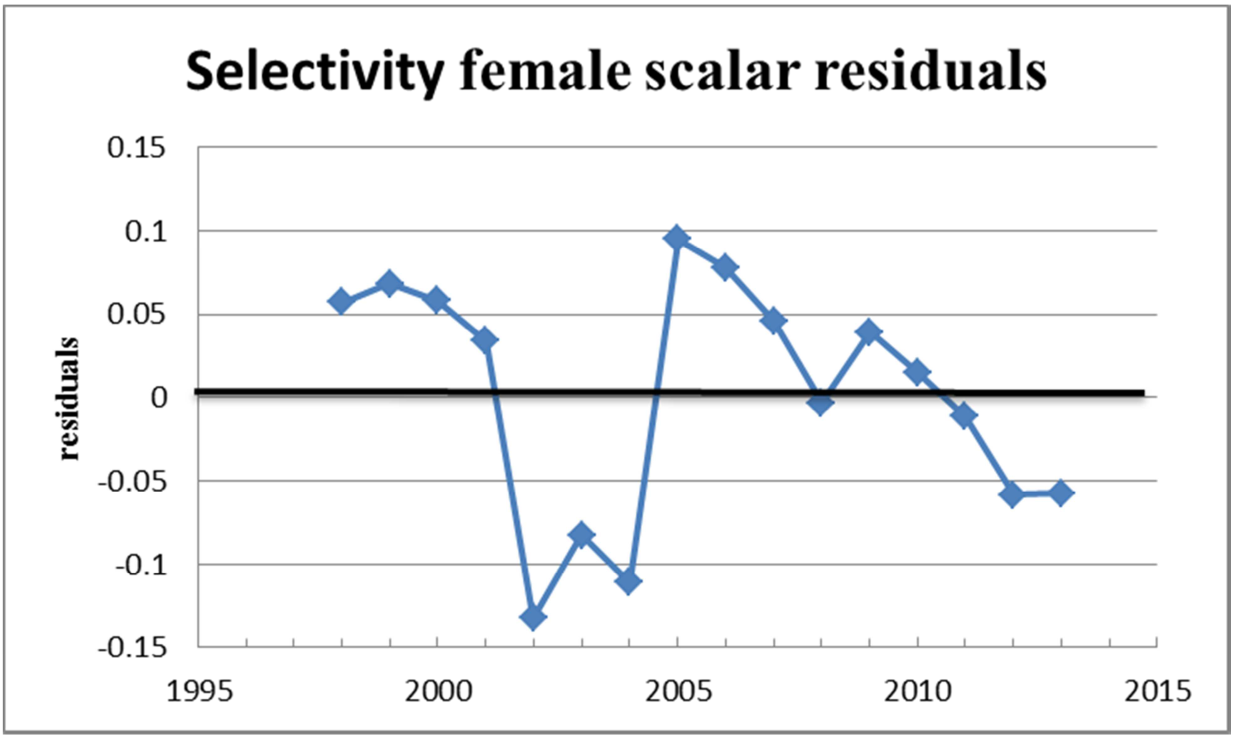
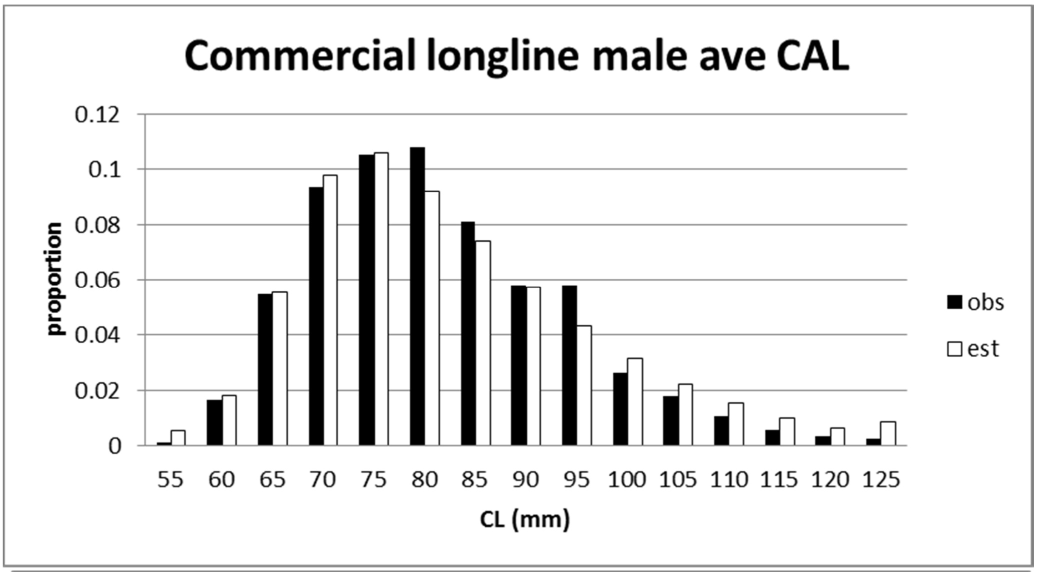


Figure 3a: Nightingale commercial longline **RC** CAL fits averaged over years.



