AN UPDATED ASSESSMENT OF THE SOUTH AFRICAN KINGKLIP RESOURCE INCLUDING SOME SENSITIVITY TESTS

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ABSTRACT

The deterministic Age-Structured Production Model (ASPM) assessment of the kingklip resource by Mori and Butterworth (2002) is updated to take account of further catch and abundance survey data that have since become available for the years 2000 to 2007. The assessment is conducted for the West coast and the South coast separately, and compared to a retrospective model fit up to 1999. The model is fit to two different sources of data: the trawl abundance surveys, and the CPUE series for both trawl and longline catches. When steepness h is set to 0.5, the spawning biomass of the West coast component shows a recovery since 1992; however, that of the South coast component shows a continuing decrease since 1995. The spawning biomass relative to its unexploited equilibrium level (B_{sp}/K_{sp}) for the South coast is 0.12 for the base case scenario (h = 0.5). This is a consequence of the continued high catches by the trawl fishery over the last decade on the South coast, though these have declined more recently. These analyses suggest that, if the South coast component of the resource is an isolated stock, then annual South coast catches by the trawl fishery would need to be reduced to below 1 000 tons at least for sustainability. Several sensitivity tests were conducted for the South coast base case scenario, however there is no substantial impact on the estimated status of this component of the kingklip resource. The resource is assessed as a single stock through the crude approach of summarising survey estimates for the two coasts; this unexpectedly leads to estimated status which is better than that for either coast considered separately. This result suggests the need for further investigations using both more elaborate modelling assumptions and further data, and some specific suggestions are made in this regard.

INTRODUCTION

South African kingklip landings currently constitute a proportion of the by-catch from hake-directed trawls off the West and South coasts. A directed longline fishery for this species had existed since 1983, before it was terminated in 1990. Since that date longline catches have been restricted to by-catch from hake-directed longlining. A concern for this resource is the continued high kingklip by-catch in the hake-directed trawl fishery, particularly on the South coast, though this has reduced somewhat over recent years.

This paper updates the assessment of the kingklip resource for the South and West coasts separately that was presented by Mori and Butterworth (2002). Further data inputs available are taken into account and some corrections to data as previously advised are incorporated as well. All available indices of abundance are taken into account, and deterministic projections under various levels of constant catch are reported.

Several sensitivities tests of the base case model are performed, as outlined in a subsequent section, to investigate the implications for the status of the resource if certain assumptions are modified.

DATA

Catch Data

Total annual catches of kingklip for the West and South coasts from hake-directed trawls over the period 1932–2006 and from hake-directed longliners for the periods 1983–2006 are shown in Table 1 and Figure 1. The total annual catches for 2007 were not available for the present analysis; however, to be able to include the information from surveys for 2007, the assumption was made to set the total annual catches for 2007 to be the same as for 2006.

For the years 1932 to 1991 the catch data used are from Punt and Japp (1994). The trawl catch extends over the period 1932 to 1991 and longline catch from 1983 to 1990 for each of the West and South coasts. In the previous assessment (Mori and Butterworth, 2002) catch data from 1992 to 1999 were scaled versions of the trawled kingklip catch obtained from the hake-directed trawl catch and effort data from deep-sea operations from 1978 to 1999 (Marine and Coastal Management: R. Leslie, pers. commn). The scaling was obtained from a comparison of data from the two sources in overlapping years (1978-1991). The MCM hake-directed trawl catch data were found to be an underestimate of the total catch indicated by Punt and Japp (1994). An average scaling factor was obtained over these years to estimate the amount by which the recorded catches differ. The total trawl catch from 1991 to 1999 was then estimated by multiplying the MCM hake-directed trawl catch database values by this scaling factor. Upon re-extracting the catch data for the present assessment, differences in splitting catches between the West and South coasts for this period were found (Marine and Coastal Management: R. Leslie, pers. commn). In this paper the new annual catches for the 1991–1999 period are used.

