Updated assessments and projections under alternative future catch levels for the horse mackerel resource

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Abstract

The age-structured production model assessment of Johnston and Butterworth (2007) is updated to take account of further catch and survey data. In addition length-frequency data from surveys and the *Desert Diamond*, and a GLM standardised CPUE series from the *Desert Diamond* are now included when fitting the model to the data. The assessments do indicate an increase in abundance of about 20% over the last five years, primarily as a result of good recruitment. However, long term projections under different levels of future catches remain fairly similar to those of Johnston and Butterworth (2007).

1 Introduction

This document provides an update and extension to the age-structured production model assessment of Johnston and Butterworth (2007). Details of the changes are provided in the following section.

As in Johnston and Butterworth (2007), results are provided for four alternative assessments reflecting combinations of two possible choices for survey catchability (relative bias) q and stock-recruitment steepness h. Deterministic projections, comparable to those in Johnston and Butterworth (2007), are reported for each of these four cases for various combinations of future pelagic, demersal and midwater catches.

2 Method

An age-structured production model (ASPM) is used to model the South African horse mackerel fishery. The model assumes one combined stock (West coast plus South coast). For the most part it is unchanged from the 2007 assessment model (Johnston and Butterworth, 2007). Key differences are that:

- the catch and survey biomass time-series are updated;
- midwater CPUE data from the *Desert Diamond* are incorporated;

- length-frequency data from demersal surveys and the *Desert Diamond* are incorporated;
- fluctuations about expected recruitment are estimated for the years 1983-2008;
- a midwater fishery selectivity function is introduced; and
- the demersal fishery selectivity function (taken to be the same as that for the trawl surveys) is parameterised and estimated.

The ASPM and its associated likelihood function components are described in full in Appendix A.

2.1 Demersal and midwater selectivity

For the 2007 assessment, the selectivity of the demersal fleet was input and was not differentiated from the selectivity of the midwater fleet. Now, because of the introduction of both demersal and midwater length-frequency data, it is preferable to separate and estimate the selectivity of these two fleets. Experimentation showed that a function of the form used in the 2007 assessment (increasing linearly to $S_a = 1$) provided a good fit to the data. Furthermore, the data indicate that selectivity may decrease for large horse mackerel. Therefore, selectivity functions of the following form are used:

$$S_a^f = \begin{cases} a / a_{kink}^f & a < a_{kink}^f \\ 1 & a_{kink}^f < a \le 5 \\ e^{-\mu^f (a-5)} & a > 5 \end{cases}$$

where

f	indicates the fishery/fleet concerned and in this case, is either d (demersal) or m (midwater);
S_a^f	is the selectivity for horse mackerel of age a for fleet f;
a_{kink}^f	is the age at which selectivity reaches 1 for fleet f; and
μ^f	reflects the rate at which selectivity decreases for horse mackerel older than 5 years for fleet f.

2.2 Recruitment fluctuations

It is assumed that recruitment fluctuates about its expected values for the years 1983-2008. Estimation of these fluctuations is possible because of the availability of length-frequency data for the years in question.

2.3 Parameters estimated

The fit of the model to the data estimates the following thirty-two parameters:

K^{sp}	the pre-exploitation spawning biomass;
q_{spr}	the catchability coefficient corresponding to the Spring demersal survey;
a_{kink}^d	the position (age) of the kink in the demersal selectivity function;

μ^d	the rate of decay of the demersal selectivity function after age 5;
a^m_{kink}	the position (age) of the kink in the midwater selectivity function;
μ^m	the rate of decay of the midwater selectivity functions after age 5; and
ς_y	fluctuations about expected recruitment for the years 1983-2008

2.4 Model variants

As was the case for the 2007 assessment, four model variants are considered corresponding to four combinations of values for the "steepness" of the stock-recruitment curve, h, and the catchability coefficient of the autumn demersal survey, q_{aut}, which is called q_2 in Johnston and Butterworth (2007).

- Model 1: q_{aut} = 0.5; h = 0.6
- Model 2: q_{aut} = 1.0; h = 0.6
- Model 3: q_{aut} = 0.5; h = 0.9
- Model 4: q_{aut} = 1.0; h = 0.9

2.5 Projections

The model is used to project the resource biomass ahead for the period 2010-2030. It is assumed that demersal catch remains constant at the catch level reported for 2009, which is 4185 MT. All permutations of the following scenarios are considered:

Future pelagic catch scenarios
- 5000 MT annually
- 10000 MT annually
- 15000 MT annually

Future midwater catch scenarios
- 29815 MT annually
- 39815 MT annually
- 55815 MT annually

Note, that the midwater projection scenarios were chosen so that the total demersal and midwater catches would match those used by Johnston and Butterworth (2007).

3 Data

3.1 Historical catches

The historical catch records for the demersal, midwater and pelagic fisheries for the years 1949-2009 are reported in Table 2, and shown graphically in Figure 1.

3.2 Biomass indices

Three biomass indices are used when fitting the model. Fairweather (pers. commn) provided two sets of biomass estimates and the associated CVs that are derived from demersal swept area surveys conducted on the South coast during both spring and autumn. Observer data, provided by van der Westhuizen (pers. commn), were used to produce a GLM standardised CPUE series for a midwater trawl vessel, *Desert Diamond*, which operates on the South coast. The GLM is described in details in Appendix B. These biomass indices are reported in Table 1.

3.2 Length-frequency data

Three length-frequency datasets are used when fitting the model. Fairweather (pers. commn) provided catch-at-length data from the Spring and Autumn demersal surveys. Van der Westhuizen (pers. commn) provided catch-at-length data from the *Desert Diamond*. These datasets each cover the same years as the corresponding biomass index (Table 1), except that catch-at-length data from 2010 cannot be used as the catch taken is not yet available for that year. The catch-at-length proportions for each dataset averaged over years are shown in Figure 2.

4 Results

Table 3 reports the various model estimates for each of the four models considered, as well the associated standard errors. Figure 3 provides a graphical representation of the model fit to the biomass indices. Figure 4 shows the estimated spawning biomass relative to pristine spawning biomass trajectories for the years 1949-2010. Estimated selectivity functions for the surveys and fisheries are shown in Figure 6. Projection results are tabulated in Tables 4 a-d. Results of similar projections from the 2007 assessment are included in the tables for comparison. Figures 7-9 show the projection results graphically, also with comparisons to similar projections from the 2007 assessment.

5 Discussion

Table 3 indicates that there is little to choose between three of the four models in likelihood terms. The exception is Model 4 ($q_{aut} = 1.0, h = 0.9$) for which the fit to the catch-at-length data is appreciably worse.

The assessments all show improvements (by about 20%) in spawning biomass over the last five years (Figure 4). Figure 5 suggests that this is a result of good recruitment. However in terms of medium to long term projections (Table 4 and Figures 7-9), there appears relatively little difference to the results of Johnston and Butterworth (2007).

Reference

Johnston, S.J. and Butterworth, D.S. 2007. The South African horse mackerel assessment for 2007 using an age-structured production model, with future biomass projections. MCM document, 2007:WG-Dem:HM:10

Year	Autumn survey		Spring survey		CPUE
	Abundance (MT)	CV	Abundance (MT)	CV	
1986			97363	0.13	
1987			332973	0.14	
1988	159074	0.29			
1989	138203	0.54			
1990	122746	0.28	551217	0.22	
1991	352187	0.23	575014	0.17	
1992	422209	0.23	477289	0.27	
1993	435281	0.20	307167	0.16	
1994	340719	0.26	337586	0.16	
1995	195129	0.24	276369	0.23	
1996	261770	0.23			
1997	241017	0.23			
1998					
1999	330631	0.24			
2000	322417	0.33			
2001			316721	0.18	
2002					
2003	146723	0.24	231362	0.20	0.752
2004	195733	0.32	366499	0.19	0.628
2005	175042	0.21			0.874
2006	386566	0.20	350279	0.19	0.973
2007	243582	0.40	473216	0.19	1.374
2008	279857	0.27	300000	0.17	0.987
2009	337160	0.24			1.121
2010	271795	0.37			1.291

Table 1: Biomass indices and the associated CVs (if available) used when fitting the model. Shaded data indicate surveys that were not performed by the *Africana* or that did not extend beyond 200m and, therefore, are excluded when fitting the model.

Year	Demersal	Midwater	Pelagic
1949	-	-	3360
1950	445	-	49900
1951	1105	-	98900
1952	1226	-	102600
1953	1456	-	85200
1954	2550	-	118100
1955	1926	-	78800
1956	1334	-	45800
1957	959	-	84600
1958	2073	-	56400
1959	2075	-	17700
1960	3712	-	62900
1961	3627	-	38900
1962	3079	-	66700
1963	1401	-	23300
1964	9522	-	24400
1965	7017	-	55000
1966	7596	-	26300
1967	6189	-	8800
1968	9116	-	1400
1969	12252	-	26800
1970	17872	-	7900
1971	33348	-	2200
1972	20556	-	1300
1973	35315	-	1600
1974	36654	-	2500
1975	69845	-	1600
1976	34814	-	400
1977	68816	-	1900
1978	35375	-	3600
1979	60068	-	4300
1980	42627	-	400
1981	33883	-	6100
1982	33091	-	1100
1983	41507	-	2100
1984	38817	-	2800
1985	31280	-	700
1986	35812	-	500
1987	41972	-	2834
1988	34333	-	6403
1989	34163	-	25872
1990	43647	-	7645
1991	23974	-	582
1992	23277	-	2057
1993	18426	-	11651
1994	8479	-	8207
1995	6702	-	1986
1996	9707	-	18920
1997	11332	-	12654
1998	9676	4206	26680
1999	9248	926	2057
2000	17159	7480	4503
2001	15656	12388	915
2002	9073	6888	8148
2003	8145	20727	1012
2004	17246	14840	2048
2005	11898	22387	5627
2006	4367	17823	4824
2007	6510	23331	1903
2008	6790	21432	2280
2009	4185	28938	2087

Table **2**: Annual landings (MT) of horse mackerel for demersal, midwater (Johnston and Butterwork, 2007; Fairweather, pers. commn) and pelagic (Coetzee, pers. commn) fisheries.

