Updated assessment of the toothfish (*Dissostichus eleginoides*) resource in the Prince Edward Islands vicinity to include data from 1997 to 2018

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ABSTRACT

The assessment of the Prince Edward Islands (PEI) toothfish (*Dissostichus eleginoides*) resource carried out by Brandão and Butterworth (2018) is updated to take further data now available for 2018 into account. This update also incorporates tag-recapture data and a new basis to estimate the extent of cetacean depredation. For the new Base case and most of the assessment sensitivities, the resource is estimated to be at a depletion (in relation to its average pre-exploitation level in terms of spawning biomass) in the 36-40% range. If the model is forced to fit the trotline CPUE indices, the estimated average pre-exploitation level in terms of spawning biomass is 19%, but this requires an assumption of very high levels of tag loss and the last two tag-recapture data points are not fitted well.

INTRODUCTION

The assessment of the Prince Edward Islands (PEI) toothfish (*Dissostichus eleginoides*) resource carried out by Brandão and Butterworth (2018) is updated to take further data now available for 2018 into account. One of the sensitivity models of Brandão and Butterworth (2018) (in which the 2008 and 2009 CPUE indices for trotlines are omitted) is adopted as the new Base case model in this paper. This is in accordance with decisions taken when selecting the Base case Operating Model in the development of an OMP for toothfish.

As in Brandão and Butterworth (2018), estimates of the "split" month factors are used to provide an estimate for cetacean depredation (what applies to longlines only) to be used in the assessment, instead of the more *ad hoc* assumptions used previously (Brandão and Butterworth, 2013). The new Base case model in this paper assumes that there is also a small amount of cetacean predation on trotlines, rather than to adopt the no cetacean predation scenario for trotlines as in Brandão and Butterworth (2018).

Brandão and Butterworth (2014) presented an alternative to the Base case model in which tag-recapture data are also incorporated in this Age-Structured Production Model (ASPM) assessment of the Prince Edward Islands resource. In this paper the Base case model is the one that continues to include tagging data. Sensitivity tests of the Base case model are also carried out to investigate what aspects of the assessment may conflict with the tag-recapture data, and also to force better fits to the CPUE indices. As for previous assessments, the biological parameter values adopted for toothfish in Subarea 48.3 (Agnew *et al.,* 2006) are assumed to apply.

The assessments of the toothfish resource presented in this paper have been carried out on a "fishing"-year *y* defined to extend from 1 December of year *y*-1 to 30 November of year *y*.

DATA UPDATES

Further data available for 2018 have been incorporated in the present analyses; these were not available for previous assessments of toothfish in the Prince Edward Islands vicinity. As only partial data for 2019 were available at the time of this analysis, these data have not been used in the present assessment. A detailed description of the data used in the toothfish assessment is given in Brandão and Butterworth (2018). The following new data or analyses assumptions related to the further data only now available are:

- The annual amount of cetacean depredation on trotlines is assumed to be 5% instead of 0%. Table 1 shows the catch (removals) figures with and without the assumed cetacean predation amounts by longlines (as described in Brandão and Butterworth (2018)) and trotlines. This basis for inflating the longline catch figures to account for predation was also applied to the catches estimated for illegal vessels, as it seems likely that these vessels were also longliners and would therefore have had the same problems with cetacean predation as the legal longline fishery has had.
- The updated series of relative abundance indices obtained from the CPUE GLMM standardisation procedure described in Brandão and Butterworth (2019) for the trotline commercial data which now include 2018 data is listed in Table 2. The new Base case in this paper omits the 2008 and 2009 trotline CPUE indices from the assessments.
- Catch-at-length information for the trotline fishery for 2008 to 2018 is now available. All catch-at-length proportions have been weighted by the size of the catch for the finer scale fishing areas from which they were taken. A relative weight (w_{len}) of 1.0 for the catch-at-length contribution to the log-likelihood has been applied in this paper.
- Tagging of toothfish in PEI started in 2005, with the annual number of fish tagged and recaptures shown in Table 3, which includes new information for 2018. These data are input into the assessments that include tagging data by splitting them into numbers by age (based on the toothfish growth curve), and the recaptures are also split by fleet.

ASSESSMENT METHODOLOGY

The assessment methodology is the same as detailed in Brandão and Butterworth (2018), except for the following two differences:

i) the new Base case omits the 2008 and 2009 trotline CPUE indices, and
ii) cetacean depredation is assumed to occur on trotlines as well.

Four sensitivity tests have been conducted to better understand various aspects of the assessment. These sensitivity tests are:

i) an alternative amount of longline cetacean predation is assumed (referred to as 50%),
ii) a tag-reporting rate of 0.8 instead of 1 is assumed,
iii) all CPUE indices from 2010 are up-weighted by a factor of 10, and
iv) a tag loss of 0.5 (i.e. 50% of the tags are lost) is assumed.

RESULTS AND DISCUSSION

Table 4 shows the results for the new Base case three-fleet assessment of the toothfish resource, as well as for the previous (2018) model (referred to "Previous" in this paper) that best matches the present Base case (i.e. the sensitivity model that omitted the first two trotline CPUE indices of

Brandão and Butterworth (2018)) and a sensitivity for when an alternative factor for longline cetacean predation is assumed. Both these updated assessments suggest that the current (start of 2020) status of the resource to be at 37% of average pre-exploitation equilibrium spawning biomass, a value which has decreased from 40% for the start of 2019. The previous assessment suggested that this status of the resource at the beginning of 2019 was at 38%. The assessments carried out in 2007 suggested values in the region of 37% to 40% (Brandão and Butterworth, 2007), while those carried out in 2013 (Brandão and Butterworth, 2013) suggested very high values (in the region of 86% to 90%). Further data together with tag-recapture data now incorporated appear to have stabilised this estimate considerably.

Figure 1 shows estimated spawning biomass and recruitment trends for the new Base case model. The model estimates a large peak in recruitment in 1990 in response to the large estimated illegal catch taken in 1997, so as to better fit the trend in the CPUE abundance indices. Fits to the CPUE data are shown in Figure 2 for the new Base case. The model fails to fit the comparatively very high 1997 longline CPUE value. The model also struggles to fit the last three CPUE indices for longline very well. Assuming a larger cetacean predation factor of 50% does improve slightly the fit to the longline CPUE indices (see the σ_{CPUE} values in Table 4). The model struggles to fit the large variability of the trotline fishery CPUE indices, especially as evident for the low indices of 2016 and 2017 followed by a high index in 2018.

Fits of the new Base case model to the catch-at-length distributions for the longline, pot and trotline fisheries are shown in Figure 3, and the standardised catch-at-length residuals are shown in Figure 4. From a broad perspective, the pattern of the catch-at-length residuals does not indicate model misspecification. The selectivity functions estimated for the new Base case model are shown in Figure 5.

Figure 6 shows the fit to the cumulative recapture numbers of toothfish for the new Base case model, combining the recaptures by longlines and trotlines.