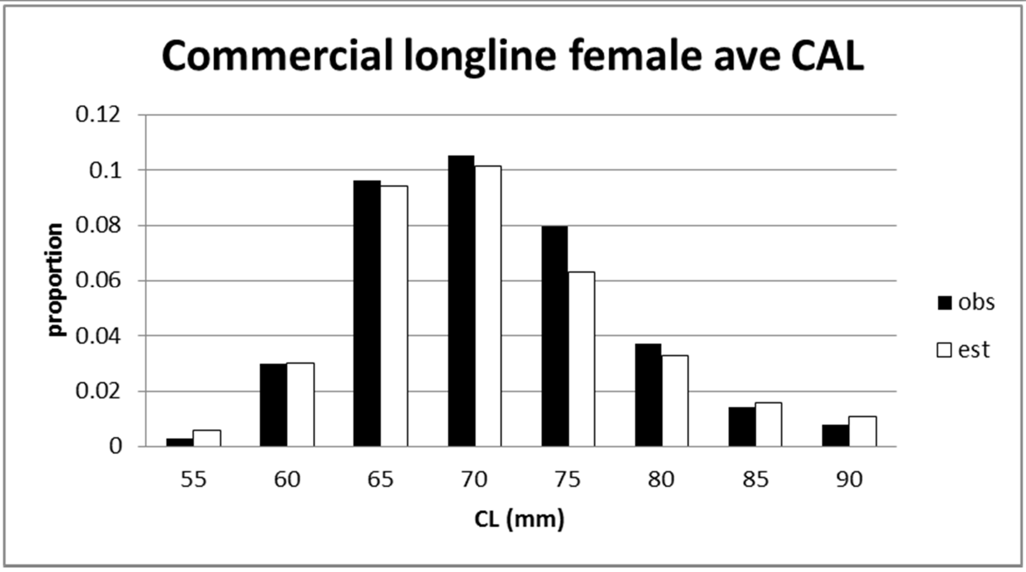
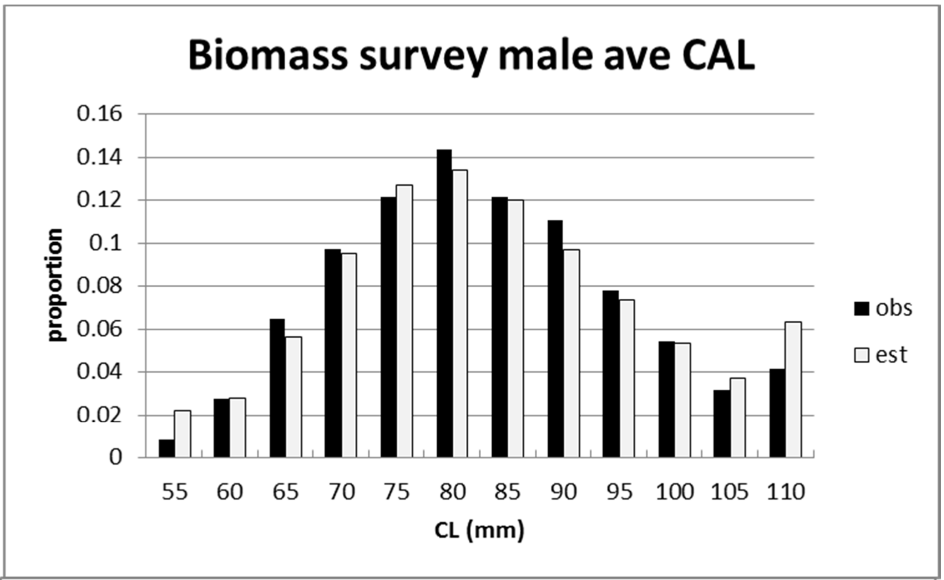


Figure 3b: Nightingale biomass survey Leg1 **RC** CAL fits averaged over years.



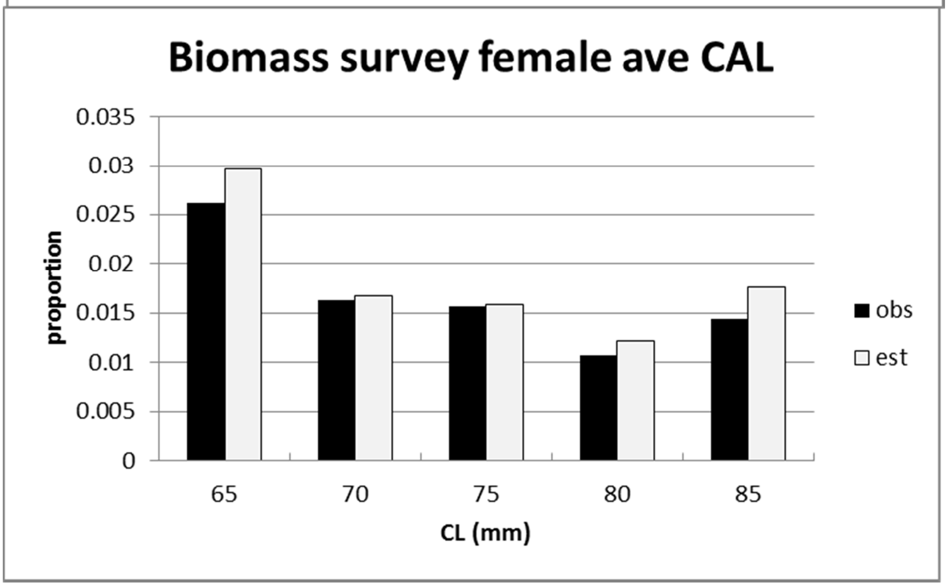
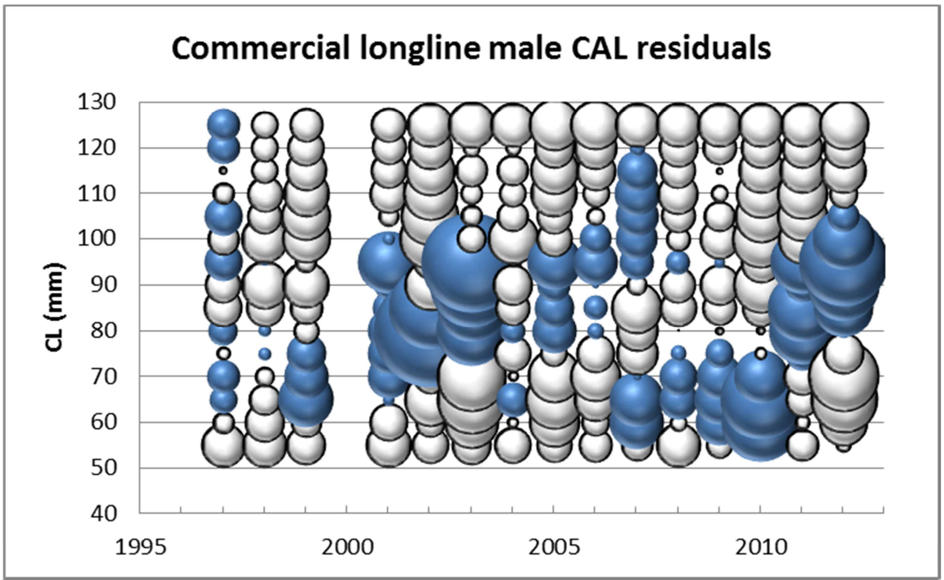


Figure 4a: Nightingale standardised commercial **longline RC** CAL residuals. The dark bubbles reflect positive and the light bubbles negative residuals, with the bubble radii proportional to the magnitudes of the residuals.