			Model 1	Model 2	Model 3	Model 4
Input parameters	q_2		0.5	1.0	0.5	1.0
	h		0.6	0.6	0.9	0.9
Estimated parameters	K^{sp}	estimate	1170	868	1090	809
		std err	1.29×10^5	1.74×10^4	1.19×10^5	8.46×10^4
	q_{spr}	estimate	0.50	1.03	0.50	0.92
		std err	0.048	0.098	0.046	0.099
	a_{kink}^d	estimate	1.37	1.96	1.36	2.20
		std err	0.31	0.45	0.31	0.50
	μ^d	estimate	0.30	0.12	0.33	0.57
		std err	0.20	0.13	0.18	0.27
	a_{kink}^m	estimate	5.00	5.00	5.00	4.49
		std err	0.0053	0.0028	0.0051	1.64
	μ^m	estimate	0.75	0.53	0.76	0.54
		std err	0.36	0.28	0.37	0.33
Negative log-likelihoods	-ln$L$ (S-R)		5.60	6.18	5.42	5.71
	-ln$L$ (abund)		-0.23	-5.99	0.46	0.31
	-ln$L$ (CAL)		20.67	25.54	20.60	25.45
	-ln$L$ (total)		26.04	25.73	26.48	31.47

Table 3: Summary of assessment results. Under the 'Negative log-likelihoods' heading: 'S-R' refers to the contribution from stock-recruitment residuals, 'abund' refers to the contribution from biomass indices and 'CAL' refers to the contribution from length-frequency data. Biomass units are thousands of tons.

Model 1 ($q_{aut} = 0.5, h = 0.6$)				
Projected demersal + midwater catch (MT)	Year	Projected pelagic catch (MT)		
		5000	10000	15000
34000	2007	0.63 (0.65)	0.63 (0.65)	0.63 (0.65)
	2020	0.63 (0.62)	0.54 (0.51)	0.44 (0.39)
	2030	0.61	0.48	0.31
44000	2007	0.63 (0.65)	0.63 (0.65)	0.63 (0.65)
	2020	0.57 (0.54)	0.47 (0.43)	0.37 (0.31)
	2030	0.52	0.37	0.16
60000	2007	0.63 (0.65)	0.63 (0.65)	0.63 (0.65)
	2020	0.45 (0.42)	0.36 (0.3)	0.25 (0.18)
	2030	0.34	0.12	0

Table 4a: Values of future spawning biomass relative to K^{sp} for three future pelagic constant catch scenarios and three future demersal plus midwater catch scenarios. Results are presented for model 1. Values are shaded if they fall below 0.45 for 2020 and 0.35 for 2030. Values in brackets are the corresponding projections from the 2007 assessment.

Model 2 ($q_{aut} = 1.0, h = 0.6$)				
Projected demersal + midwater catch (MT)	Year	Projected pelagic catch (MT)		
		5000	10000	15000
34000	2007	0.36 (0.48)	0.36 (0.48)	0.36 (0.48)
	2020	0.40 (0.47)	0.26 (0.33)	0.09 (0.16)
	2030	0.40	0.04	0
44000	2007	0.36 (0.48)	0.36 (0.48)	0.36 (0.48)
	2020	0.29 (0.37)	0.13 (0.21)	0.02 (0.04)
	2030	0.17	0	0
60000	2007	0.36 (0.48)	0.36 (0.48)	0.36 (0.48)
	2020	0.07 (0.17)	0.01 (0)	0 (0)
	2030	0	0	0

Table 4b: As for Table 4a, but for model 2.

Model 3 ($q_{aut} = 0.5, h = 0.9$)				
Projected demersal + midwater catch (MT)	Year	Projected pelagic catch (MT)		
		5000	10000	15000
34000	2007	0.7 (0.7)	0.7 (0.7)	0.7 (0.7)
	2020	0.68 (0.66)	0.6 (0.55)	0.5 (0.44)
	2030	0.67	0.56	0.45
44000	2007	0.7 (0.7)	0.7 (0.7)	0.7 (0.7)
	2020	0.62 (0.59)	0.53 (0.48)	0.44 (0.37)
	2030	0.6	0.48	0.36
60000	2007	0.7 (0.7)	0.7 (0.7)	0.7 (0.7)
	2020	0.52 (0.47)	0.43 (0.36)	0.33 (0.24)
	2030	0.47	0.34	0.18

Table 4c: As for Table 4a, but for model 3.

Model 4 ($q_{aut} = 1.0, h = 0.9$)				
Projected demersal + midwater catch (MT)	Year	Projected pelagic catch (MT)		
		5000	10000	15000
34000	2007	0.57 (0.58)	0.57 (0.58)	0.57 (0.58)
	2020	0.57 (0.53)	0.45 (0.38)	0.32 (0.22)
	2030	0.55	0.39	0.18
44000	2007	0.57 (0.58)	0.57 (0.58)	0.57 (0.58)
	2020	0.48 (0.42)	0.36 (0.27)	0.22 (0.1)
	2030	0.44	0.25	0
60000	2007	0.57 (0.58)	0.57 (0.58)	0.57 (0.58)
	2020	0.33 (0.23)	0.19 (0.05)	0.07 (0)
	2030	0.2	0.01	0

Table 4d: As for Table 4a, but for model 4.

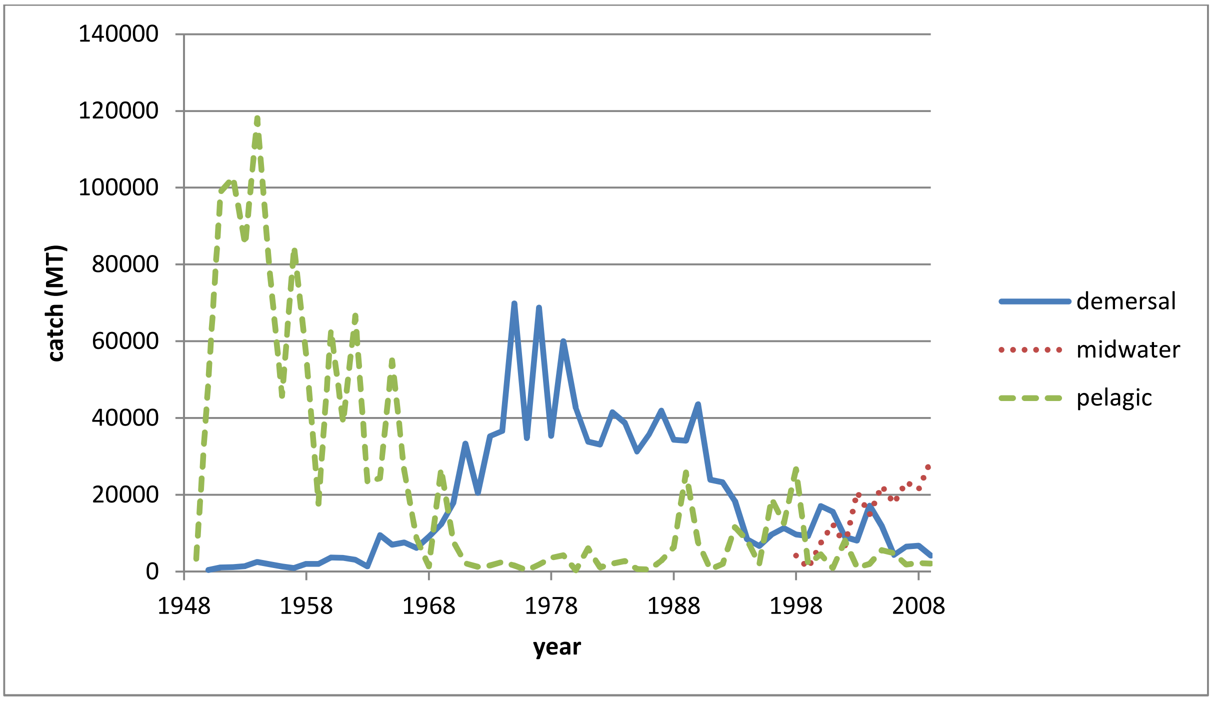

Figure 1: Annual landings (MT) of horse mackerel for demersal, midwater (Johnston and Butterworth, 2007; Fairweather, pers. commn) and pelagic (Coetzee, pers. commn) fisheries.

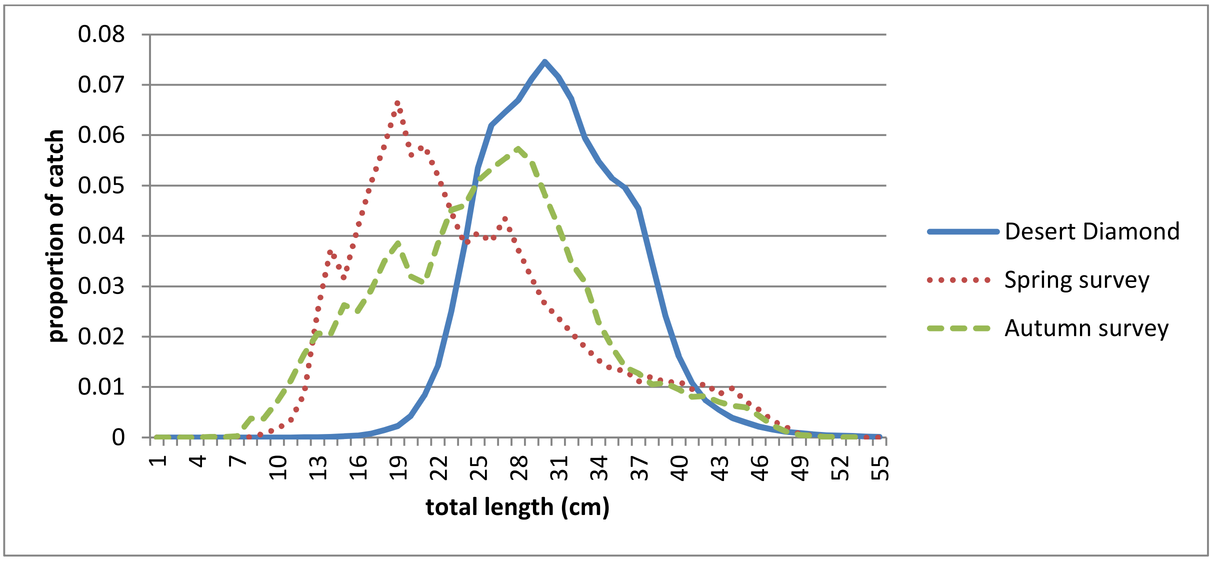

Figure 2: Mean catch-at-length proportions for the *Desert Diamond*, Spring demersal survey and Autumn demersal survey.