Survey abundance data

Survey abundance data for each of the West and South coasts from 1986–2007 obtained from Marine and Coastal Management are used (Table 2). The West coast surveys were carried out in Jan/Feb (summer) and Jul/Aug (winter) for 1986 to 1990, and thereafter for summer only. No surveys for either coast were conducted in 1998. An error has been found in the survey abundance indices for the South coast that were used in Mori and Butterworth (2002). Previously no distinction had been made between surveys that surveyed the coast up to 200m and those that surveyed the coast up to 500m. The choice made here between using abundance indices for the 200 or 500m coastal area was based on selecting the longest series. Thus, for the South coast surveys conducted in May/June (autumn) a 500m coastal area was selected, while for those in Sept/Oct (spring) a 200m coastal area was chosen.

For the one stock hypothesis, one survey abundance series in each year was considered. This series was obtained by adding the West coast summer survey estimate to that from the South coast autumn survey, thus using the longest series from each coast.

CPUE data

CPUE abundance data for the years 1983 to 1991 for the trawl and longline fisheries from Punt and Japp (1994) are used (see Table 3). Recent attempts to develop CPUE index for kingklip from trawl fishery data have been unsuccessful thus far because of problems in distinguishing directed from incidental catches.

THE MODEL

The Age-Structured Production Model (ASPM) used is as in Mori and Butterworth (2002), which is similar to the one used by Punt and Japp (1994). Detailed specification of the model is given in the Appendix. The biological parameters used in the assessment are those used by Punt and Japp (1994). These values, including those for selectivity, are listed in Table 4.

The "base case" scenario assumes a steepness parameter (h) value of 0.5, as assumed in Punt and Japp (1994). However, because of uncertainty in the value of this parameter, a sensitivity test setting this parameter to 0.75 (a default frequently used internationally, e.g. in CCAMLR) was conducted.

The following further sensitivity tests were carried out, the first three for the South coast only:

- omit CPUE data from the model fitting procedure,
- incorporate additional variance for the survey abundance indices,
- differentiate between the different gear types (old or new) and between vessels (the *Africana* or the *Nansen*) used during the surveys, and
- consider a one stock hypothesis.

In order to assess the current stock level, and to be able to compare it with the understanding in 2002, but now using the same historical data as in the "base case", the assessments were also fitted to the updated data up to 1999 only as in Mori and Butterworth (2002).

Deterministic projections for various catch scenarios have been conducted for the "base case" scenario, and the sensitivity case. The longline catch is fixed at its average value over 2002–2006, and projections consider different levels of trawl-caught kingklip.

RESULTS

The assessment of kingklip conducted by Punt and Japp (1994) estimated the component on the West coast to be severely depleted compared to the South coast. A subsequent assessment by Mori and Butterworth (2002) showed the depletion level of the South coast component to be severe, and the West coast component is to be gradually recovering. The large depletion of the South coast arose because of the increase in trawl catches on the South coast since 1990, which is the year the longline fishery terminated (Figure 1).

The analyses conducted in this paper show the same pattern as observed by Mori and Butterworth (2002), both when further data are taken into account as well as when the assessment model is fitted to the updated data until 1999 only (Table 5). The current assessment estimates the depletion (B_{sp}/K_{sp}) at the beginning of 2007 for the South coast at 12% of the pre-exploitation abundance, just slightly higher than the estimated 11% when the model is fitted to only data up to 1999 (see below re retrospective pattern implications). For the West coast, this depletion is estimated at 47%. The q estimates for the surveys are all less than 1, suggesting considerable underestimation of biomass in absolute terms by the swept-area method.

The fits of the base case model to the various abundance indices available are shown in Figures 2a–b for the West coast, and Figures 3a–b for the South coast for each assessment (i.e. data up to 1999 and data up to 2007). The assessments to the data up to 1999 show results extended to 2007 under the subsequent catches that actually occurred. The current assessment shows that all of the abundance indices for the West coast suggest a slight recovery (Figure 2b). On the other hand, for the South coast, the abundance indices show a recovery from 1991 to 1994, probably because of the termination of longline fishery; however, since 1995, the abundance indices fall substantially due to the increased trawl by-catch in recent years (Figure 3a–b). The retrospective model fit shows the stock to collapse by 2002 in the South coast under the actual catches taken, suggesting that the model is giving a somewhat pessimistic view of the current status of this component, though the decline over the past decade is clear.