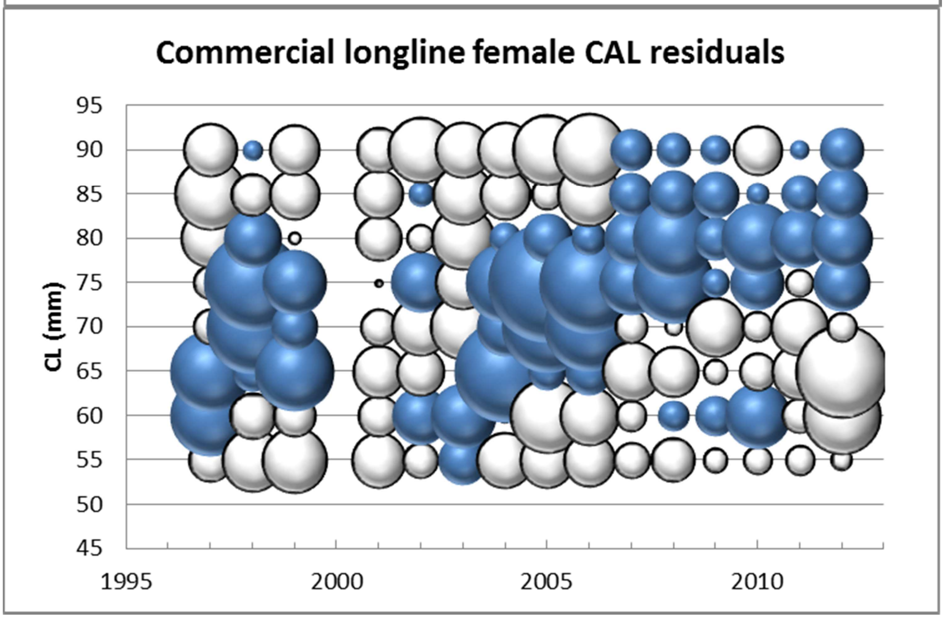


Figure 4b: Inaccessible standardised **biomass survey** Leg1 **RC** CAL residuals. The dark bubbles reflect positive and the light bubbles negative residuals, with the bubble radii proportional to the magnitudes of the residuals.