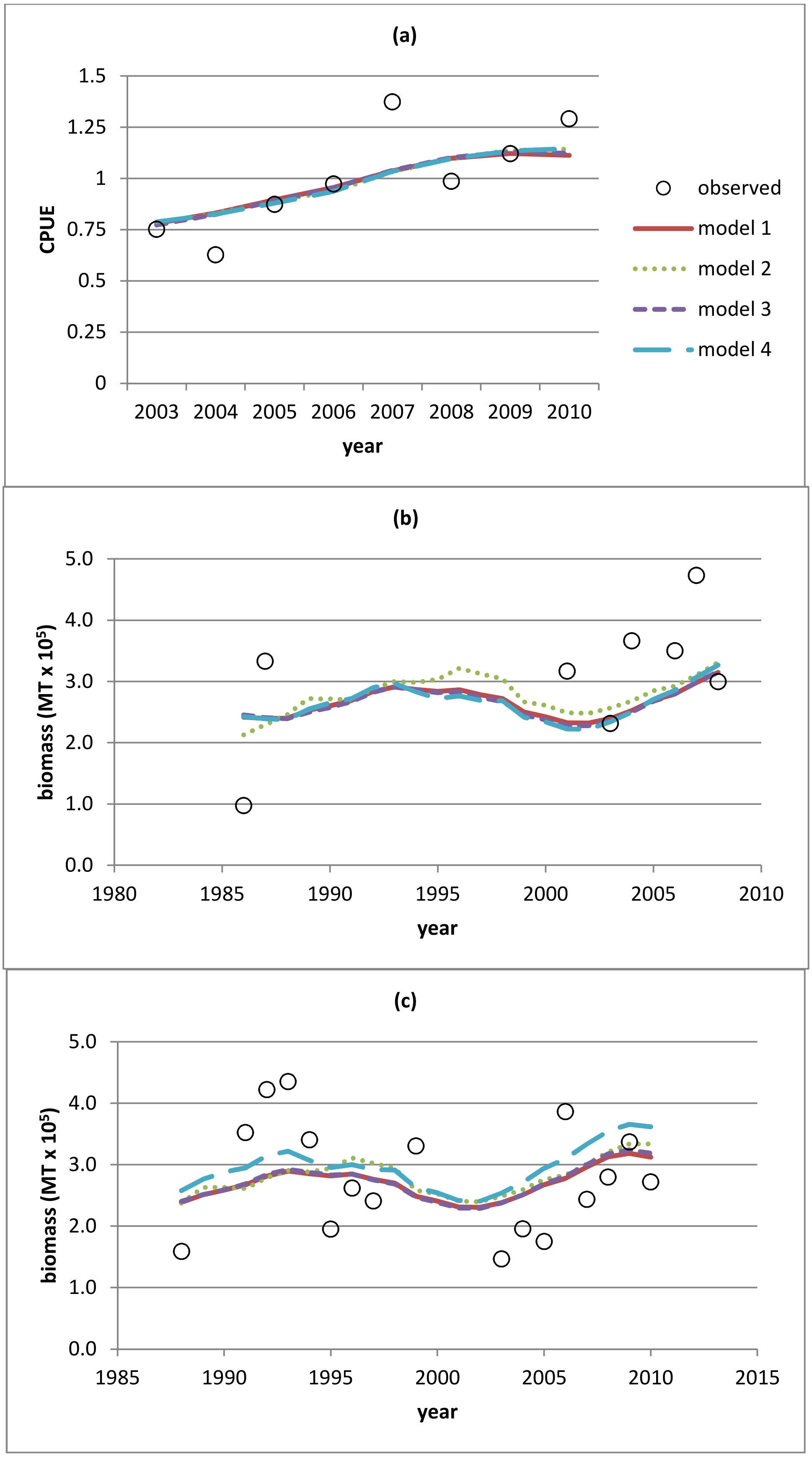

Figure 3: Model fits to (a) midwater CPUE series, (b) Spring demersal survey biomass estimates and (c) Autumn demersal survey biomass estimates.

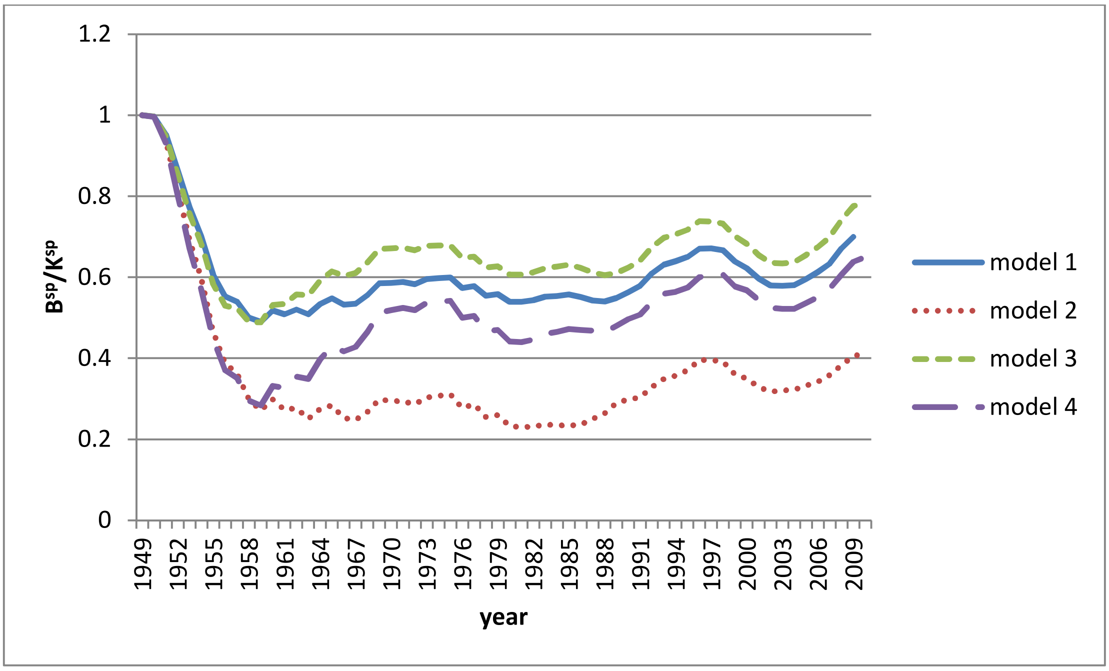

Figure 4: Trends in spawning biomass as a percentage of pristine spawning biomass for all model variants.

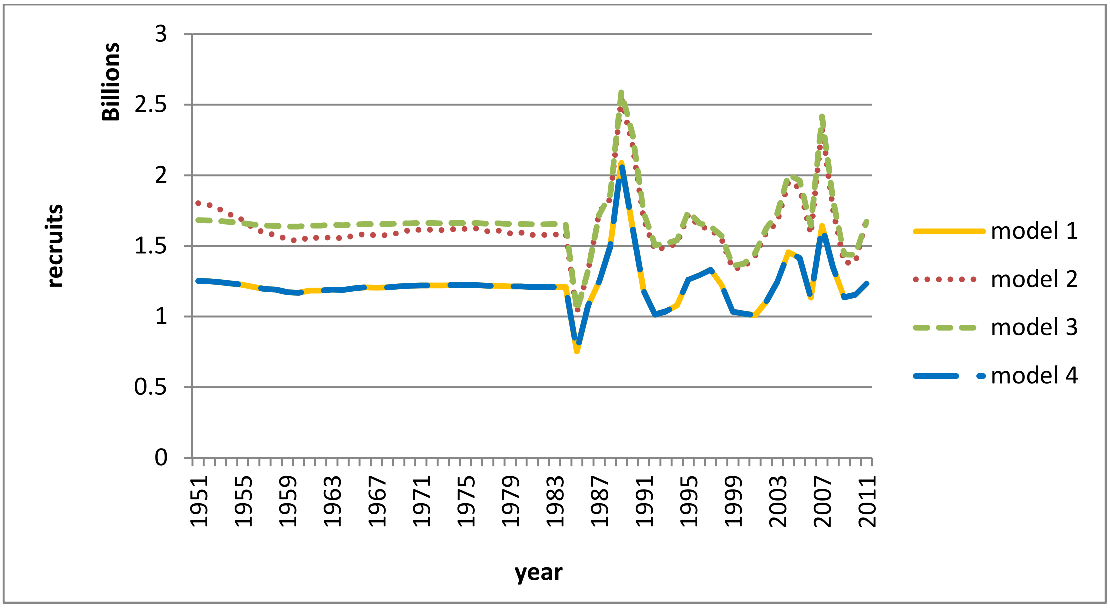

Figure 5: Trends recruitment for all model variants. Units of recruits are billions of individuals.

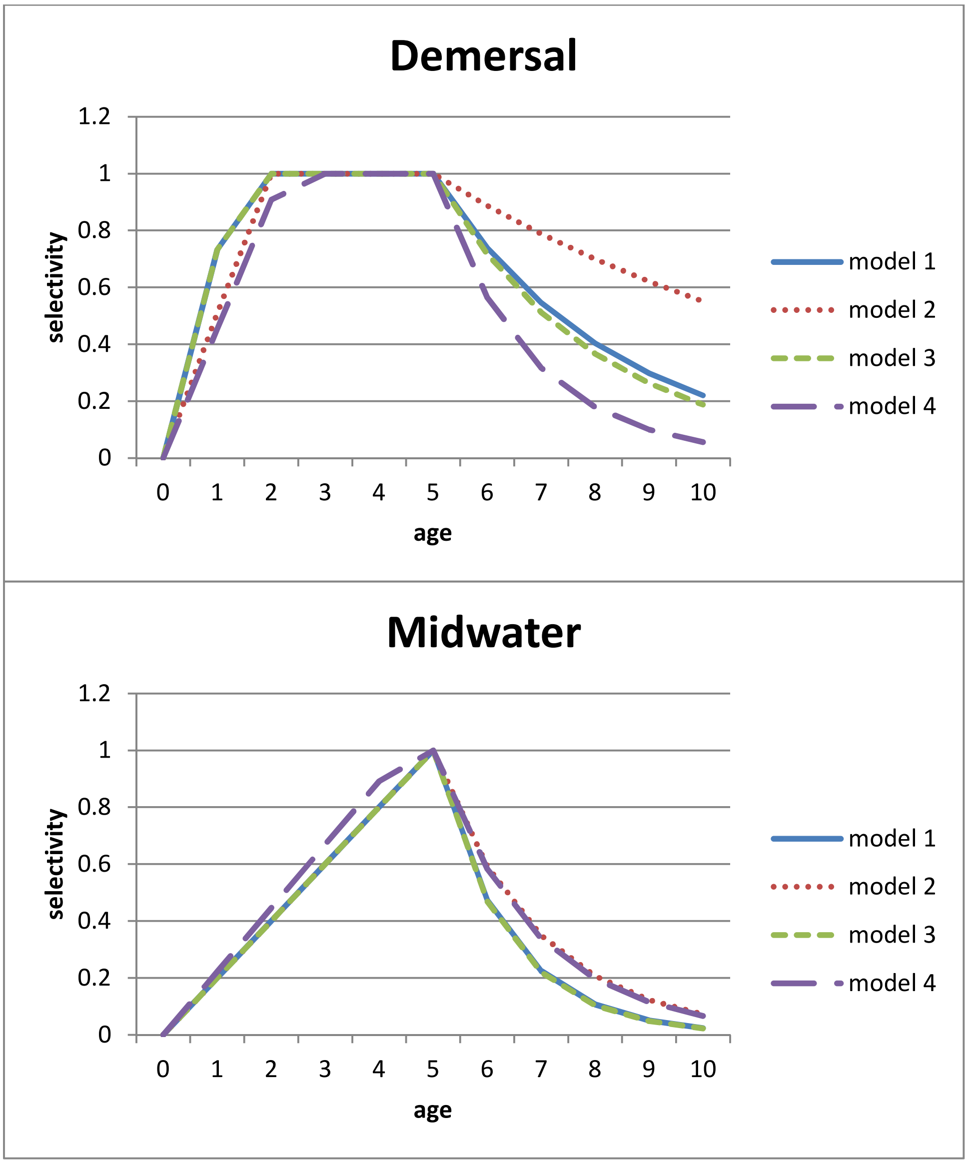

Figure 6: Estimated demersal fishery and midwater fishery selectivity-at-age functions for all model variants.