Table 5 shows the results for three other sensitivity tests performed which are variants of the new Base case model. These reflect attempts to improve the fit to the trotline CPUE indices, as well as to address some concerns about some of the assumptions made in the new Base case model. To ease comparisons, results for the new Base case are reproduced in this Table as well. The two sensitivity tests that achieved lower depletion levels are the one that assumes a tag-reporting rate of 0.8 and the one that assumes a tag loss of 50%. Figure 7 compares (a) the spawning biomass and (b) recruitment for the previous model and the present new Base case, as well as the four sensitivity tests reported in Tables 4 and 5. Figure 7b shows clearly that the sensitivity test that assumes a large tag loss results in large peaks in recruitment in 1983 and in 1990. Figure 8 shows fits to the CPUE indices for these sensitivity tests (including those for the new Base case as well as the previous model). The sensitivity test that fits the first longline CPUE index better is the one that assumes a large tag loss. Up-weighting all CPUE indices since 2010 results in a better fit to the trotline CPUE indices, but leads to a worse fit to the longline CPUE indices (see the σ_{CPUE} values in Table 5).

Figure 9 shows the fit to the cumulative recapture numbers of toothfish for the sensitivity tests and the new Base case. To force the model to fit the trotline better (see the σ_{CPUE} values in Table 5 and Figure 8), a tag loss of 0.5 was required, but this model does not fit the last two tagging data points (Figure 9).

CONCLUSIONS

The three-fleet model that takes the information available from the longline, pot and trotline fisheries into account estimates the spawning biomass of the resource at the start of 2020 to be about 37% of its average pre-exploitation level. There has been a slight improvement in the CV

estimates following the inclusion of the further data now available. In terms of status (relative to its pre-exploitation level) the resource is now (at the start of 2019) estimated to be at 40% rather than about 38% (see Table 4).

A concern with this assessment, however, remains that it is heavily influenced by the large peaks in recruitment estimated in the 1990s, and does not fully reflect the marked drop in CPUE shortly after illegal catches commenced.

Alternative fits to the data are possible under different constraints. Achieving a better fit to the trotline CPUE indices results in the fit to the tagging data deteriorating.

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Table 1. Yearly catches of toothfish (in tonnes) estimated to have been taken from the Prince Edward Islands EEZ, which are used for the analyses conducted in this paper. The bases for the estimates of cetacean predation and the illegal catches for 2004 through to 2013 are detailed (or referenced) in the text. Catches (strictly "removals") from the longline fisheries (both "legal" and "illegal"), and modified to include cetacean predation (see text for the basis for this), are also given. Fishing years are defined as the period from December of the preceding year to November of the year indicated.

Fishing Year	Legal			Illegal (IUU)	Total		
	Longline fishery	Pot fishery	Trotline fishery		Without predation	With predation on longline (+10%) and on trotline fishery (+5%)	With predation on longline (+50%) and on trotline fishery (+5%)
1997	2 754.9	—	—	21 350	24 104.9	24 104.9	24 104.9
1998	1 224.6	—	—	1 808	3 032.6	3 032.6	3 032.6
1999	945.1	—	—	1 014	1 959.1	1 959.1	1 959.1
2000	1 577.8	—	—	1 210	2 787.8	2 880.8	3 252.5
2001	267.8	—	—	352	619.8	661.1	826.4
2002	237.3	—	—	306	543.3	597.6	815.0
2003	251.1	—	—	256	507.1	557.8	760.6
2004	182.5	34.3	—	156	372.8	406.6	542.0
2005	142.6	141.9	—	—	284.5	298.8	355.8
2006	169.1	—	—	—	169.1	186.0	253.6
2007	245.0	—	—	—	245.0	269.5	367.5
2008	88.8	—	56.4	—	145.2	156.9	192.4
2009	41.8	—	30.7	—	72.5	78.2	94.9
2010	49.2	—	174.6	—	223.7	237.5	257.1
2011	1.0	—	290.4	—	291.4	306.0	306.4
2012	52.4	—	223.5	—	275.9	292.3	313.3
2013	49.7	—	215.6	—	265.3	281.1	300.9
2014	—	—	366.9	—	366.9	385.2	385.2
2015	—	—	431.3	—	431.3	452.9	452.9
2016	—	—	298.0	—	298.0	312.9	312.9
2017	—	—	110.8	—	110.8	116.3	116.3
2018	—	—	342.7	—	342.7	359.8	359.8
2019†	—	—	543.0	—	543.0	570.2	570.2
1997–2019 total	8 280.7	176.2	3 083.9	26 452	37 992.7	38 504.1	39 932.4

† The catch assumed for 2019 is the TAC for the year (with the whole catch assumed to have come from the trotline fleet.

Table 2. Relative abundance indices for toothfish provided by the standardised commercial CPUE series for the Prince Edward Islands EEZ for the longline and trotline fisheries (Brandão and Butterworth, 2015a, 2019). The trotline CPUE data for 2008 and 2009 are omitted from the GLMM analyses as it is assumed that these indices reflect a "learning" period for the new gear. Fishing years are defined as the period from December of the preceding year to November of the year indicated.

Fishing Year	Longline fishery	Trotline fishery
1997	3.412	—
1998	1.467	—
1999	1.288	—
2000	1.000	—
2001	0.581	—
2002	0.706	—
2003	0.425	—
2004	0.557	—
2005	0.735	—
2006	0.614	—
2007	0.673	—
2008	0.601	—
2009	0.641	—
2010	0.531	1.220
2011	0.159	1.000
2012	0.334	1.110
2013	0.333	0.922
2014	—	0.742
2015	—	0.819
2016	—	0.525
2017	—	0.521
2018		0.906

Table 3. Summary of the number of tagged toothfish and the number of recaptures by year. The numbers in bold *italics* reflect recaptures of toothfish in the first year at large.

	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Numbers Tagged	175	179	120	140	75	131	206	162	253	379	458	324	115	363
Recaptures														
2005	***1***													
2006	**1†**													
2007	1	1	***2***											
2008														
2009			1	2										
2010			1	1										
2011		1	2	2		4	***1***							
2012	1	1		1		2								
2013					1		4		***1***					
2014		1	1	2		1	1	3	3 (***5†***)	***5***				
2015			1	3			1	3	9	9 (***6†***)	***6***			
2016				1	1	2		3		13	1**(7†)**	***2***		
2017							1	1	5	9	6			
2018								2	2	9	11	6	1	

† These tags, even though recaptured in the following year, had not been at large for more than a year (i.e. more than a 12 month period).

Table 4. Estimates for a **Base case** three fleet (longline, trotline and pot) model that assumes different commercial selectivities for the three gears, and also a change in selectivity for the longliners between 2002 and 2003, when fitted to the CPUE, catch-at-length data and tag-recapture data for toothfish from the Prince Edward Islands EEZ. Results for a **sensitivity** to an increase to the extent of predation in the longline fishery are also shown. The estimates shown are for the pre-exploitation toothfish spawning biomass (K^{sp}), the current spawning stock depletion $\left(B^{sp}_{2020}\right)$ in terms of both K^{sp} and $MSYL^{sp}$, and the (fleet specific) exploitable biomass $\left(B^{\exp}_{2020}\right)$ at the beginning of the year 2020 (assuming the same selectivity as for 2019). Estimates of parameters pertinent to fitting the catch-at-length information are also shown, together with contributions to the (negative of the) log-likelihood. Numbers in brackets represent CVs. The details of the various model variants reported are given in the text.