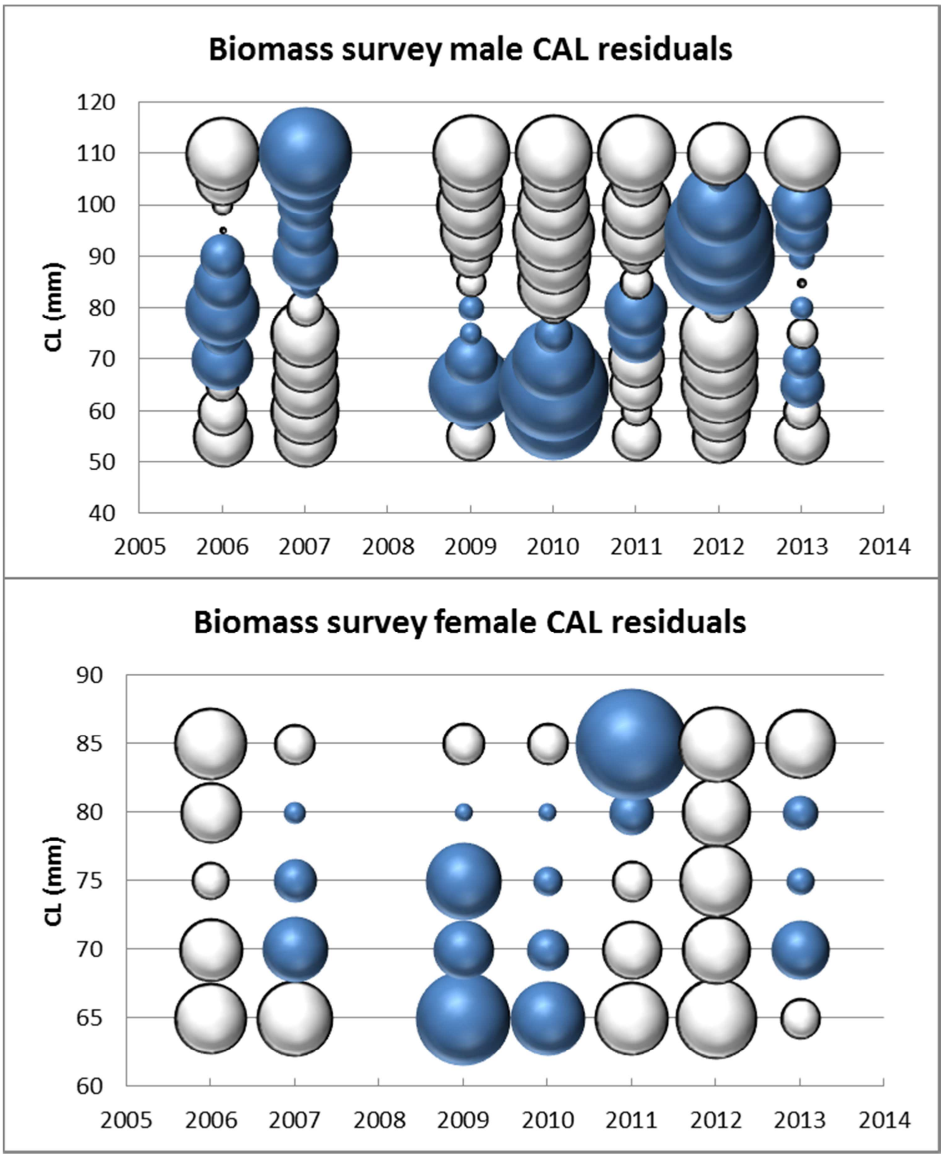


Figure 5a: Comparative plots of *Bexp*, *Bsp* and *Bsp/K* for the **RC** (80% juvenile and 50% adult mortality in 2011 due to OLIVA), **ROB0** (**20%** juvenile and 50% adult mortality in 2011 due to OLIVA), **ROB1** (80% juvenile and **25%** adult mortality in 2011 due to OLIVA), **ROB2** (80% juvenile and **10%** adult mortality in 2011 due to OLIVA) and **ROBBOTH** (**20%** juvenile and **10%** adult mortality in 2011 due to OLIVA).

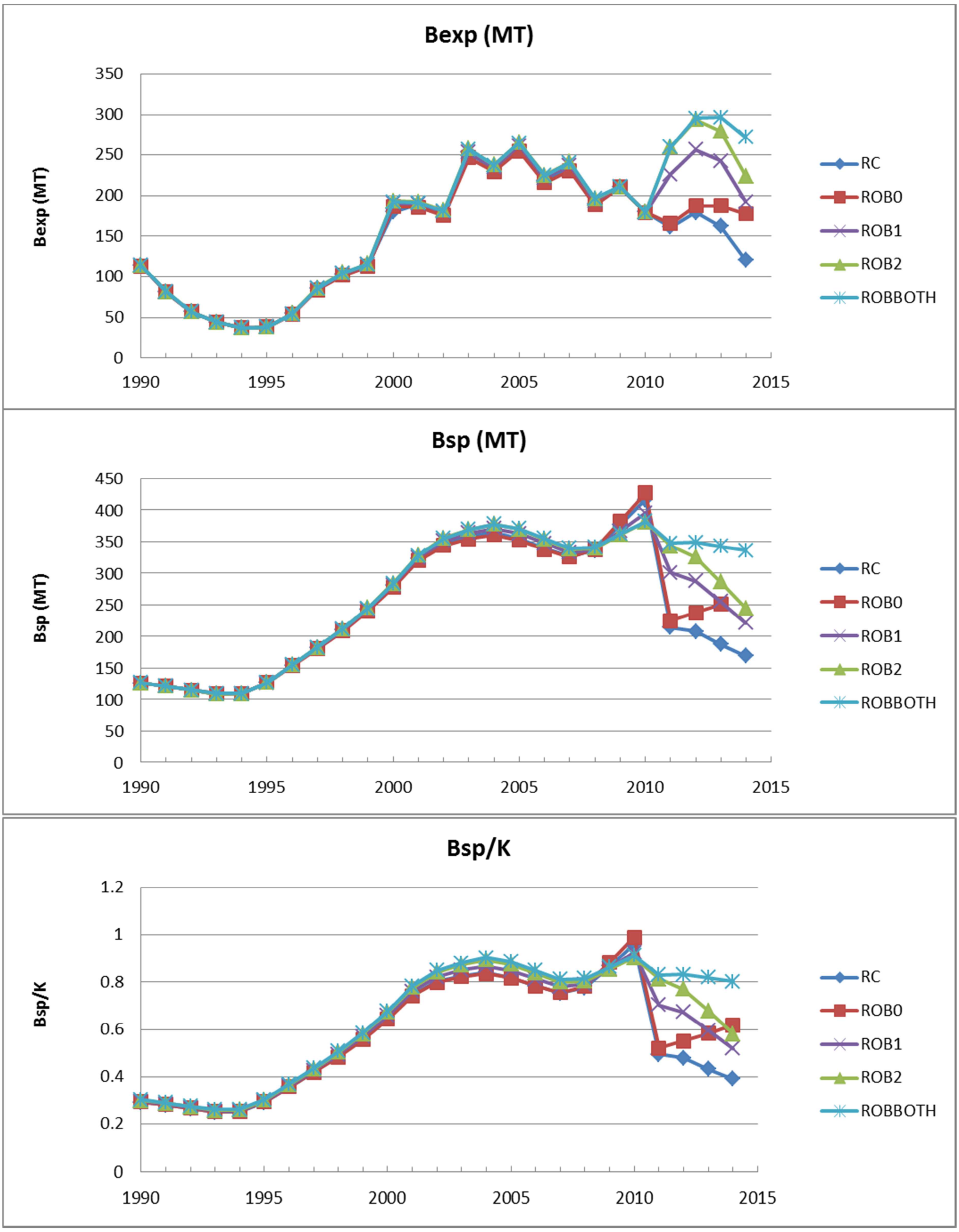


Figure 5b: Comparative plots of the estimated longline catch rates (CR) for the **RC** (80% juvenile and 50% adult mortality in 2011 due to OLIVA), **ROB0** (**20%** juvenile and 50% adult mortality in 2011 due to OLIVA), **ROB1** (80% juvenile and **25%** adult mortality in 2011 due to OLIVA), **ROB2** (80% juvenile and **10%** adult mortality in 2011 due to OLIVA) and **ROBBOTH** (**20%** juvenile and **10%** adult mortality in 2011 due to OLIVA). The observed GLM longline CPUE data are shown as open circles, with the 2012 and 2013 nominal longline CPUE value shown as solid black circles.