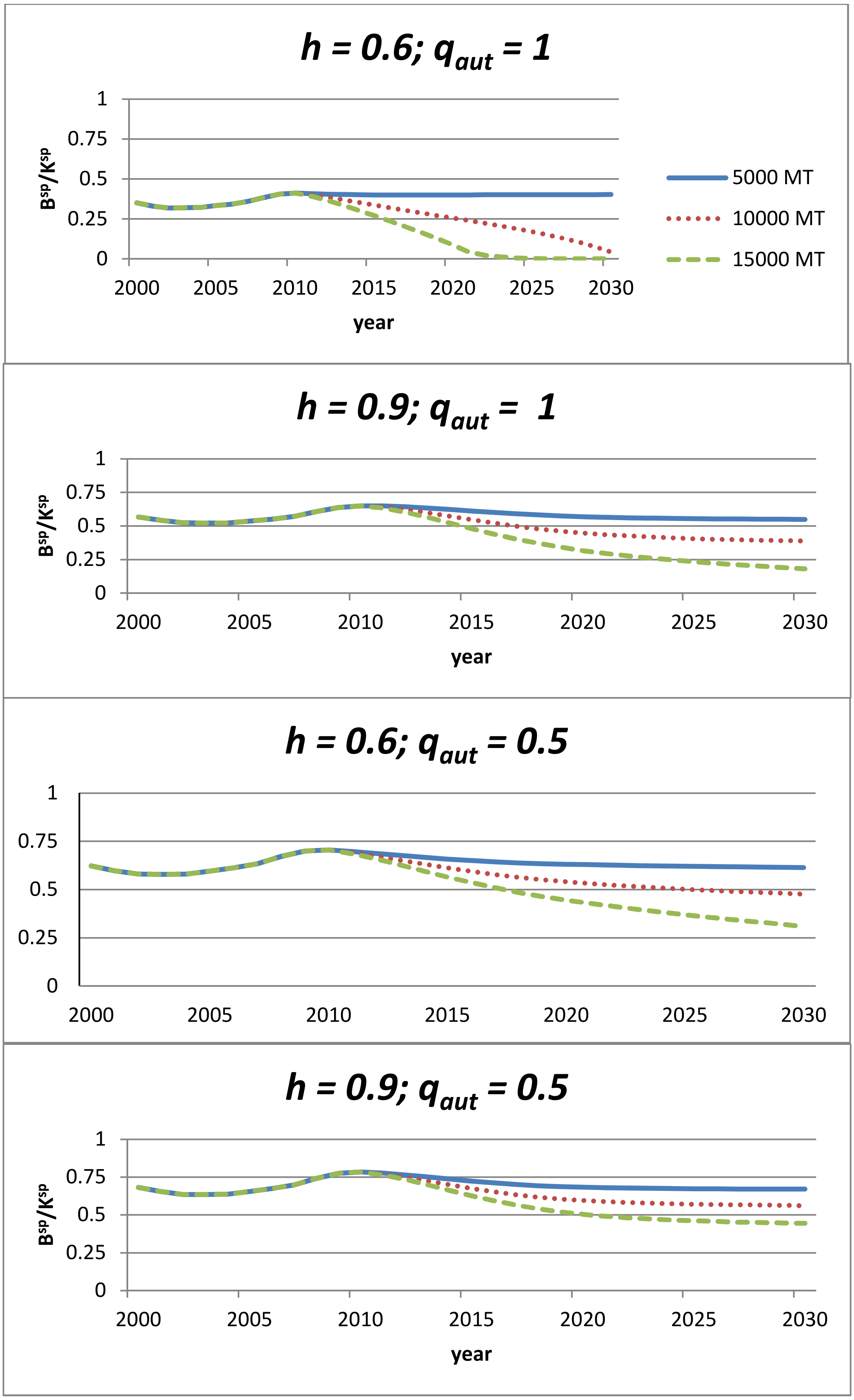

Figure 7a: Trajectories of spawning biomass relative to K^{sp} for the 34000 MT demersal plus midwater constant catch scenario and all three future pelagic scenarios. Trajectories are shown for the four model variants.

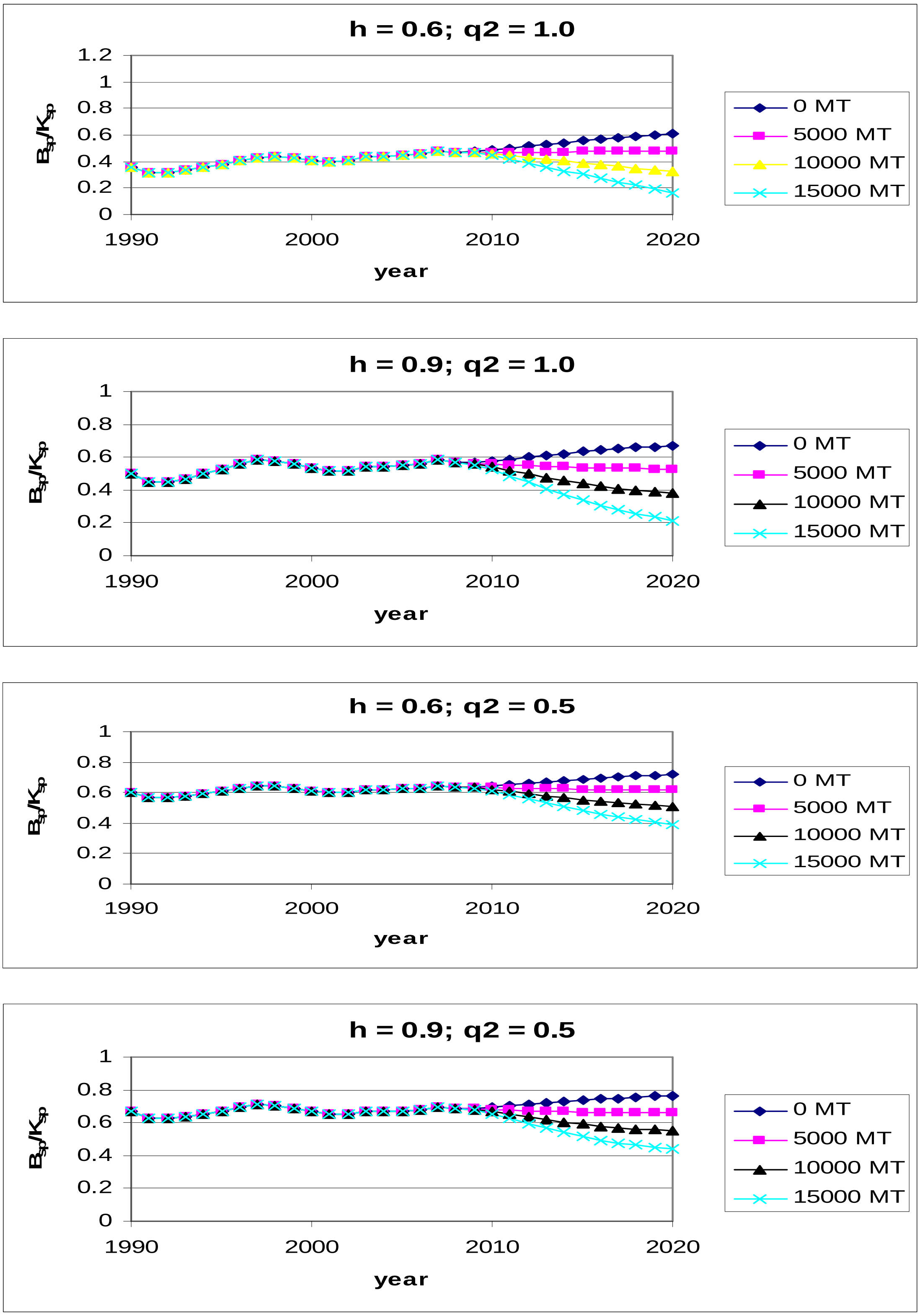

Figure 7b: Projected spawning biomass relative to K^{sp} trajectories from Johnston and Butterworth (2007) for the 34000 MT demersal constant catch scenario.

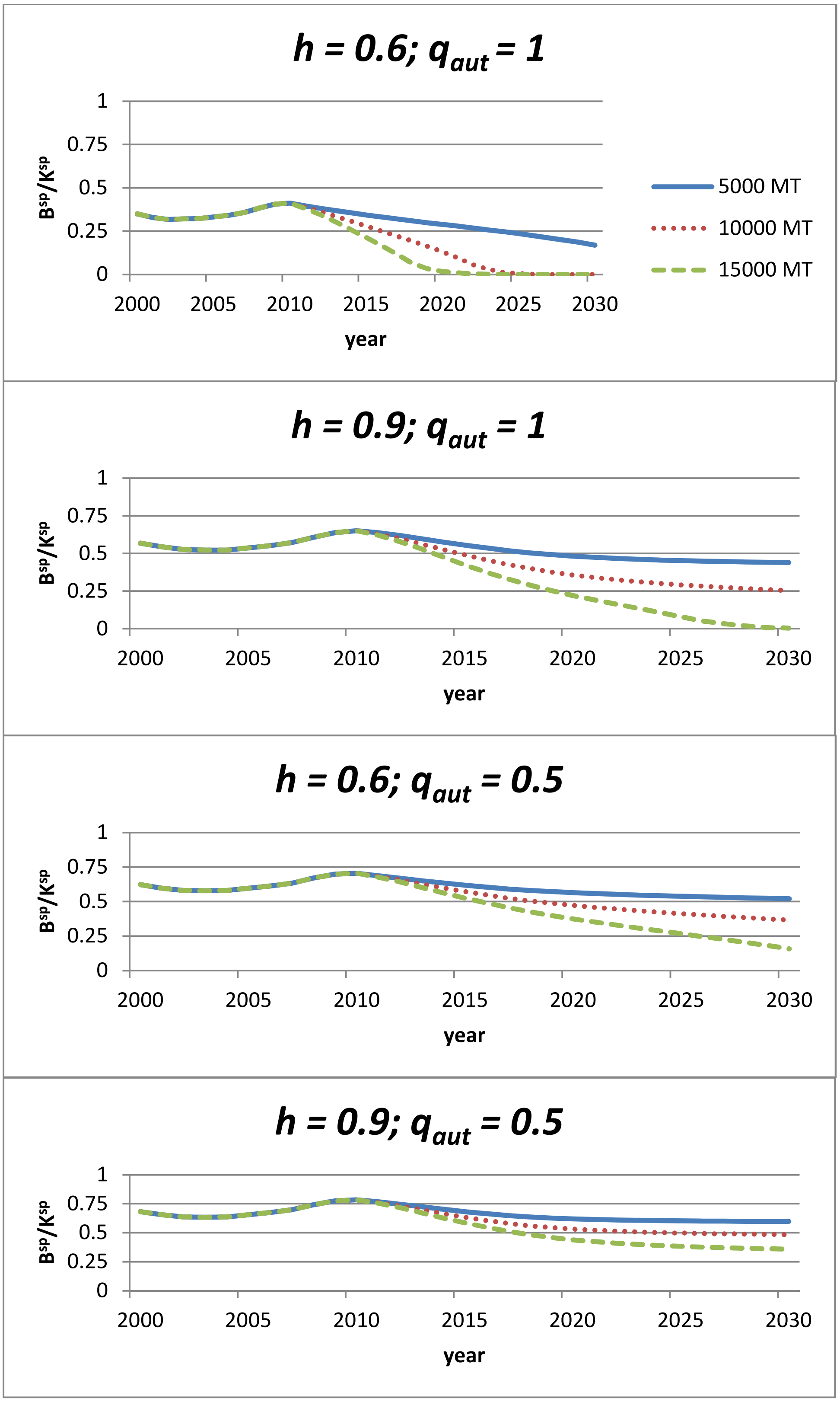

Figure 8a: Trajectories of spawning biomass relative to K^{sp} for the 44000 MT demersal plus midwater constant catch scenario and all three future pelagic scenarios. Trajectories are shown for the four model variants.