Parameter estimates		Model		
		Previous (omit first 2 years of trotline CPUE; predation: longline +10%, trotline +0%)*	**Base case (omit first 2 years of trotline CPUE; predation: longline +10%, trotline +5%)**	**Predation: longline +50%, trotline +5%**
K^{sp} (tonnes)		27 726 (0.105)	25 582 (0.101)	26 797 (0.100)
$MSYL^{sp}$ (Longline)/K^{sp}		0.243	0.244	0.244
B^{sp}_{2019}/K^{sp}		0.377 (0.094)	0.397 (0.093)	0.397 (0.093)
B^{sp}_{2020}/K^{sp}		—	0.374 (0.094)	0.375 (0.094)
B^{sp}_{1997}/K^{sp}		1.371 (0.099)	1.402 (0.102)	1.393 (0.101)
$B^{sp}_{2020}/MSYL^{sp}$ (Longline)		1.551*	1.536	1.537
$B^{sp}_{2020}/MSYL^{sp}$ (Trotline)		1.538*	1.520	1.522
$B^{\exp}_{2020}$ (tonnes)	Longline	10 048 (0.133)*	8 268 (0.136)	8 762 (0.135)
	Pot	14 735 (0.117)*	12 679 (0.109)	13 284 (0.108)
	Trotline	11 485 (0.121)*	9 871 (0.121)	10 389 (0.120)
σ_{CPUE}	Longline	0.355	0.363	0.326
	Trotline	0.229	0.225	0.226
σ_R		0.500††	0.500††	0.500††
a^{97-02}_{50} (yr)		6.499	6.499	6.499
δ^{97-02} (yr^{-1})		0.020	0.020	0.020
ω^{97-02} (yr^{-1})		0.058	0.054	0.054
a^{03-19}_{50} (yr)	Longline	6.402	6.406	6.406
	Pot	8.440	8.655	8.690
	Trotline	7.214	7.179	7.182
δ^{03-19} (yr^{-1})	Longline	0.135	0.134	0.134
	Pot	0.850	0.901	0.908
	Trotline	0.270	0.256	0.256
ω^{03-19} (yr^{-1})	Longline	0.077	0.071	0.070
	Pot	0.000	0.000	0.000
	Trotline	0.040	0.034	0.034
β		0.115 (0.020)	0.115 (0.020)	0.115 (0.020)
σ_{len}	Longline	0.042	0.042	0.042
	Pot	0.035	0.035	0.035
	Trotline	0.036	0.037	0.037

†† Input value.

* The results shown for the "current" biomass-related values for the previous Base case are for 2019, and not for 2020 as for the results for present Base case model except for B^{sp}/K^{sp}.

Table 4 cont. Estimates for a **Base case** three fleet (longline, trotline and pot) model that assumes different commercial selectivities for the three gears, and also a change in selectivity for the longliners between 2002 and 2003, when fitted to the CPUE, catch-at-length data and tag-recapture data for toothfish from the Prince Edward Islands EEZ. Results for a **sensitivity** to an increase to the extent of predation in the longline fishery are also shown. The estimates shown are for the pre-exploitation toothfish spawning biomass (K^{sp}), the current spawning stock depletion $\left(B^{\exp}_{2020}\right)$ in terms of both K^{sp} and $MSYL^{sp}$, and the (fleet specific) exploitable biomass $\left(B^{\exp}_{2020}\right)$ at the beginning of the year 2020 (assuming the same selectivity as for 2019). Estimates of parameters pertinent to fitting the catch-at-length information are also shown, together with contributions to the (negative of the) log-likelihood. Numbers in brackets represent CVs. The details of the various model variants reported are given in the text.

Parameter estimates		Model		
		Previous (omit first 2 years of trotline CPUE; predation: longline +10%, trotline +0%)*	**Base case (omit first 2 years of trotline CPUE; predation: longline +10%, trotline +5%)**	**Predation: longline +50%, trotline +5%**
-ln *L*: Length		-930.8	-956.1	-956.0
-ln *L*: CPUE		-16.87	-17.66	-19.42
-ln *L*: Recruitment		13.84	13.393	12.392
-ln *L*: Tagging		200.2	223.9	226.0
-ln *L*: Total		-733.6	-736.5	-737.1
MSY (tonnes)	Longline	1 110†	1 028†	1 078†
	Pot	1 225	1 134	1 189
	Trotline	1 162	1 077	1 129

† Based upon the average of the two selectivity functions estimated.

Table 5. Estimates for three **sensitivity tests** to the **Base case** model detailed in the caption to Table 5. The details of the various sensitivity tests reported are given in the text.

Parameter estimates		Model			
		Base case (omit first 2 years of trotline CPUE; predation: longline +10%, trotline +5%)	**Sensitivity: w_{CPUE}(trotline)=10 for all years**	**Sensitivity: tag-reporting rate 0.8**	**Sensitivity: 50% of tags lost**
K^{sp} (tonnes)		25 582 (0.101)	26 412 (0.103)	22 458 (0.115)	13 115 (0.104)
$MSYL^{sp}$ (Longline)/K^{sp}		0.244	0.243	0.244	0.245
B^{sp}_{2019}/K^{sp}		0.397 (0.093)	0.404 (0.094)	0.360 (0.105)	0.193 (0.140)
B^{sp}_{2020}/K^{sp}		0.374 (0.094)	0.374 (0.095)	0.336 (0.106)	0.161 (0.156)
B^{sp}_{1997}/K^{sp}		1.402 (0.102)	1.544 (0.104)	1.482 (0.138)	1.932 (0.106)
$B^{sp}_{2020}/MSYL^{sp}$(Longline)		1.536	1.544	1.378	0.659
$B^{sp}_{2020}/MSYL^{sp}$(Trotline)		1.520	1.534	1.365	0.655
$B^{\exp}_{2020}$ (tonnes)	Longline	8 268 (0.136)	6 892 (0.145)	6 666 (0.145)	2 384 (0.188)
	Pot	12 679 (0.109)	12 876 (0.113)	10 016 (0.117)	2 868 (0.169)
	Trotline	9 871 (0.121)	7 887 (0.120)	7 822 (0.129)	2 468 (0.166)
σ_{CPUE}	Longline	0.363	0.429	0.346	0.326
	Trotline	0.225	0.201	0.218	0.181
σ_R		0.500††	0.500††	0.500††	0.500††
a^{97-02}_{50} (yr)		6.499	6.499	6.497	6.500
δ^{97-02} (yr^{-1})		0.020	0.020	0.021	0.021
ω^{97-02} (yr^{-1})		0.054	0.064	0.052	0.041
a^{03-19}_{50} (yr)	Longline	6.406	6.393	6.408	6.423
	Pot	8.655	8.126	8.670	8.916
	Trotline	7.179	7.177	7.186	7.238
δ^{03-19} (yr^{-1})	Longline	0.134	0.137	0.134	0.131
	Pot	0.901	0.766	0.905	0.961
	Trotline	0.256	0.256	0.256	0.256
ω^{03-19} (yr^{-1})	Longline	0.071	0.088	0.071	0.065
	Pot	0.000	0.000	0.000	0.000
	Trotline	0.034	0.051	0.034	0.032
β		0.115 (0.020)	0.115 (0.002)	0.115 (0.020)	0.116 (0.018)
σ_{len}	Longline	0.042	0.042	0.042	0.041
	Pot	0.035	0.034	0.035	0.035
	Trotline	0.037	0.037	0.037	0.037

†† Input value(s).