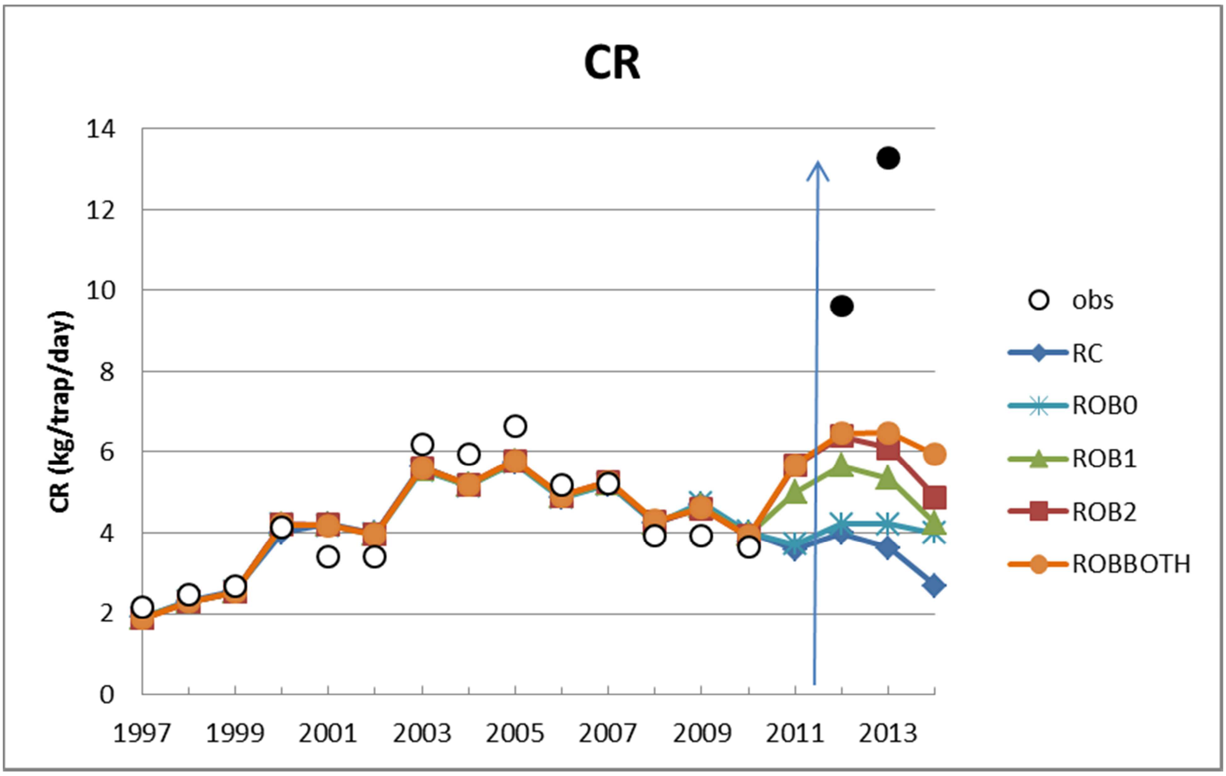


Figure 6a: Comparative plots of *Bexp*, *Bsp* and *Bsp/K* for the **RC** (F_{2009}=0.3), **ROB3** (F_{2009}=0.2), **ROB4** (F_{2009}=0.4) and **ROB5** (F_{2009}=0.5).