The trajectories for depletion (B_{sp}/K_{sp}) and the spawning biomass (B_{sp}) for the base case (h = 0.5) with 95% confidence intervals are shown for both assessments in Figures 4a–b for both the West and South coasts.

Projections under various constant trawl catch scenarios for the base case (h = 0.5) are shown in Figure 5. Future constant catch levels for the longline fishery have been kept at the average of the past five years (2002–2006). These average longline catches are 250 tons for the West coast and 150 tons for the South coast. Projections with 95% confidence intervals are also shown for future constant catches for the trawl fishery set at the annual average for the past five years (1 400 tons for the West coast and 2 600 tons for the South coast). A constant future catch at this level for the West coast shows a slight increase in abundance. However, for the South coast, when considered to be an isolated stock, downward trends continue even for catches reduced to 1 000 tons. This indicates that the recent average trawl catch level of 2 600 tons on the South coast is considerably above a sustainable level.

Figure 6 shows twenty year projections of the kingklip abundance on both the West and the South coast for the sensitivity test (h = 0.75). To ease comparison, the base case (h = 0.5) projections are also shown. Future constant catches for each coast are set to be the average of the past five years of each respective fishery. The change in the value of h scarcely affects projection trends.

Table 6 gives the results for the various sensitivity tests conducted for the South coast component of the kingklip resource. Results for the base case model are repeated here to facilitate comparisons. There are no substantial differences in the status of the South coast component of kingklip under these sensitivity tests. An additional variance of 0.37 and 0.42 for the spring and summer surveys respectively is estimated by the model. The sensitivity test that takes into account the different gear types and the different vessels used by the surveys does however estimate catchability coefficients that are quite different depending on gear type and between the *Africana* and the *Nansen* (Table 6).

The one stock hypothesis results in a much more optimistic status of the kingklip resource (Table 6) in contrast to the two stock hypothesis, even compared to the West coast stock alone. This is not what might be expected, and suggests a need for further investigation, and in particular for a more refined consideration of data from the surveys on the two coasts than simply adding them together because of the possibilities of differences in catchability and annual migration patterns which need to be taken into account.

Further work could consider:

a) fitting also the survey length information, and allowing for variation about the deterministic stock-recruitment relationship assumed; and
b) a single stock model with different selectivities/catchabilities on the West and South coasts to allow for seasonal migration impacts on the abundance in each region.

ACKNOWLEDGEMENTS

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Table 1. Yearly catches (in tons) of kingklip taken by the trawl and longline fisheries on the West and South coasts of South Africa (R. Leslie, pers. commn).