Table 5 cont. Estimates for three **sensitivity tests** to the Base case model detailed in the caption to Table 5.The details of the various sensitivity tests reported are given in the text.

Parameter estimates		**Model**			
		Base case (omit first 2 years of trotline CPUE; predation: longline +10%, trotline +5%)	**Sensitivity: w_{CPUE}(trotline)=10 for all years**	**Sensitivity: tag-reporting rate 0.8**	**Sensitivity: 50% of tags lost**
-ln *L*: Length		-956.1	-958.1	-958.4	-964.3
-ln *L*: CPUE		-17.66	-117.75	-18.76	-21.44
-ln *L*: Recruitment		13.393	24.792	19.322	50.531
-ln *L*: Tagging		223.9	221.4	223.8	228.9
-ln *L*: Total		-736.5	-829.6	-734.1	-706.3
MSY (tonnes)	Longline	1 028†	1 050†	903†	532†
	Pot	1 134	1160	996	584
	Trotline	1 077	1097	946	554

† Based upon the average of the two selectivity functions estimated.

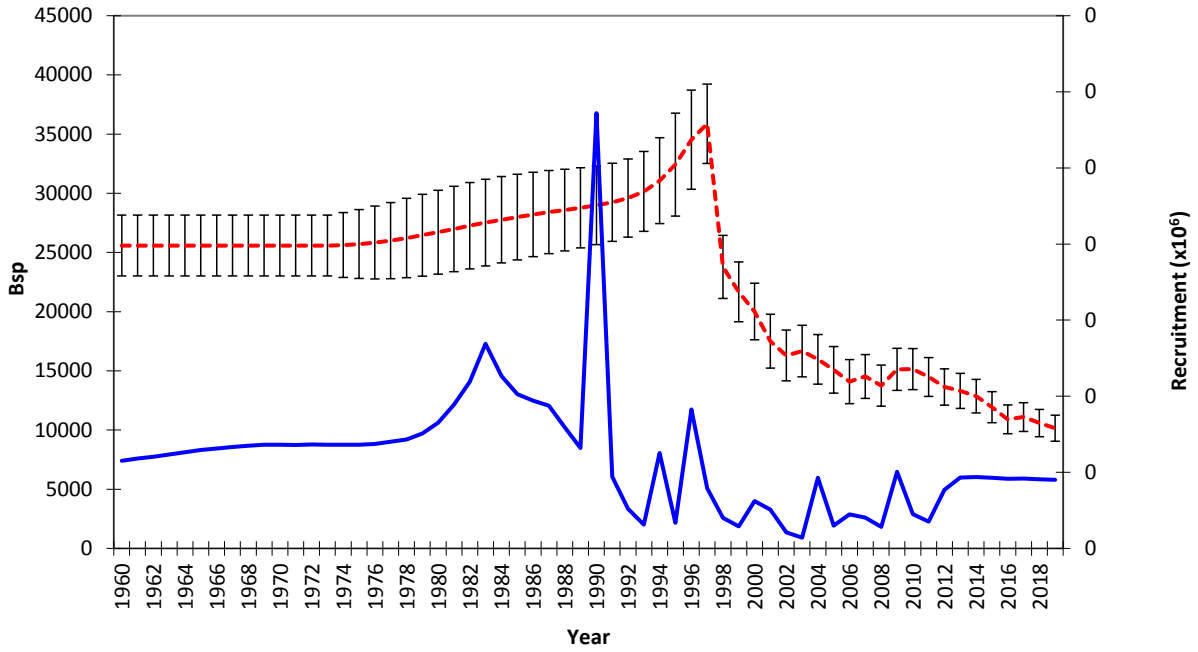

Figure 1. Spawning biomass estimates (dashed line) and estimated recruitment (full line) for the three-fleet model for the **Base case** that takes tagging data into account (with cetacean predation of +10% for longlines and +5% for trotlines). Confidence limits (Hessian-based) of one standard error for the spawning biomass are also shown.

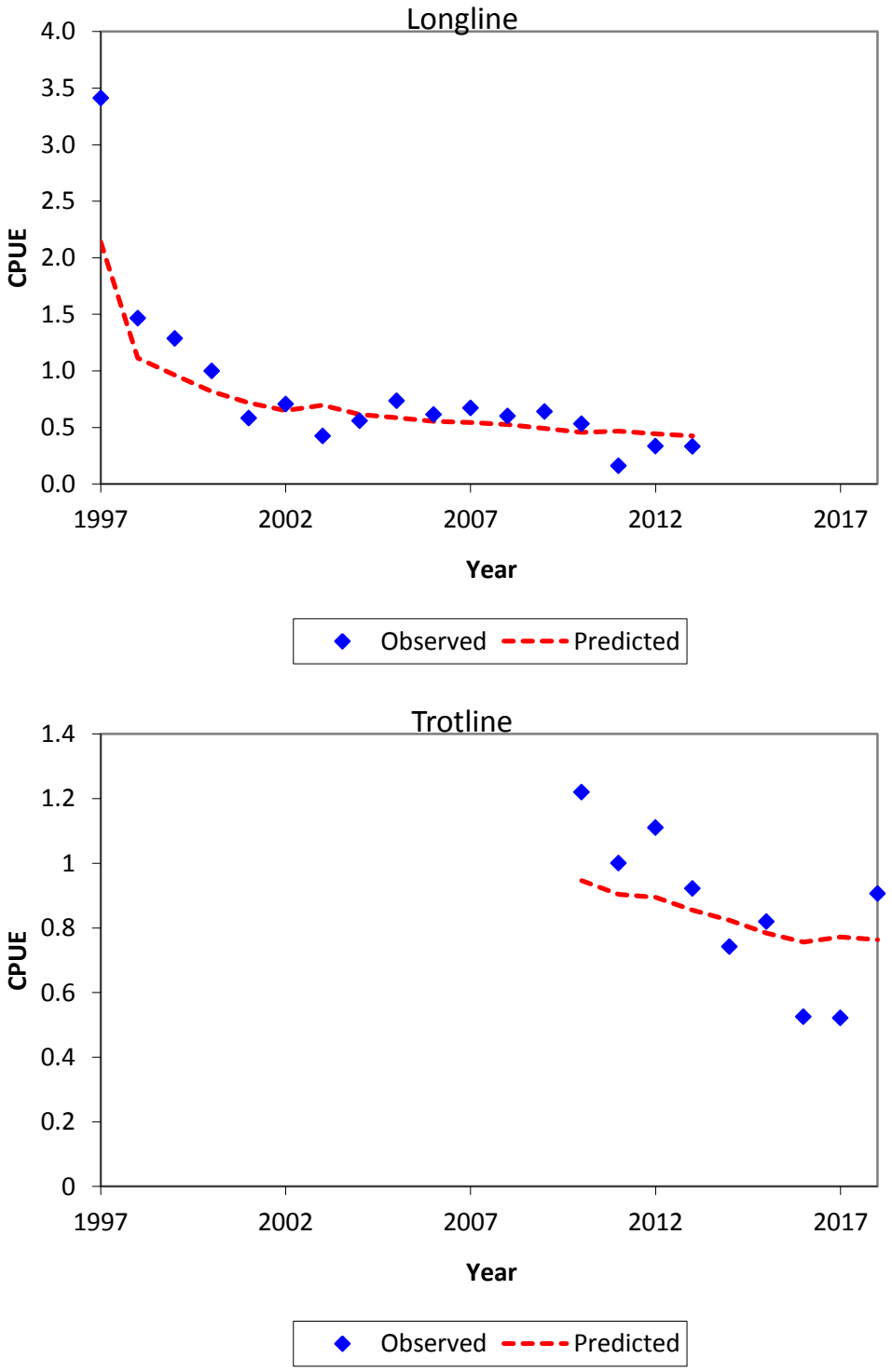

Figure 2. Exploitable biomass and the GLM-standardised CPUE indices to which the model is fit (the predicted values are exploitable biomass multiplied by the estimated catchability *q* to express them in CPUE units) for the **Base case**.