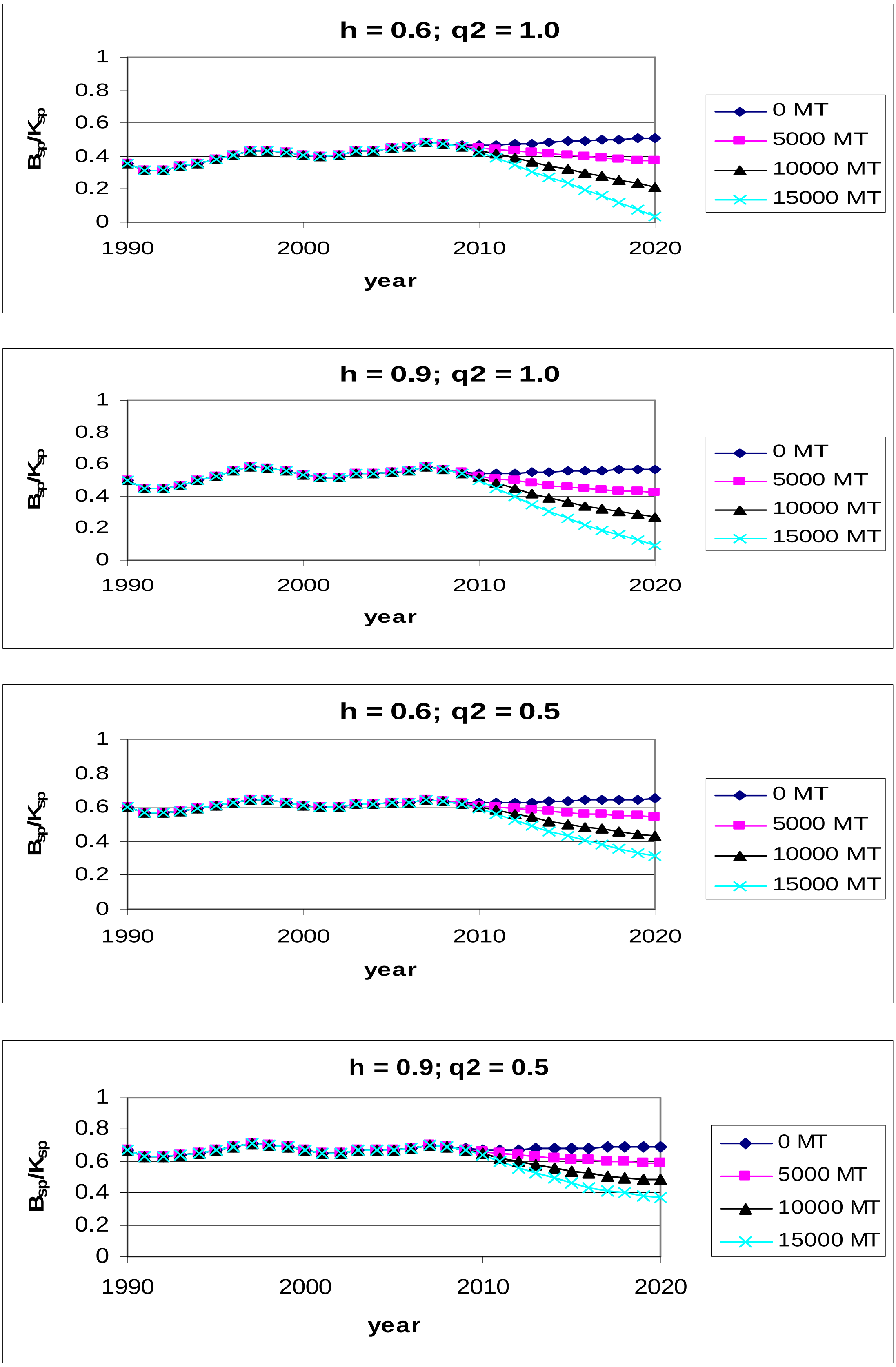

Figure 8b: Projected spawning biomass relative to K^{sp} trajectories from Johnston and Butterworth (2007) for the 44000 MT demersal constant catch scenario.

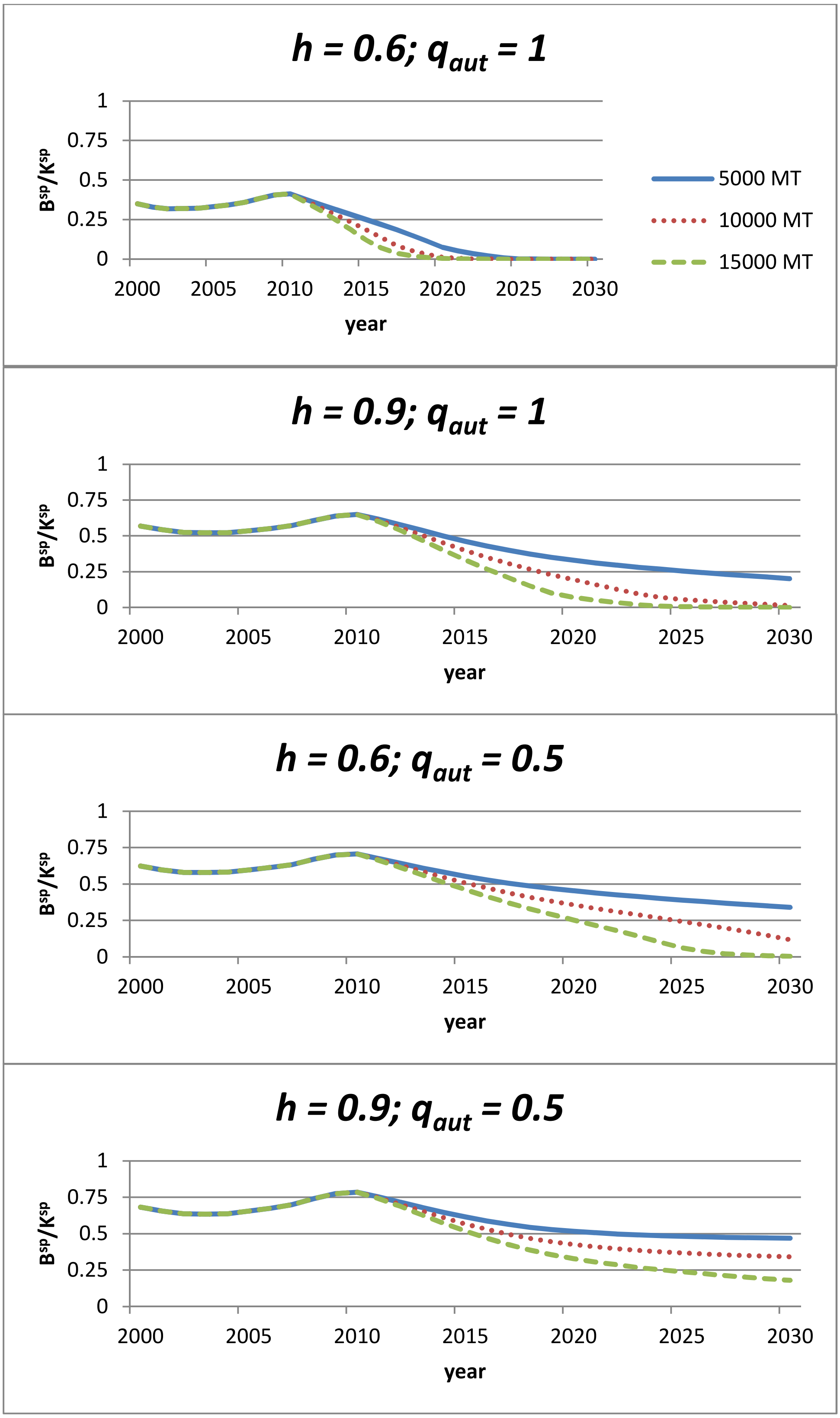

Figure 9a: Trajectories of spawning biomass relative to K^{sp} for the 60000 MT demersal plus midwater constant catch scenario and all three future pelagic scenarios. Trajectories are shown for the four model variants.