Year	West coast		South coast		Year	West coast		South coast	
	Trawl	Longline	Trawl	Longline		Trawl	Longline	Trawl	Longline
1932	480	0	120	0	**1970**	1 740	0	1 160	0
1933	320	0	80	0	**1971**	2 940	0	1 960	0
1934	320	0	80	0	**1972**	3 120	0	2 080	0
1935	560	0	140	0	**1973**	3 480	0	2 320	0
1936	560	0	140	0	**1974**	2 093	0	1 395	0
1937	560	0	140	0	**1975**	2 149	0	1 433	0
1938	560	0	140	0	**1976**	1 520	0	1 951	0
1939	560	0	140	0	**1977**	1 690	0	1 000	0
1940	560	0	140	0	**1978**	2 030	0	2 280	0
1941	480	0	120	0	**1979**	2 369	0	2 243	0
1942	480	0	120	0	**1980**	3 147	0	2 146	0
1943	480	0	120	0	**1981**	2 621	0	1 491	0
1944	480	0	120	0	**1982**	2 000	0	1 131	0
1945	1 040	0	260	0	**1983**	1 983	842	1 432	200
1946	800	0	200	0	**1984**	2 159	1 881	1 433	1 159
1947	880	0	220	0	**1985**	1 400	1 314	2 000	5 656
1948	1 200	0	300	0	**1986**	1 709	1 231	977	7 453
1949	1 260	0	540	0	**1987**	1 676	1 948	799	4 504
1950	1 330	0	570	0	**1988**	1 264	2 091	663	3 311
1951	1 680	0	720	0	**1989**	1 144	1 607	486	2 209
1952	1 960	0	840	0	**1990**	740	557	528	708
1953	1 890	0	810	0	**1991**	973	0	978	0
1954	1 400	0	600	0	**1992**	1 517	0	1 043	0
1955	1 610	0	690	0	**1993**	1 947	0	1 144	0
1956	1 400	0	600	0	**1994**	1 183	92	1 822	48
1957	1 050	0	450	0	**1995**	1 480	65	1 658	48
1958	1 190	0	510	0	**1996**	1 191	170	2 386	60
1959	1 400	0	600	0	**1997**	1 465	155	2 635	120
1960	1 050	0	450	0	**1998**	1 387	53	1 611	87
1961	1 470	0	630	0	**1999**	1 352	141	2 489	171
1962	1 190	0	510	0	**2000**	1 507	199	2 142	103
1963	1 260	0	540	0	**2001**	1 747	183	3 166	57
1964	980	0	420	0	**2002**	1 586	312	3 440	202
1965	1 750	0	750	0	**2003**	1 267	317	3 162	160
1966	2 220	0	1 480	0	**2004**	1 473	266	2 889	141
1967	1 920	0	1 280	0	**2005**	1 561	255	2 086	121
1968	1 740	0	1 160	0	**2006**	1 111	82	1 635	101
1969	1 740	0	1 160	0	**2007**	1 111†	82†	1 635†	101†

† Catch data for 2007 assumed to be the same catch as for the previous year.

Table 2. Abundance indices of kingklip in tons together with CVs obtained from surveys (separated by season) for the West and South coasts of South Africa. Values in bold denote abundance estimates obtained using the new rather than the old gear on *Africana*, while italicised values denote abundance estimates obtained from surveys carried out on the *Nansen*.

Year	West coast				South coast				Coasts combined	
	Jan/Feb (summer)		Jul/Aug (winter)		Sep/Oct (spring) (0 – 200 m)		May/Jun (autumn) (0 – 500 m)			
	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV
1986	3 749	0.159	2 917	0.156	4 800	0.229			3 749	0.159
1987	2 883	0.184	5 800	0.250	3 551	0.172			2 883	0.184
1988	6 154	0.199	1 651	0.266			6 373	0.450	12 527	0.249
1989			997	0.324						
1990	3 885	0.258	1 443	0.397	1 258	0.357			3 885	0.258
1991	3 468	0.306			1 992	0.248	8 140	0.148	11 608	0.138
1992	8 731	0.190			2 001	0.217	4 415	0.372	13 146	0.178
1993	10 155	0.180			1 210	0.205	10 047	0.392	20 202	0.215
1994	8 208	0.183			1 319	0.276	30 494	0.596	38 702	0.471
1995	7 642	0.256			1 290	0.434	19 606	0.408	27 248	0.302
1996	12 724	0.282					3 714	0.176	16 438	0.222
1997	7 023	0.218					5 077	0.257	12 100	0.166
1998										
1999	14 242	0.288					11 479	0.604	25 721	*0.313*
2000	*14 983*	*0.415*					*12 807*	*0.256*	*27 790*	*0.253*
2001	*8 780*	*0.264*			1 581	0.198			*8 780*	0.264
2002	12 763	0.159							12 763	0.159
2003	14 363	0.249			**1 735**	**0.352**	6 256	0.523	20 619	0.235
2004	**7 460**	**0.180**			**530**	**0.334**	**3 598**	**0.555**	**11 058**	**0.218**
2005	**5 699**	**0.156**					**4 133**	**0.759**	**9 832**	**0.332**
2006	9 485	0.359			1 966	0.433	2 213	0.378	11 698	0.300
2007	**5 604**	**0.224**			**729**	**0.298**	**4 118**	**0.391**	**9 722**	**0.210**

Table 3. Standardised commercial CPUE indices of relative abundance for kingklip for the trawl and longline fishery for the South and West coasts of South Africa. These data have been obtained from Punt and Japp (1994).