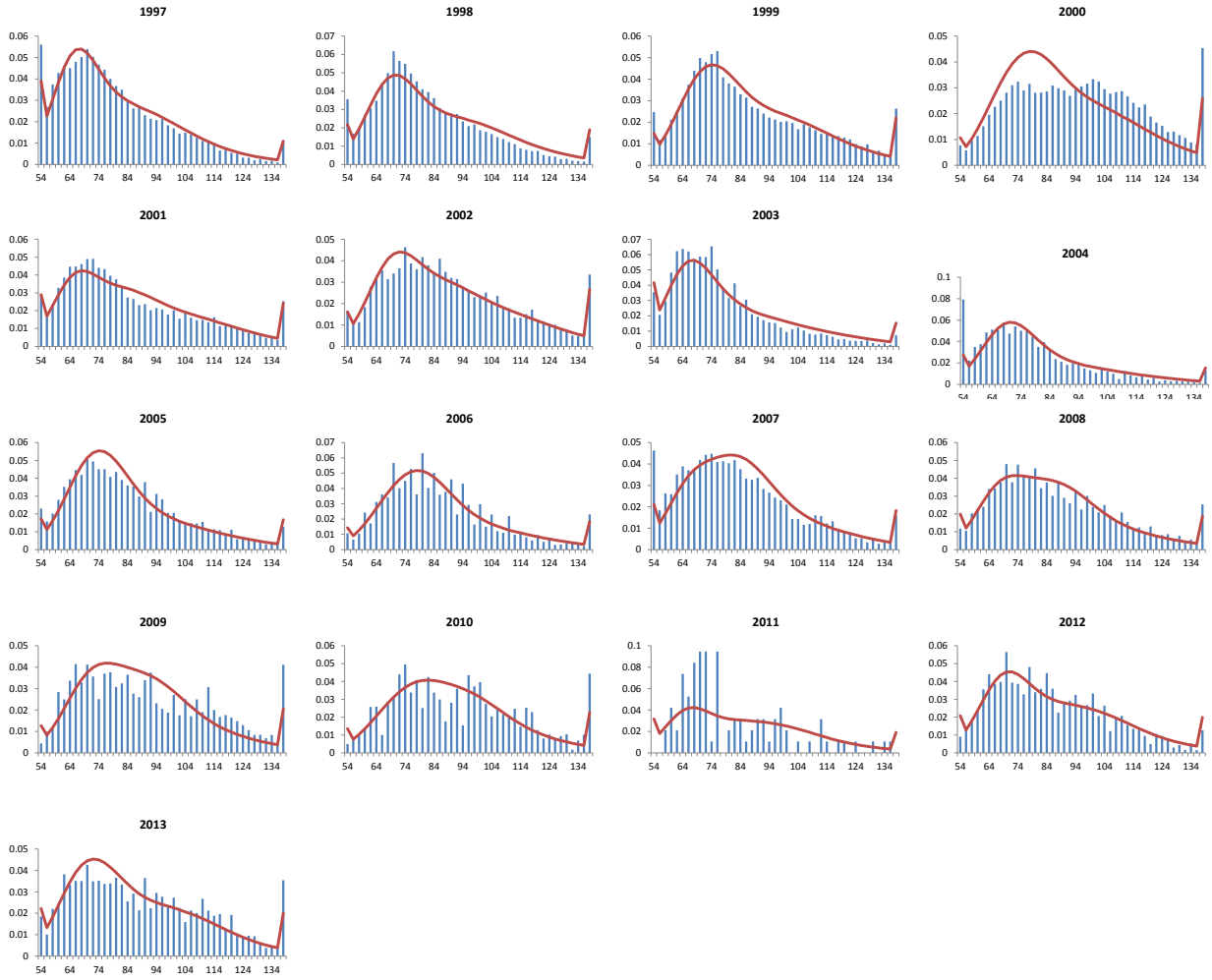

Figure 3a. Assessment predictions for the annual catch-at-length proportions in the **longline fishery** for the **Base case**. Note that lengths below 54 and above 138 cm are combined into minus- and plus-groups respectively.

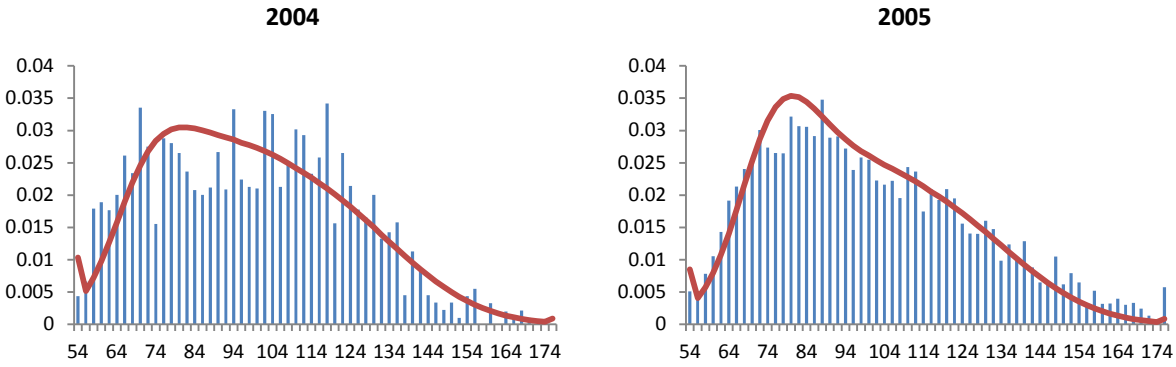

Figure 3b. Assessment predictions for the annual catch-at-length proportions in the **pot fishery** for the **Base case**. Note that lengths below 54 and above 176 cm are combined into minus- and plus-groups.