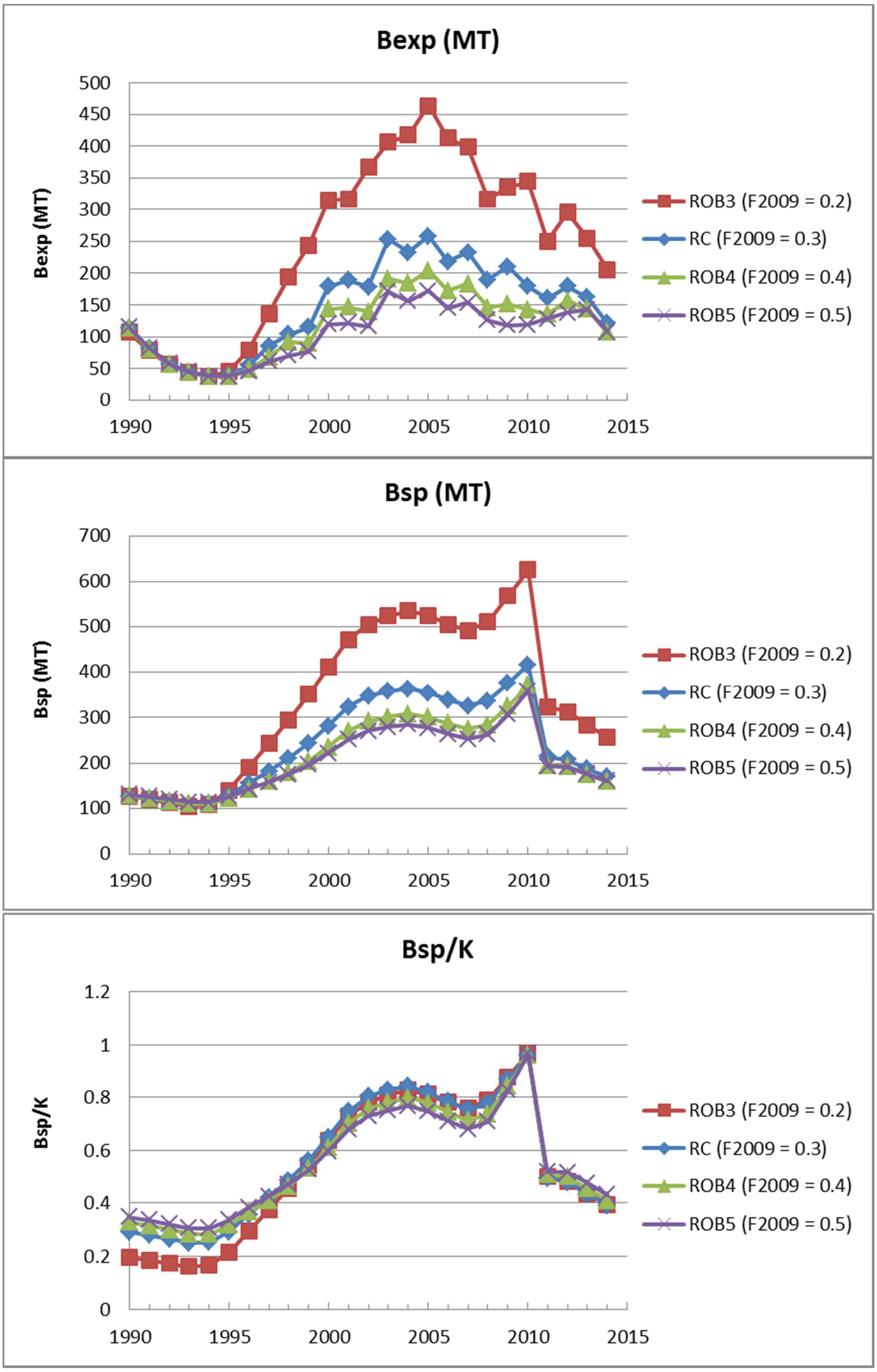


Figure 6b: Comparative fits of the models to the commercial longline CPUE for the **RC** (F_{2009}=0.3) and **ROB3** (F_{2009}=0.2), **ROB4** (F_{2009}=0.4) and **ROB5** (F_{2009}=0.5). The observed GLM longline CPUE data are shown as open circles, with the 2012 and 2013 nominal longline CPUE value shown as solid black circles.

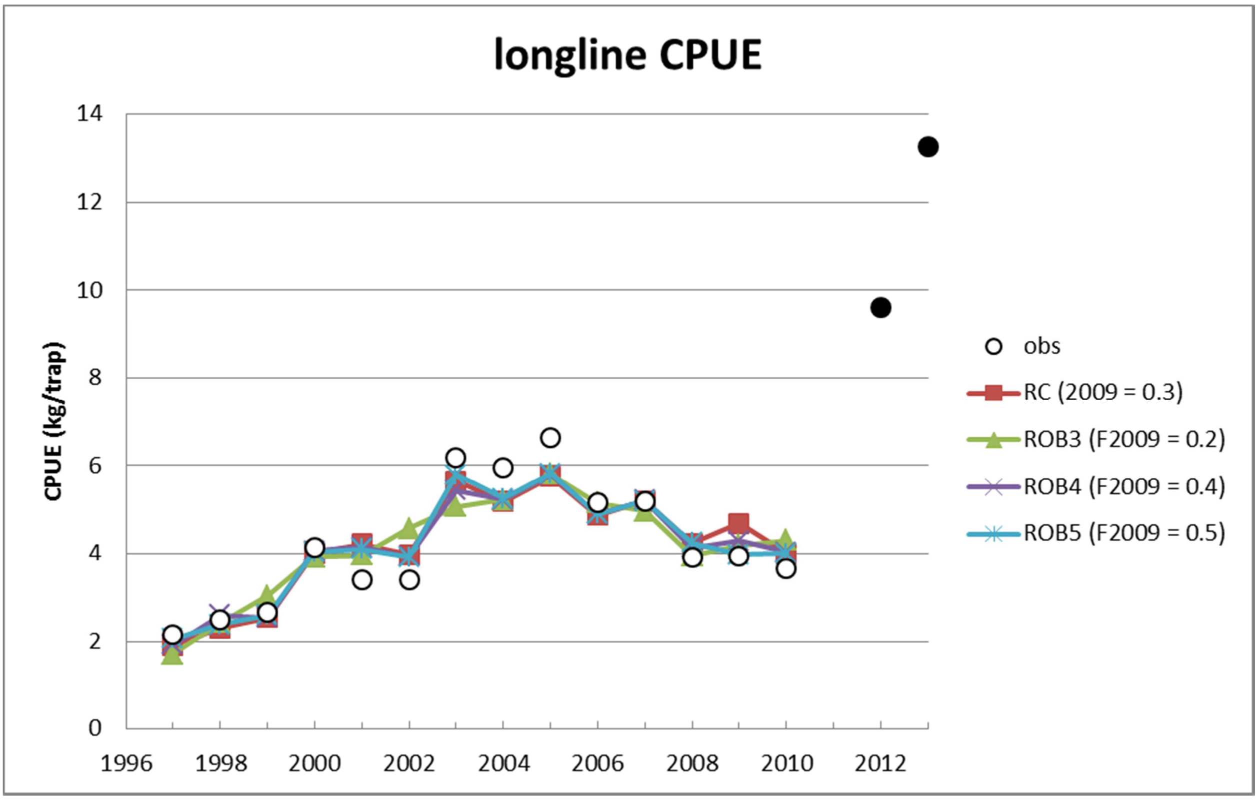


Figure 7a: **RC** projections of the resource into the future under three levels of constant catch (CC=65 MT, CC= 75 MT and CC = 85 MT). The top plot shows the different catch levels (compared to levels since 1990), the middle plot shows the past and predicted catch rates (CR), and the bottom plot shows the *Bsp/K*.