Year	West coast		South coast	
	Trawl	Longline	Trawl	Longline
1983	1.786		1.294	
1984	2.147	2.253	1.230	2.276
1985	2.193	1.302	1.250	3.082
1986	1.829	1.394	1.190	3.113
1987	1.530	1.300	0.906	2.397
1988	1.420	1.294	0.826	2.202
1989	0.897	1.234	0.763	1.551
1990	0.720	1.000	0.520	1.000
1991	1.000		1.000	

Table 4. Biological parameters values for kingklip for the West and South coasts of South Africa. Parameter values assumed for the trawl and the longline selectivity functions are also given. Note that for simplicity, maturity is assumed to be knife-edge in age. These values are as used by Punt and Japp (1994).

Parameter	West coast	South coast	Coasts combined
Natural mortality M (yr^{-1})	0.2	0.2	0.2
Von Bertalanffy growth			
L_∞ (cm)	129.2	136.0	132.6
κ (yr^{-1})	0.141	0.142	0.142
t_0 (yr)	-0.32	0.22	0.05
Weight (in gm) length relationship			
e (g.cm^{-1})	0.00083	0.00162	0.00132
f	3.41	3.26	3.31
Age of "plus group" (yr)	30	30	30
Age at maturity (yr)	5	5	5
Steepness parameter (h)	0.5	0.5	0.5
Selectivity parameters			
a_{50}^L (years)	5.5	5.5	5.5
a_{50}^T (years)	2.5	2.5	2.5
δ^L (years)	0.333	0.333	0.333
δ^T (years)	0.167	0.167	0.167
γ (year^{-1})	0.07	0.07	0.07

Table 5. Estimated model parameters for the base case model (h = 0.5) as well as for the sensitivity test with h = 0.75. Results for the base case are given when the model is fitted to data up to 1999 (as for the previous assessment) and for data up to 2007. The "current" year refers to the most recent year of the assessment (i.e. 1999 or 2007).

Parameter estimates	**West coast**			**South coast**		
	data up to 1999 (h=0.5)	**data up to 2007 (h=0.5)**	**data up to 2007 (h=0.75)**	**data up to 1999 (h=0.5)**	**data up to 2007 (h=0.5)**	**data up to 2007 (h=0.75)**
-ln L: Total	2.530	6.770	-2.466	-10.795	-6.987	-3.646
-ln L: Survey (summer/spring)	13.288	16.480	9.811	-1.327	3.644	5.220
-ln L: Survey (winter/autumn)	4.745	5.000	4.482	5.321	7.166	7.777
-ln L: CPUE (trawl)	-5.771	-5.462	-5.894	-11.287	-12.060	-12.561
-ln L: CPUE (longline)	-9.731	-9.247	-10.865	-3.501	-5.736	-4.082
K^{sp}	63 114	66 268	48 854	49 763	57 460	47 018
$B^{sp}_{current}$	25 287	31 018	21 888	5 396	7 144	4 519
$B^{sp}_{current}/K^{sp}$	0.401	0.468	0.448	0.108	0.124	0.096
K^{trawl}_{exp}	38 610	40 540	29 887	29 679	34 270	28 042
$B^{\exp,trawl}_{current}$	18 495	22 136	16 785	4 598	5 917	4 736
$B^{\exp}_{current}/K^{\exp}$	0.479	0.546	0.562	0.155	0.173	0.169
$q^{summer/spring}_{survey}$	0.367	0.352	0.315	0.248	0.146	0.639
$q^{winter/autumn}_{survey}$	0.143	0.126	0.128	0.855	0.493	0.384
σ^{trawl}_{CPUE}	0.319	0.331	0.526	0.173	0.159	0.150
$\sigma^{longline}_{CPUE}$	0.151	0.162	0.205	0.368	0.267	0.339
B^{sp}_{MSY}	27 423	28 794	18 243	21 924	25 315	18 063
$B^{\exp}_{MSY}$	19 673	20 657	14 140	15 152	17 496	13 378
$\mathrm{MSY}_{\mathrm{trawl}}$	2 531	2 657	2 739	1 915	2 212	2 509
$\mathrm{MSYL}_{\mathrm{trawl}}/K^{sp}$	0.435	0.435	0.373	0.441	0.441	0.384
$\mathrm{MSYL}_{\mathrm{trawl}}/K^{\exp}_{trawl}$	0.510	0.510	0.473	0.511	0.511	0.477