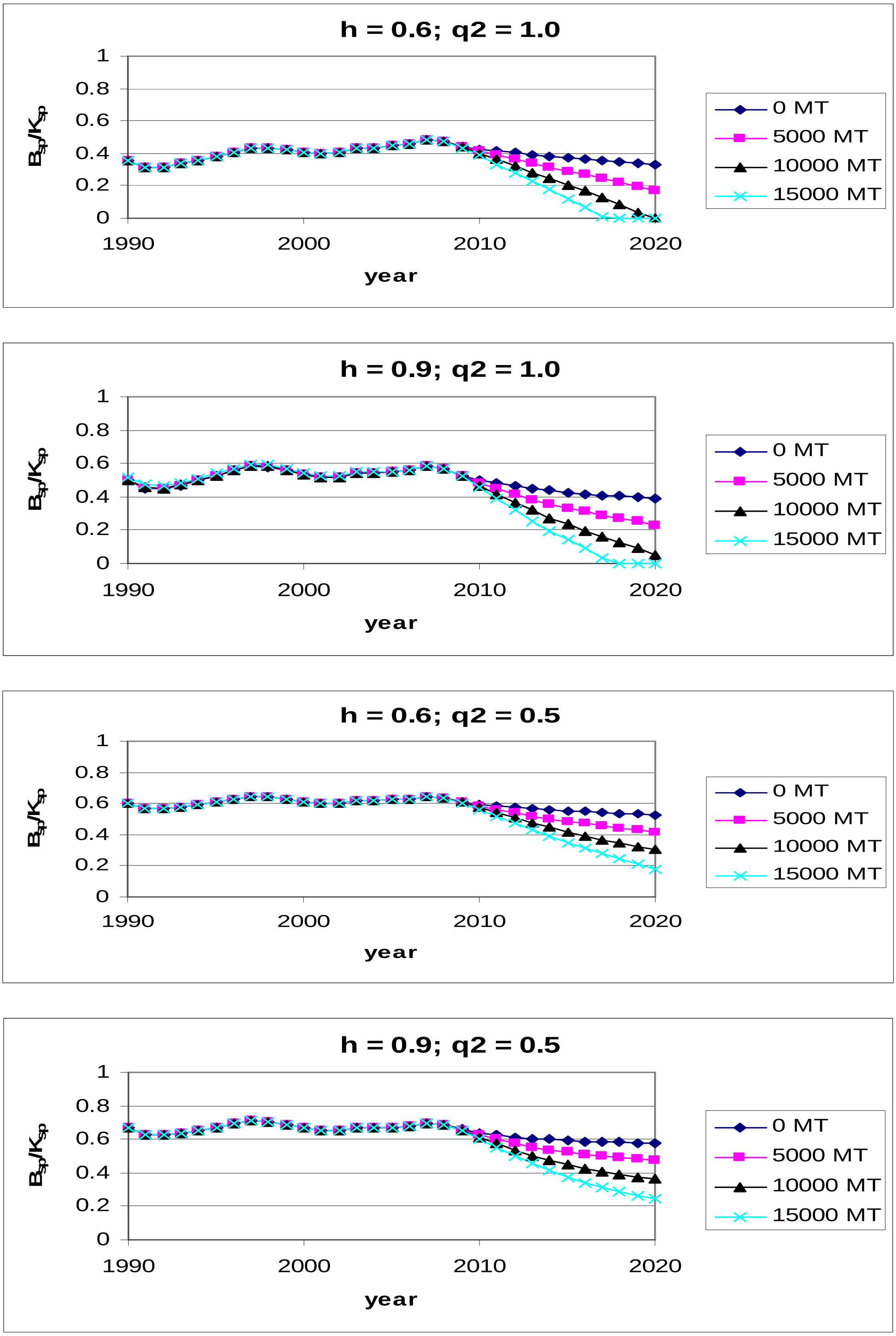

Figure 9b: Projected spawning biomass relative to K^{sp} trajectories from Johnston and Butterworth (2007) for the 60000 MT demersal constant catch scenario.

Appendix A

Mathematical details of the age-structured production model (ASPM)

A.1 Dynamics

The dynamics of the population are described using the following deterministic equations:

$$N_{y+1,0} = R_{y+1} \tag{A.1}$$

$$N_{y+1,a+1} = (N_{y,a}e^{-\frac{M_a}{2}} - C_{y,a})e^{-\frac{M_a}{2}} \qquad 0 \le a \le m\text{-}2 \tag{A.2}$$

$$N_{y+1,m} = (N_{y,m}e^{-\frac{M_m}{2}} - C_{y,m})e^{-\frac{M_m}{2}} + (N_{y,m-1}e^{-\frac{M_{m-1}}{2}} - C_{y,m-1})e^{-\frac{M_{m-1}}{2}} \tag{A.3}$$

where

$N_{y,a}$ is the number of horse mackerel of age *a* at the start of year *y*;

$C_{y,a}$ is the total number of horse mackerel of age *a* taken by the pelagic, demersal and midwater fleets combined, in year *y*;

R_y is the number of recruits at the start of year *y* (see Section A.2);

M_a is the natural mortality rate for fish of age *a*; and

m is the minimum age of the plus-group (*m* = 10 for this paper).

The approximation of the fishery as a pulse catch in the middle of the season is considered of sufficient accuracy for present purposes.

The total number of horse mackerel of age *a* caught each year ($C_{y,a}$) is given by:

$$C_{y,a} = \sum_f C^f_{y,a} \tag{A.4}$$

where *f* indicates the fishery/fleet concerned and in this case, is either *p* (pelagic), *d* (demersal) or m (midwater).

The annual catch by mass (C^f_y) for fleet *f* is given by:

$$C^f_y = \sum_{a=0}^{m} w_{a+\frac{1}{2}} C^f_{y,a}$$

$$= \sum_{a=0}^{m} w_{a+\frac{1}{2}} S^f_a F^f_y N_{y,a} e^{-M_a/2} \tag{A.5}$$

where S^f_a is the fishing selectivity-at-age for fleet *f*. [Note that the pelagic selectivity is assumed to change over time (Table A.1)]. F^f_y is the fleet-specific fishing mortality for a fully selected age class in year *y*, and $w_{a+\frac{1}{2}}$ denotes the mid-year mass of a horse mackerel of age *a*.

The fleet-specific exploitable component of abundance is computed in terms of exploitable biomass at mid-year:

$$B_y^f = \sum_{a=0}^{m} w_{a+\frac{1}{2}} S_a^f N_{y,a} e^{-M_a/2} \tag{A.6}$$

or numbers:

$$N_y^f = \sum_{a=0}^{m} S_a^f N_{y,a} e^{-M_a/2} \tag{A.7}$$

The proportion of the resource harvested each year (F_y^f) by fleet *f* is therefore given by:

$$F_y^f = C_y^f / B_y^f \tag{A.8}$$

and

$$C_{y,a}^f = S_a^f F_y^f N_{y,a} e^{-M_a/2} \tag{A.9}$$

A.2 Stock-recruitment relationship

The spawning biomass in year *y* is given by:

$$B_y^{sp} = \sum_{a=a_m}^{m} w_a N_{y,a} \tag{A.10}$$

where a_m is the age corresponding to 100% sexual maturity, which is assumed here to be described by a knife-edge function of age, and w_a is the mass of horse mackerel of age a at the start of the year.

The number of recruits at the start of fishing year *y* is related to the spawner stock size by a Beverton-Holt stock-recruitment relationship:

$$R\left(B_y^{sp}\right) = \frac{\alpha\, B_y^{sp}}{\beta + B_y^{sp}} e^{\varsigma_y} \tag{A.11}$$

where

α and β	are spawner biomass-recruitment parameters, and
ς_y	are stock-recruitment residuals reflecting fluctuations about the expected recruitment in year y.

In order to work with estimable parameters that are more biologically meaningful, the stock-recruit relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness" of the stock-recruit relationship, where "steepness" is the fraction of pristine recruitment (R_0) that results when spawning biomass drops to 20% of its pristine level:

$$hR_0 = R\left(0.2K^{sp}\right) \tag{A.12}$$

from which it follows that:

$$h = 0.2\left[\beta + K^{sp}\right] / \left[\beta + 0.2K^{sp}\right] \tag{A.13}$$

and hence:

$$\alpha = \frac{4hR_0}{5h-1} \tag{A.14}$$

and:

$$\beta = \frac{K^{sp}(1-h)}{5h-1} \tag{A.15}$$

Given a value for the pre-exploitation spawning biomass K^{sp} of horse mackerel, together with the assumption of an initial equilibrium age structure, pristine recruitment can be determined from:

$$R_0 = K^{sp} /[\sum_{a=a_m}^{m-1} w_a e^{-\sum_{a'=0}^{a-1} M_{a'}} + w_m e^{-\sum_{a'=0}^{m-1} M_{a'}} /(1-e^{-M_m})] \tag{A.16}$$

Numbers-at-age for subsequent years are then computed by means of equations (A.1)-(A.11).

A.3 Likelihood functions

The model is fitted to three biomass indices and three sets of length-frequency data. Stock-recruitment residuals also contribute to the (penalised) negative log-likelihood.

A.3.1 Biomass indices

The model is fitted to three biomass indices: Spring and Autumn demersal survey biomass estimates (Table 1), and commercial midwater CPUE data (Table 2). The associated likelihood contributions are calculated by assuming that the observed abundance index is log-normally distributed about its expected value:

$$I_y^s = \hat{I}_y^s e^{\varepsilon_y^S} \qquad \text{or} \qquad \varepsilon_y^s = \ell n(I_y^s) - \ell n(\hat{I}_y^s) \tag{A.17}$$

where

s indicates the biomass index concerned and is either aut (autumn), spr (spring) or $cpue$;

I_y^s is the observed value of index s in year y;

$\hat{I}_y^s$ $= q_s B_y^f$ is the corresponding model estimated value, where B_y^f is the model value for exploitable resource biomass at mid-year for the appropriate fleet, in year y, given by equation (A.6); and

q_s is the catchability coefficient corresponding to index s.

The negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell nL = \sum_s \sum_y \left[\ell n\sigma_y^s + \left(\varepsilon_y^s\right)^2 / 2\left(\sigma_y^s\right)^2 \right] \quad \text{(A.18)}$$

The Spring and Autumn demersal survey biomass indices are assumed to reflect demersal exploitable biomass:

$$\hat{I}_y^s = q_s B_y^d .$$

Reliable coefficients of variation are available for these series (Table 1); therefore, the standard deviations are calculated by the following formula:

$$\sigma_y^s = \sqrt{\ln(1 + CV_{s,y}^2)} \quad . \quad \text{(A.19)}$$

The CPUE index is assumed to reflect midwater exploitable biomass:

$$\hat{I}_y^{cpue} = q_{cpue} B_y^m .$$

Reliable estimates of coefficients of variation and catchability are unavailable for this series; therefore, these are set to their maximum likelihood estimates

$$\sigma^{cpue} = \sqrt{1/n \sum_y \left(\varepsilon_y^{cpue}\right)^2}$$

and

$$\ln q_{cpue} = 1/n \sum_y \varepsilon_y^{cpue} .$$

A.3.2 Length-frequency

Model estimated catch-at-length proportions are fitted to Spring and Autumn demersal survey length-frequency data, and commercial midwater length-frequency data.

Model catch-at-age estimates (equation A.9) are converted to catch-at-length estimates using an age-length relationship:

$$C_{y,l}^f = \sum_a A_{l,a} C_{y,a}^f \quad \text{(A.20)}$$

where $A_{l,a}$ is the proportion of fish of age a that are of length l, which is calculated by assuming that lengths at a given age a are normally distributed according to $N\left(l(a), \left(\beta l(a)\right)^2\right)$, where $l(a)$ is the mean length of a mackerel of age a and β is a constant taken to be equal to 0.075 (for which reasonable fits to the data were obtained).