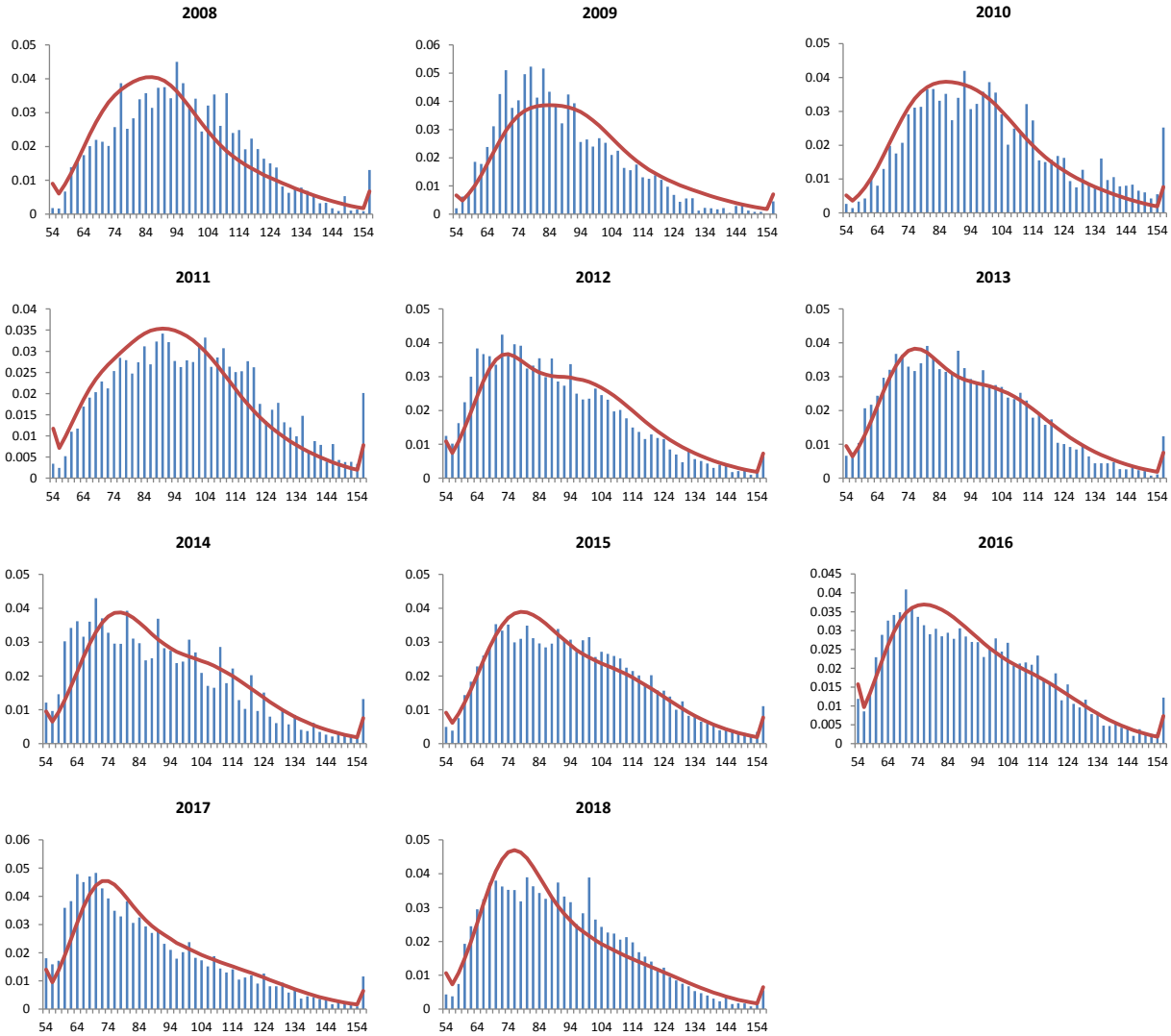

Figure 3c. Assessment predictions for the annual catch-at-length proportions in the **trotline fishery** for the **Base case**. Note that lengths below 54 and above 156 cm are combined into minus- and plus-groups respectively.

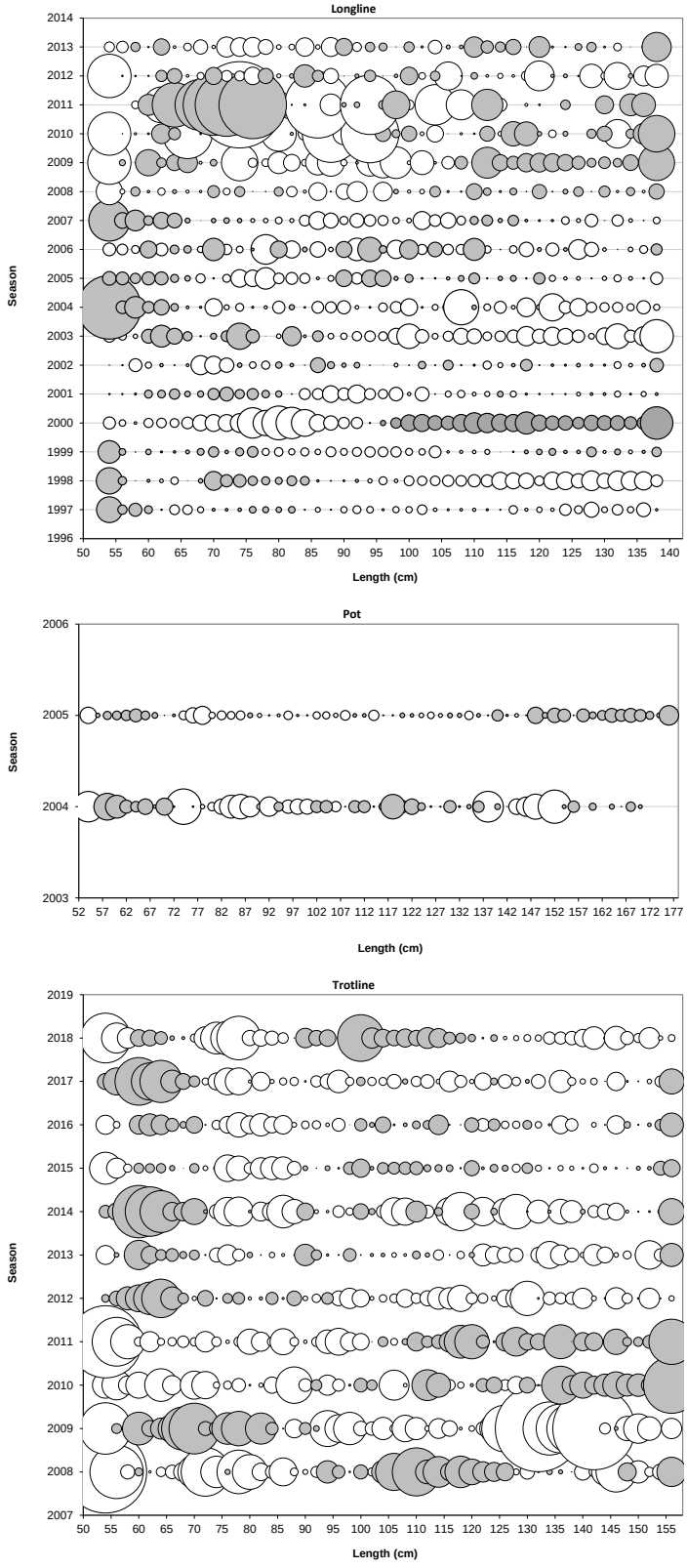

Figure 4. Bubble plots of the catch-at-length residuals for the three fisheries for the **Base case**. The size of the bubble is proportional to the corresponding standardised residual $\left(\left(\ln(obs)-\ln(pred)\right)\Big/\left(\sigma/\sqrt{pred}\right)\right)$. White bubbles represent negative residuals while grey bubbles represent positives ones.