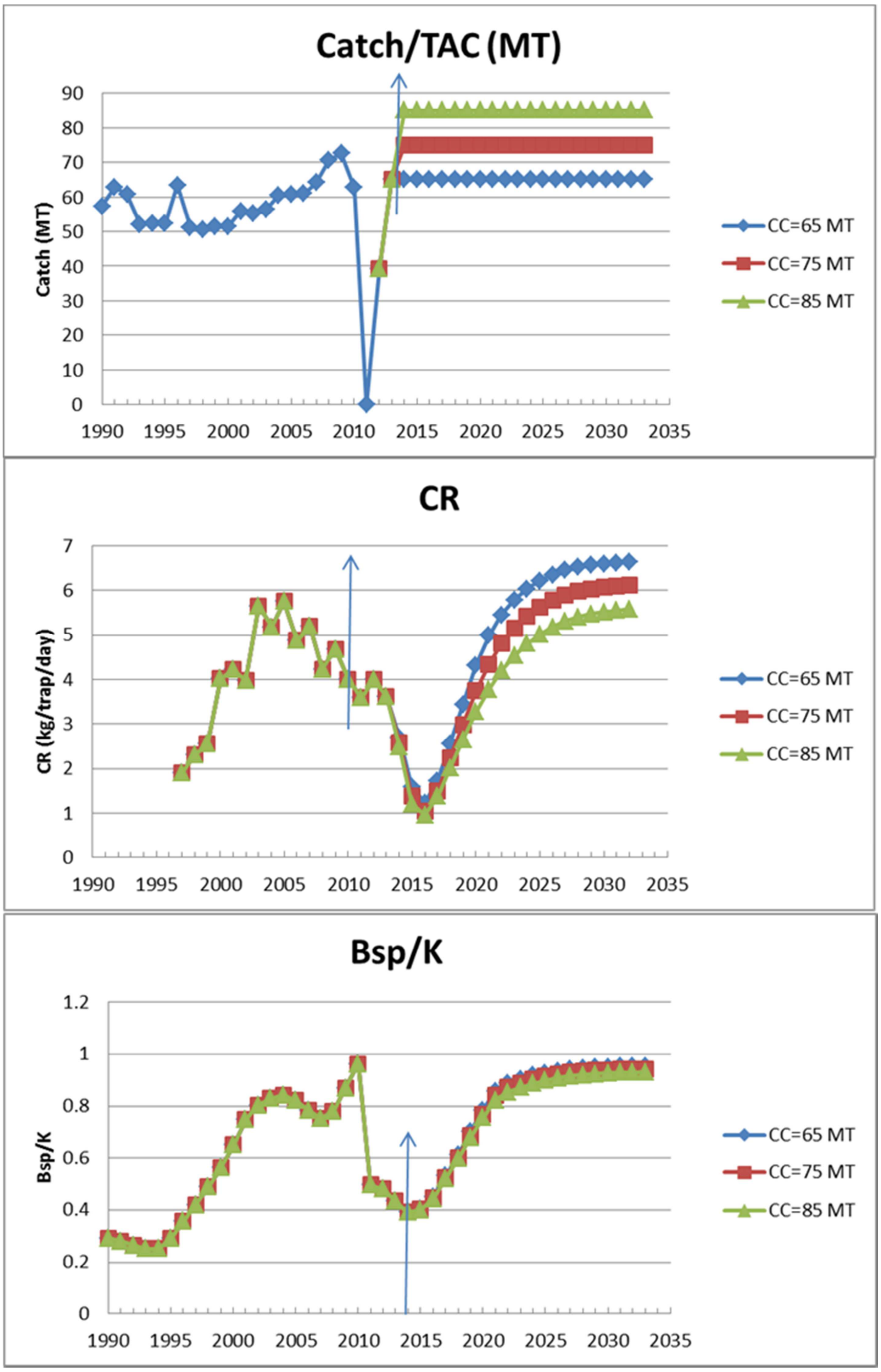


Figure 7b: **ROB2** (80% juvenile and **10%** adult mortality in 2011 due to OLIVA) projections of the resource into the future under three levels of constant catch (CC=65 MT, CC= 75 MT and CC = 85 MT). The top plot shows the different catch levels (compared to levels since 1990), the middle plot shows the past and predicted catch rates (CR), and the bottom plot shows the *Bsp/K*.