The contribution of catch-at-length data to the negative of the log-likelihood function when assuming a log-normal error distribution and when making an adjustment to effectively weight in proportion to sample size is given by:

$$-\ln L = \sum_s \sum_y \sum_l \left[\ln\left(\sigma^s_{cal} / \sqrt{p^s_{y,l}}\right) + p^s_{y,l}\left(\ln p^s_{y,l} - \ln \hat{p}^s_{y,l}\right)^2 / 2(\sigma^s_{cal})^2 \right] \tag{A.21}$$

where

$p^s_{y,l}$ is the observed proportion of fish caught in year y that are of length l for dataset s;

$\hat{p}^s_{y,l}$ $= C^f_{y,l} / \sum_l C^f_{y,l}$ is the model predicted proportion of fish caught in year y of length l in dataset s, where f is the appropriate fleet; and

σ^s_{cal} is the standard deviation associated with dataset s, estimated in the fitting procedure by:

$$\sigma^s_{cal} = \sqrt{\sum_y \sum_l p^s_{y,l}\left(\ln p^s_{y,l} - \ln \hat{p}^s_{y,l}\right)^2 / \sum_y \sum_l 1} \tag{A.22}$$

Note that allowance is made for a minus group (fish 19cm and smaller) and a plus group (fish 40cm and larger), and length classes are specified with intervals of 2cm.

A.3.3 Stock-recruitment residuals

It is assumed that these residuals are log-normally distributed and are not serially correlated. Therefore, the contribution to the (penalised) negative log-likelihood function is given by:

$$-\ln L = \sum_y \frac{\varsigma_y^2}{2\sigma_R^2} \tag{A.23}$$

where σ_R is the standard deviation of the log residuals, which is assumed to be equal to 0.3.

A.4 Input parameters

The input parameters are set to take the following values:

M natural mortality, equal to 0.3 yr^{-1};

S^p_a selectivity-at-age values used for the pelagic fleet, which are listed in Table A.1;

w_a start-of-year mass of a horse mackerel of age a, which is listed in Table A.1;

$w_{a+\frac{1}{2}}$ mid-year mass of a horse mackerel of age a, which is listed in Table A.1;

a_m age of sexual maturity, equal to 2 years;

h the steepness of the stock-recruit relationship, is taken to be either 0.6 or 0.9; and

q_{aut} catchability coefficient of the Autumn demersal survey, is considered to be either 1 or 0.5.

a	S_a^p 1948-1962	S_a^p 1963-1967	S_a^p 1968+	w_a (g)	$w_{a+\frac{1}{2}}$ (g)
0	0.00	0.14	0.28	1.82	8.74
1	0.00	0.50	1.00	22.57	43.80
2	0.30	0.40	0.50	72.14	106.83
3	1.00	0.50	0.00	146.88	191.20
4	0.50	0.25	0.00	238.71	288.41
5	0.50	0.25	0.00	339.40	390.88
6	0.25	0.13	0.00	442.17	492.73
7	0	0.00	0.00	542.11	589.96
8	0	0.00	0.00	636.01	680.06
9	0	0.00	0.00	722.00	761.75
10+	0	0.00	0.00	799.27	834.57

Table A.1: Pelagic fishery selectivity-at-age (Johnston and Butterworth, 2007) and weight-at-age vectors. Note that, as was the case for the 2007 assessment, there are three pelagic selectivity vectors for three different periods.

Appendix B

GLM standardised CPUE series

Observer data, provided by Jan van der Westhuizen (pers. commn), cover a variety of vessels and fisheries. However, the *Desert Diamond* has accounted for the vast majority (81%, by mass) of the horse mackerel caught since 2003. Therefore, this GLM uses only data recorded by the *Desert Diamond*, a midwater trawl vessel, which covers the years 2003-2010. The aim is to produce a reliable CPUE series that can be used to when fitting the horse mackerel assessment model.

Method

To provide insight into the relationship between CPUE and each effect considered, the mean marginal CPUE was calculated at different levels of each effect and plotted. The marginals suggest that there are linear relationships between CPUE and depth, wind speed and the percentage of the moon visible; therefore, these effects are treated as continuous explanatory variables. The other effects are not related to CPUE in a simple manner, so their ranges are split into intervals where necessary to reflect changes, and they are treated as categorical variables.

The trawl data indicates that the *Desert Diamond* heavily targets two separate regions, one offshore of Mossel Bay and the other offshore off Port Elizabeth (Fig. B.1). Therefore, possible interactions between the region fished, can be specified by longitude, and other effects were considered. Depth was the only effect which was found to differ significantly between regions (Fig. B.2), thus an interaction between depth and longitude is included in the GLM.

Therefore, the GLM assumes that:

$$\log(\mathrm{CPUE}+\delta) = (b_1 + \mathrm{dep.long}) \times \mathrm{depth} + b_2 \times \mathrm{wind\_speed} + b_3 \times \mathrm{lunar\_phase} + \mathrm{year} + \mathrm{month} + \mathrm{time} + \mathrm{longitude} + \mathrm{wind\_dir} + \mathrm{constant}$$

where:

CPUE is the catch per unit effort for the trawl:

$$\mathrm{CPUE} = \mathrm{catch}/(\mathrm{trawl\_time} \times \mathrm{trawl\_speed} \times \mathrm{vertical\_opening}),$$

where catch is the mass of the horse mackerel caught, trawl_time is the duration of the trawl, trawl_speed is the speed of the vessel during the trawl and vertical_opening refers to the size of the opening of the trawl net;

δ is equal to $\alpha \times \overline{\mathrm{CPUE}}$, where α=0.05, and is added to avoid the problem of taking the logarithm of zero when no horse mackerel catch was reported for the trawl;

b_1 is the regression coefficient associated with depth;

$\mathrm{dep.long}$	is the interaction of longitude and the depth effect;
b_2	is the regression coefficient associated with $\mathrm{wind\_speed}$ in Beaufort scale;
b_3	is the regression coefficient associated with $\mathrm{lunar\_phase}$;
depth	is the depth of the trawl in metres;
$\mathrm{wind\_speed}$	is the wind speed in Beaufort scale, as estimated by an onboard observer;
$\mathrm{lunar\_phase}$	is the percentage of the moon that is lighted;
year	is the effect due to the year;
month	is the effect due to the month;
time	is the effect due to the time of day, taken as the time midway through the trawl;
$\mathrm{longitude}$	is the effect due to the longitude, taken as the average of the starting longitude and ending longitude of the trawl;
$\mathrm{wind\_dir}$	is the effect due to the wind direction during the trawl; and
$\mathrm{constant}$	is the regression constant.

The choice of a small $\alpha = 0.05$ is somewhat arbitrary; therefore, to check that this choice is not of great importance, the resulting GLM standardised CPUE series are compared for $\alpha = 0.01$ and $\alpha = 0.075$ (Fig. B.3). An attempt was made to avoid this issue altogether by modelling CPUE with a Poisson distribution, however this model did not converge successfully.

Table B.1 summarises the effects and the estimates obtained for their values.

Results

The model used in the GLM was able to account for 21.6 percent of the variation of CPUE about its mean. Table B.1 gives the estimated slope parameters for the continuous variables and the estimated effect size for the categorical variables, as well the associated standard errors. Figures B.2 and B.3 show comparisons between mean marginal CPUE and GLM standardised CPUE for depth and year, respectively. A standardised CPUE series is produced by setting all effects in the GLM, apart from effect of interest, to a constant reference level. Thus, as the effect of interest is varied, all changes to the CPUE are attributable to that effect. Note that marginal and standardised results can differ because of the impacts of other effects. Figure B.4 shows diagnostic plots of the standardised residuals.

Discussion

Upward trends in both the marginal CPUE and GLM standardised CPUE (Fig. B.3) are encouraging and consistent with abundance estimates from demersal surveys (Figure 4), which indicate a recent increase in exploitable biomass. It is also apparent from Figure B.3 that the choice of α within a reasonable range has negligible effect on the standardisation results. Furthermore, the absence of a systematic pattern in the residuals and the close match to a normal distribution provides support for the model used (Fig. B.4).

Demersal surveys do not reflect the pattern in trawling locations that is clear from the trawling data (Fig. B.1). Conversations with trawler captains suggest that the regions offshore of Mossel Bay and Port Elizabeth are targeted as they are believed to have high horse mackerel densities. Therefore, it is concerning that demersal surveys do not indicate higher horse mackerel CPUEs in these heavily targeted regions or lower CPUEs off Tsitsikamma. The disparity between commercial and survey data may, in part, be due to the fact that the surveys are demersal, while the commercial data are taken from a midwater vessel. The absence of surveys in the heavily targeted region at about 200m offshore of Mossel Bay (as this area is not amenable to demersal trawls) calls into question the assumption that q_{aut}, the catchability coefficient of the Autum demersal survey, falls somewhere between 0.5 and 1.

Type	Effect	Level	Estimate	Standard error	Significant
continuous	depth	west of 23.4°E	0.00037	0.00064	
		east of 23.4°E	-0.0057	0.0013	
	wind speed	-	0.025	0.012	*
	% moon visible		-0.15	0.049	*
categorical	year	2003	0	-	-
		2004	-0.16	0.093	
		2005	0.14	0.094	
		2006	0.24	0.096	*
		2007	0.56	0.095	*
		2008	0.25	0.097	*
		2009	0.37	0.097	*
		2010	0.50	0.098	*
	month	Jan	0	-	-
		Feb	0.19	0.088	*
		Mar	0.093	0.084	
		Apr	-0.0028	0.085	
		May-Sep	-0.28	0.069	*
		Oct	-0.058	0.087	
		Nov	0.13	0.084	
		Dec	0.23	0.083	*
	time of day	00:00-01:00	0	-	-
		01:00-02:00	-0.19	0.10	
		02:00-03:00	-0.38	0.095	*
		03:00-12:00	-0.69	0.076	*
		12:00-13:00	-0.55	0.19	*
		13:00-14:00	-0.60	0.20	*
		14:00-15:00	-0.38	0.19	*
		15:00-16:00	-0.27	0.22	
		16:00-17:00	-0.14	0.20	
		17:00-18:00	-0.018	0.22	
		18:00-19:00	0.78	0.16	*
		19:00-20:00	0.53	0.094	*
		20:00-21:00	0.32	0.085	*
		21:00-22:00	0.021	0.088	
		22:00-23:00	-0.12	0.098	
		23:00-24:00	0.027	0.10	
	longitude	west of 23.4°E	0	-	-
		east of 23.4°E	0.073	0.16	
	wind direction	45°-225°	0	-	-
		225°-45°	-0.087	0.036	*

Table B.1:Summary of effects included in the model and the associated estimated values. Effects significant at the 5% level are shown by *.