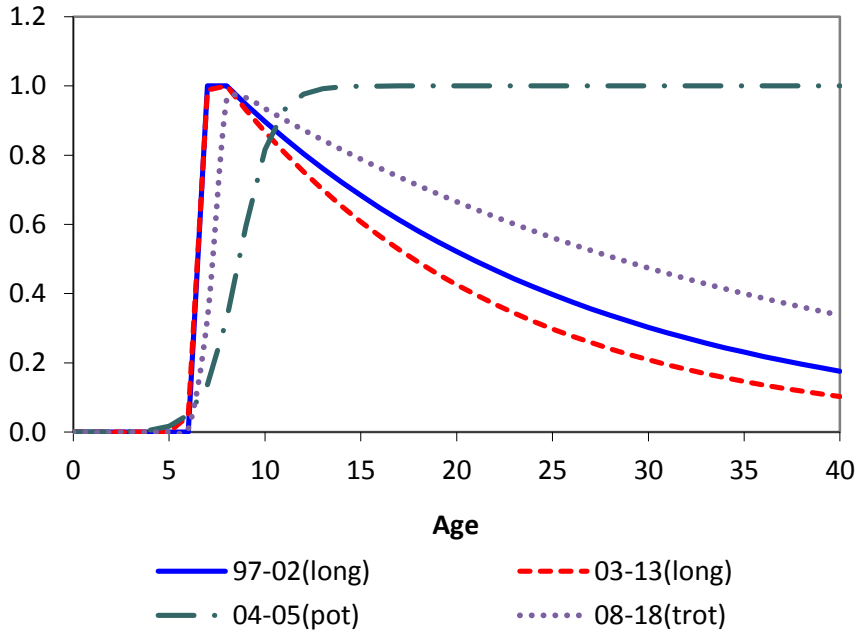

Figure 5. Estimated selectivity curves for the periods 1997–2002 and 2003–2013 for the longline fishery, for the period 2004-2005 for the pot fishery and for the period 2008–2018 for the trotline fishery. Curves are shown for the **Base case**.

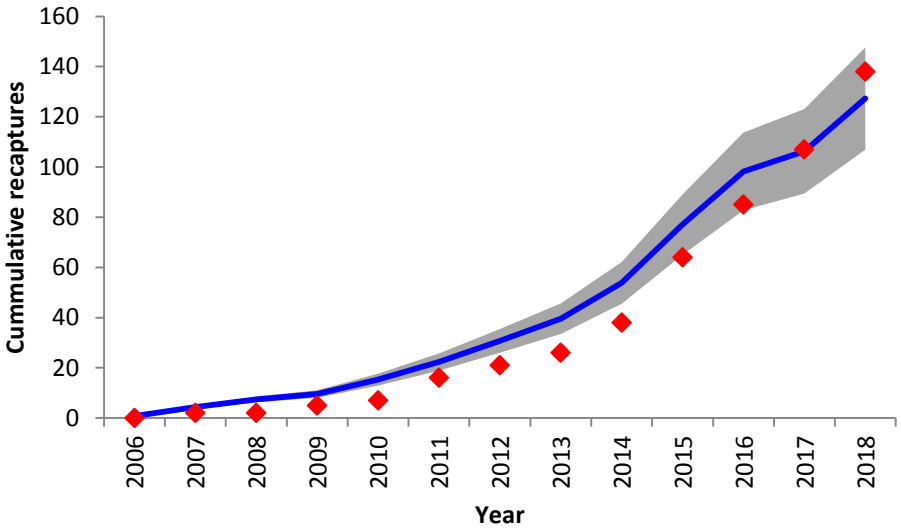

Figure 6. Observed (diamonds) and model predicted (continuous line) cumulative recapture numbers of toothfish for the **Base case** model, and combining recaptures by longlines and trotlines. The shaded area reflects the 95% confidence interval envelope.

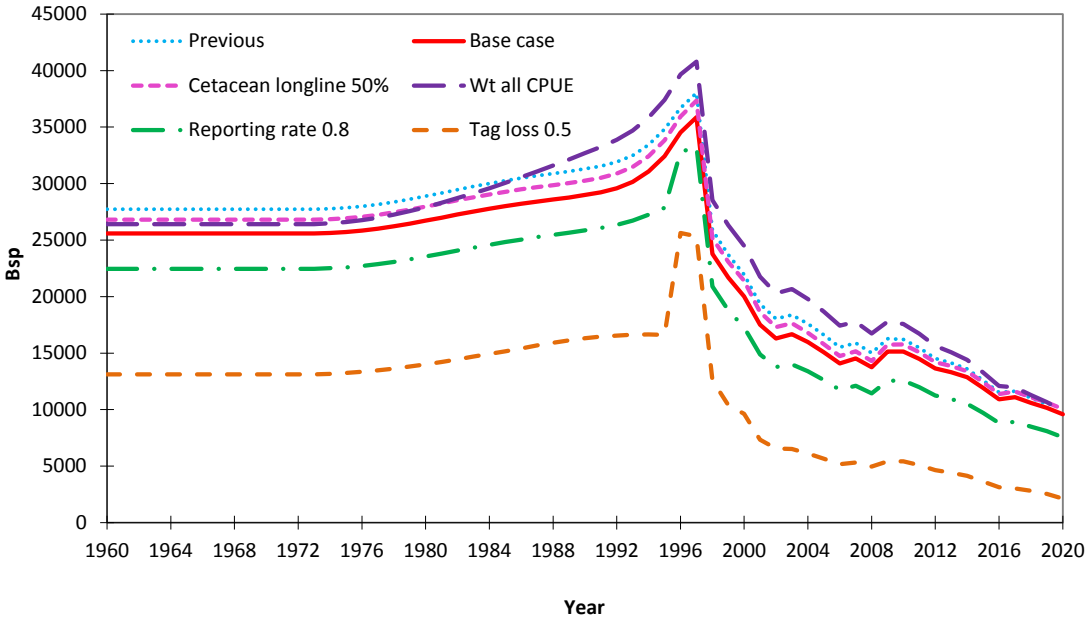

Figure 7a. Spawning biomass estimates for the **Base case** (and the previous Base case) as well as four **sensitivity tests:** 1) assumes cetacean predation on longlines of +50%, 2) up-weights all CPUE indices from 2010, 3) assumes a tag-reporting rate of 0.8 and 4) assumes a tag loss rate of 0.5.