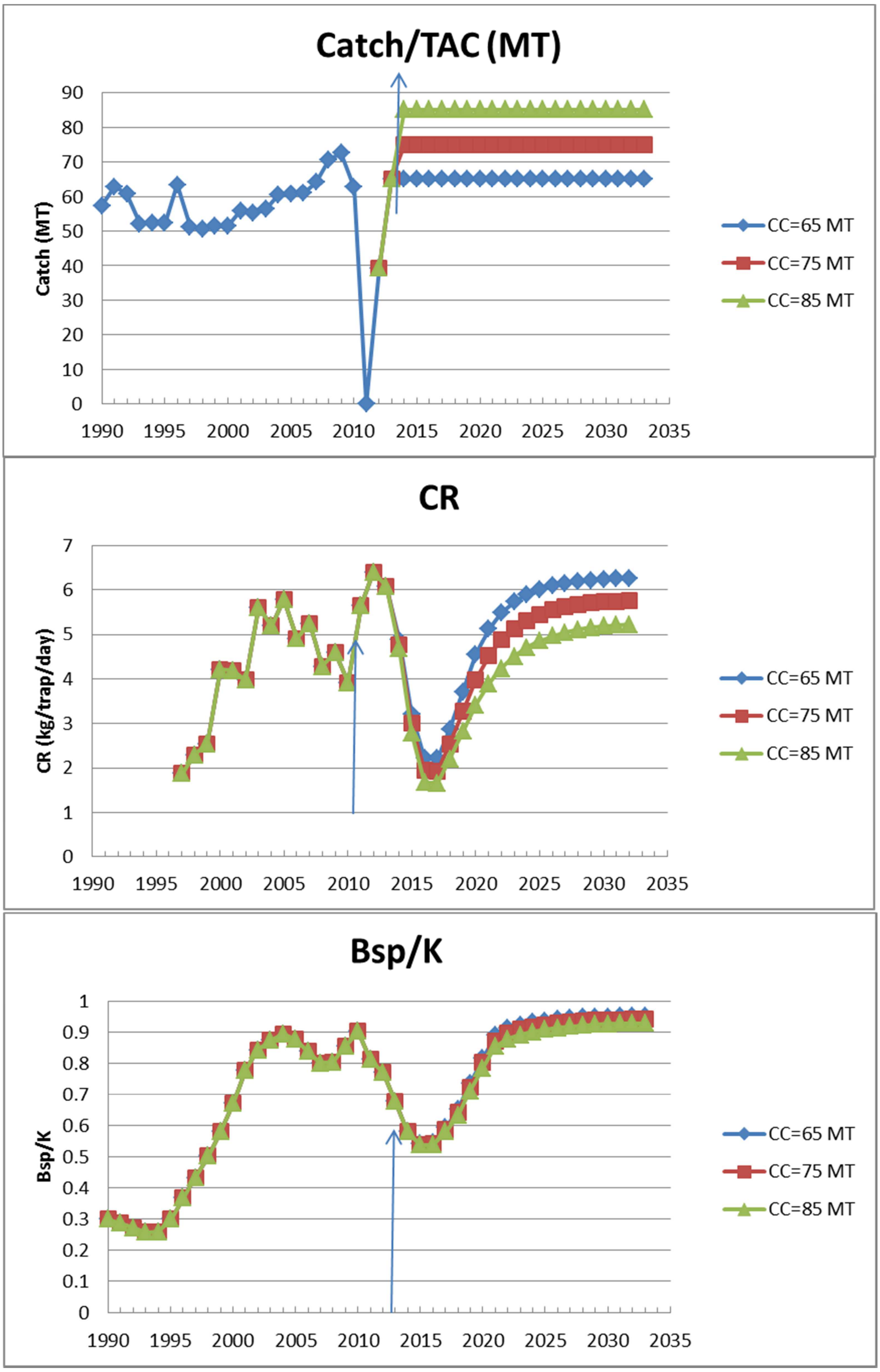


Figure 7c: **ROBBOTH** (**20%** juvenile and **10%** adult mortality in 2011 due to OLIVA) projections of the resource into the future under three levels of constant catch (CC=65 MT, CC= 75 MT and CC = 85 MT). The top plot shows the different catch levels (compared to levels since 1990), the middle plot shows the past and predicted catch rates (CR), and the bottom plot shows the *Bsp/K*.

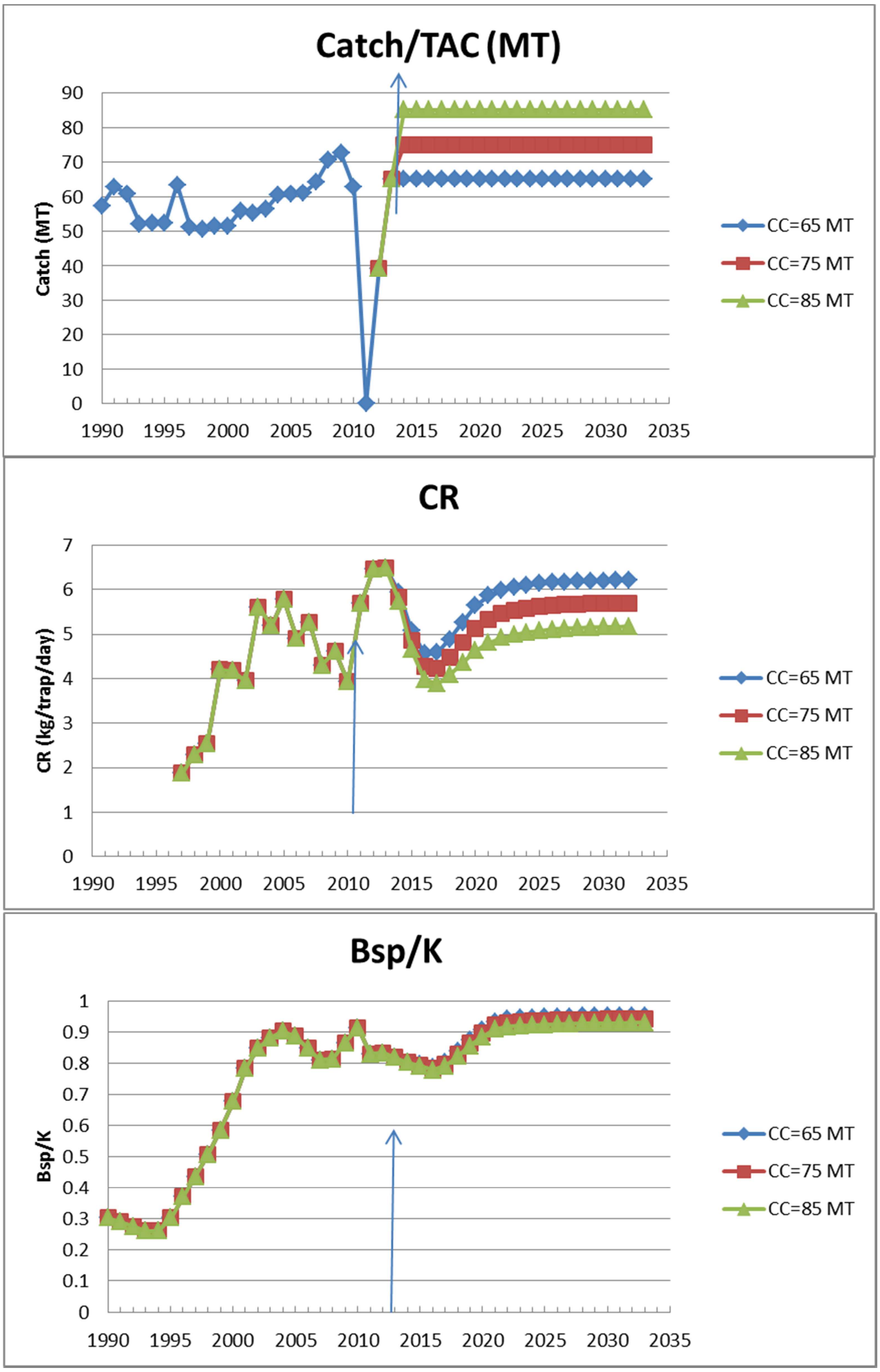


Figure 8: CR and *Bsp/K* Projections of a **CC = 65 MT** for the **RC** (80% juvenile and 50% adult mortality in 2011 due to OLIVA), **ROB0** (**20%** juvenile and 50% adult mortality in 2011 due to OLIVA, **ROB2** (80% juvenile and **10%** adult mortality in 2011 due to OLIVA) and **ROBBOTH** (**20%** juvenile and **10%** adult mortality in 2011 due to OLIVA). The observed GLM longline CPUE data are shown as open circles, with the 2013 nominal longline CPUE value shown as a solid black circle.