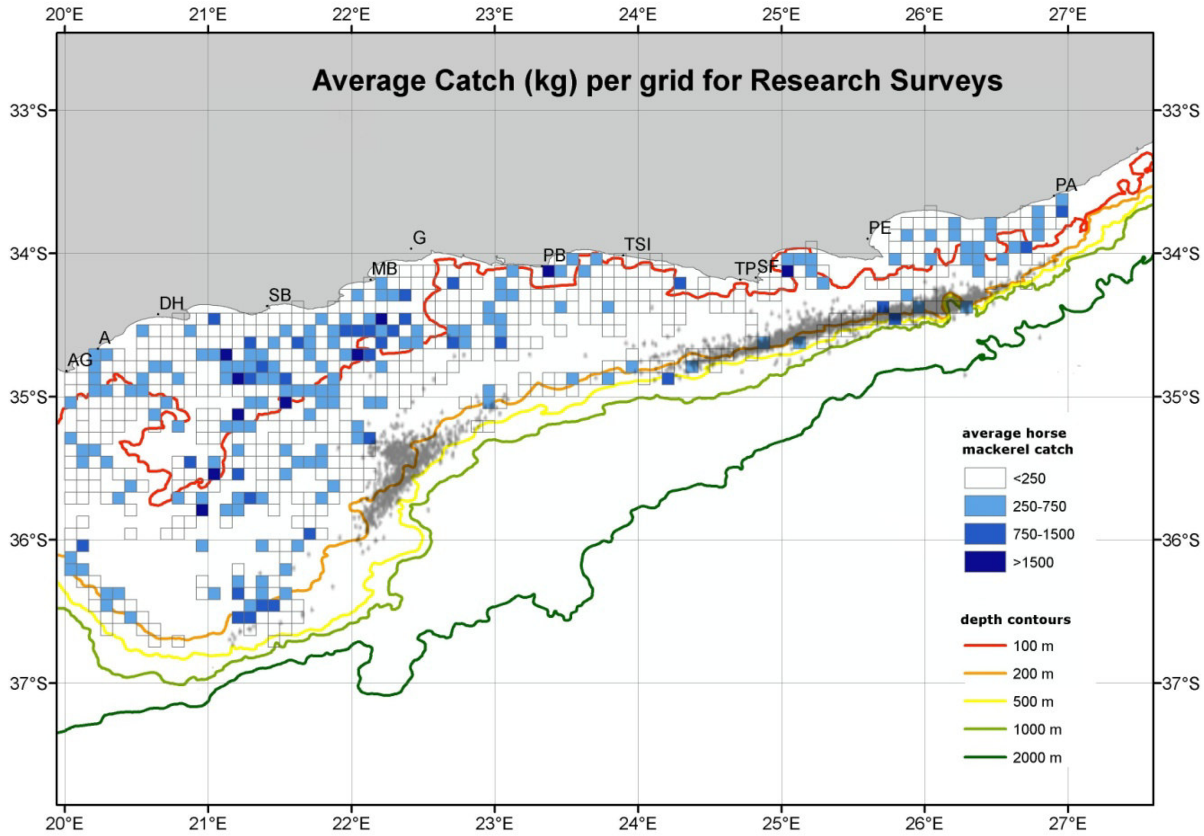

Figure B.1: Correspondence between *Desert Diamond* trawl locations and demersal survey average horse mackerel catches (with standardised effort) over the last decade. *Desert Diamond* trawl locations are marked by semi-transparent grey dots.

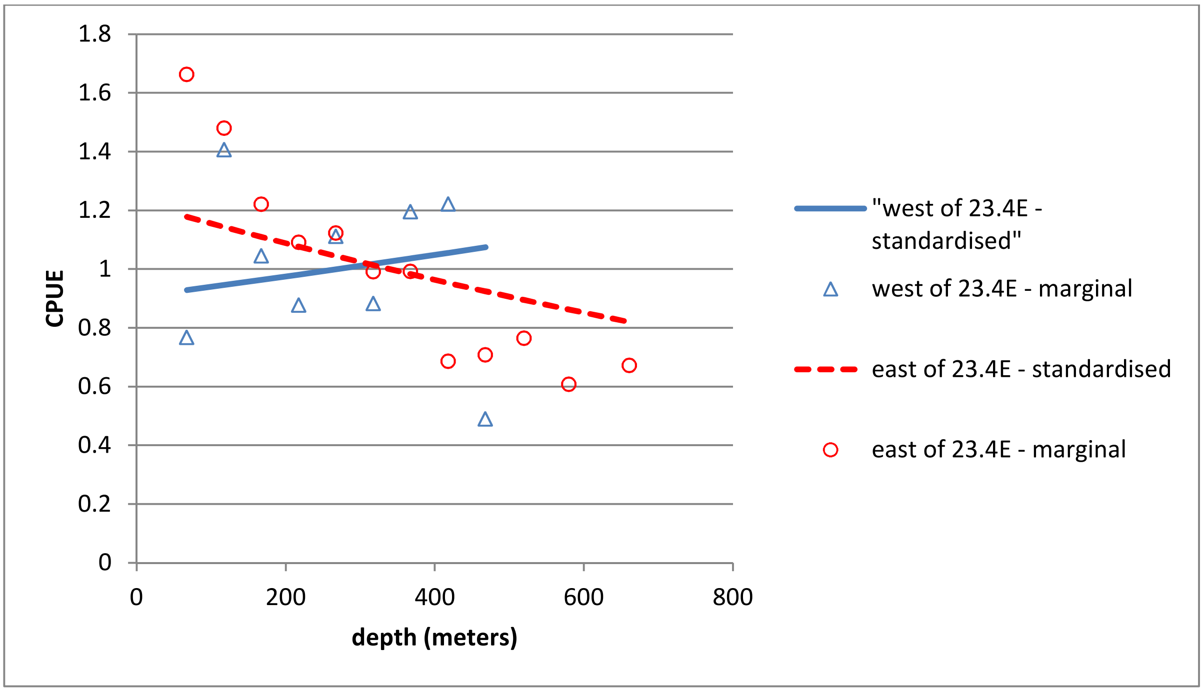

Figure B.2: Comparison between mean marginal CPUE and standardised CPUE at various depths for the two fishing regions.

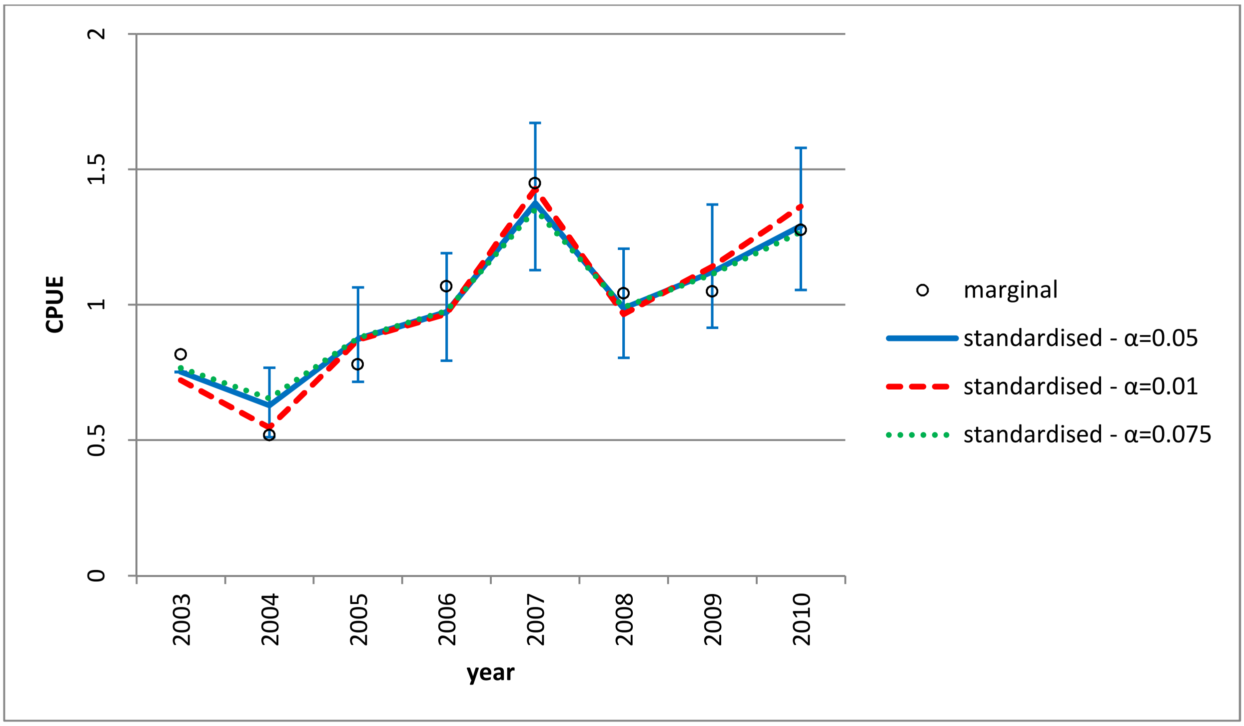

Figure B.3: Comparison between mean marginal CPUE and standardised CPUE for each year. The standardised CPUE series is shown for different values of α. Error bars indicate the 95% confidence interval of the standardised CPUE series (relative to the 2003 value) for $\alpha = 0.05$, as this is the series which is used in the assessment.

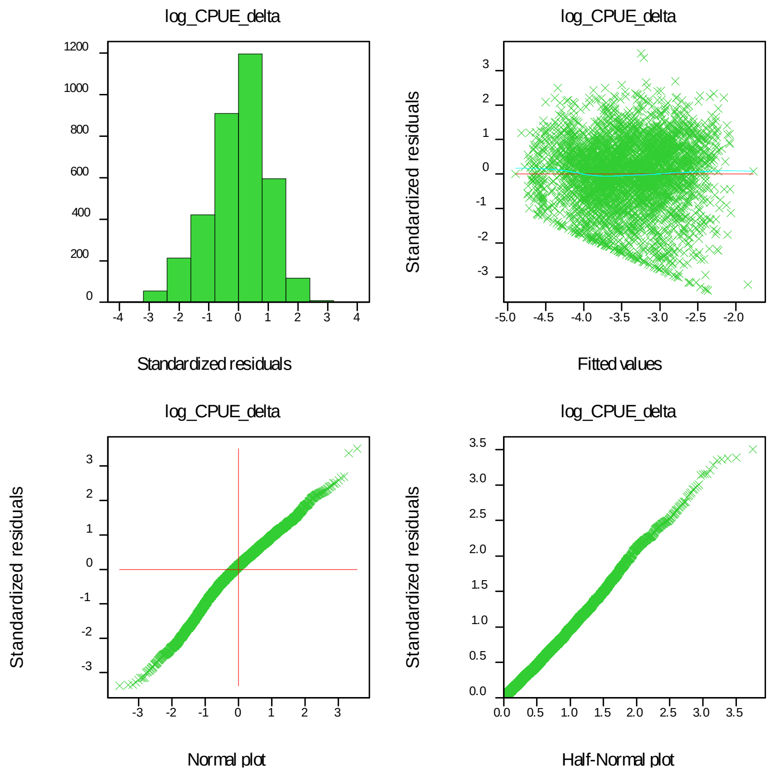

Figure B.4: Diagnostic plots of standardized residuals.