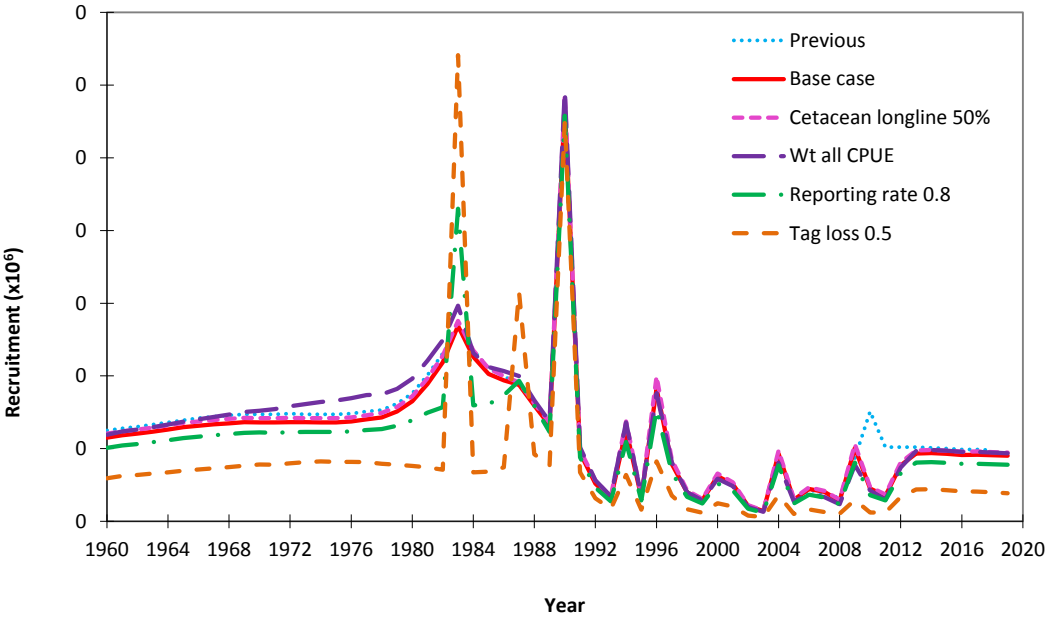

Figure 7b. Estimated recruitment for the **Base case** and the four **sensitivities** detailed in the caption to Figure 7a.

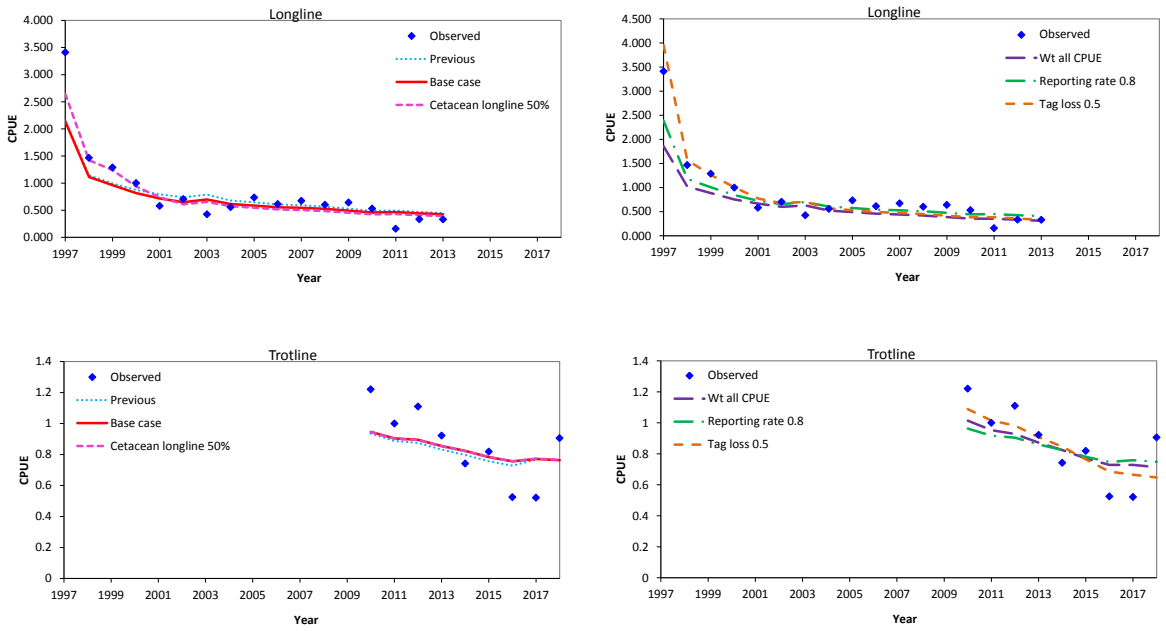

Figure 8. Exploitable biomass and the GLM-standardised CPUE indices to which the model is fit (the predicted values are exploitable biomass multiplied by the estimated catchability *q* to express them in CPUE units) for the previous Base case and the present **Base case** as well as four **sensitivity** tests that 1) assumes cetacean predation on longlines of +50%, 2) up-weights all CPUE indices from 2010, 3) assumes a tag-reporting rate of 0.8 and 4) assumes a tag loss rate of 0.5.

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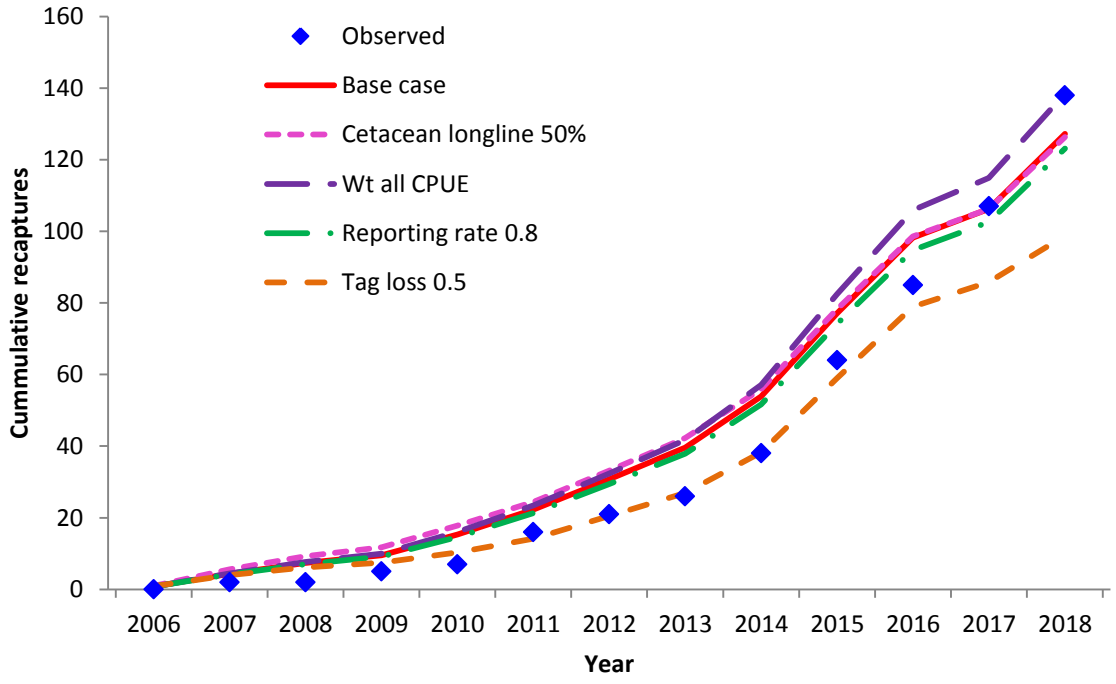

Figure 9. Observed (asterisks) and model predicted cumulative recapture numbers of toothfish for the **Base case** model and for four **sensitivity** tests that 1) assumes cetacean predation on longlines of +50%, 2) up-weights all CPUE indices from 2010, 3) assumes a tag-reporting rate of 0.8 and 4) assumes a tag loss rate of 0.5.