Table 6. Estimated model parameters for the base case model (h = 0.5) as well as for several sensitivity tests. The "current" year refers to the most recent year of the assessment (i.e. 2007). 95% confidence intervals calculated from the Hessian matrix are shown for some parameters.

Parameter estimates	South coast				Coasts combined (h=0.5)
	data up to 2007 (h=0.5)	Omit CPUE data (h=0.5)	Additional variance (h=0.5)	Differentiation of gear type and vessel (h=0.5)	
-ln L: Total	-6.987	10.805	-22.413	-12.683	57.151
-ln L: Survey (spring)	3.644	3.667	-3.399	3.091	57.151
-ln L: Survey (autumn)	7.166	4.139	-1.226	2.006	—
-ln L: CPUE (trawl)	-12.060	—	-12.048	-12.033	—
-ln L: CPUE (longline)	-5.736	—	-5.741	-5.746	—
K^{sp}	57 460 (55 647; 59 273)	57 546 (55 614; 59 478)	57 543 (55 695; 60 391)	57 640 (55 049; 60 231)	210 593 (88 153; 333 027)
$B^{sp}_{current}$	7 144 (3 664; 10 623)	7 308 (3 619; 10 997)	7 302 (1 864; 12 741)	7 487 (2 569; 12 405)	142 852 (12 334; 273 366)
$B^{sp}_{current}/K^{sp}$	0.124 (0.095; 0.153)	0.127 (0.096; 0.158)	0.127 (0.082; 0.172)	0.130 (0.050; 0.209)	0.678 (0.563; 0.793)
K^{trawl}_{exp}	34 270	34 321	34 319	34 377	126 666
$B^{\exp,trawl}_{current}$	5 917	6 034	6 030	6 163	92 627
$B^{\exp}_{current}/K^{\exp}$	0.173	0.176	0.176	0.179	0.731
q^{spring}_{survey} (old gear)	0.146	0.145	0.139	0.148	0.119
q^{spring}_{survey} (new gear)	—	—	—	0.119	—
q^{autumn}_{survey} (old gear)	0.493	0.490	0.550	0.440	—
q^{autumn}_{survey} (new gear)	—	—	—	0.581	—
q^{autumn}_{survey} (*Nansen*)	—	—	—	1.011	—
σ^{spring}_{add}	—	—	0.366	—	—
σ^{autumn}_{add}	—	—	0.422	—	—
σ^{trawl}_{CPUE}	0.159	—	0.159	0.159	—
$\sigma^{longline}_{CPUE}$	0.267	—	0.267	0.267	—
B^{sp}_{MSY}	25 315	25 353	25 351	25 394	92 481
$B^{\exp}_{MSY}$	17 496	17 522	17 521	17 550	64 697
MSY_{trawl}	2 212	2 215	2 215	2 219	8 212
$MSYL_{trawl}/K^{sp}$	0.441	0.441	0.441	0.441	0.439
$MSYL_{trawl}/K^{\exp}_{trawl}$	0.511	0.511	0.511	0.511	0.511

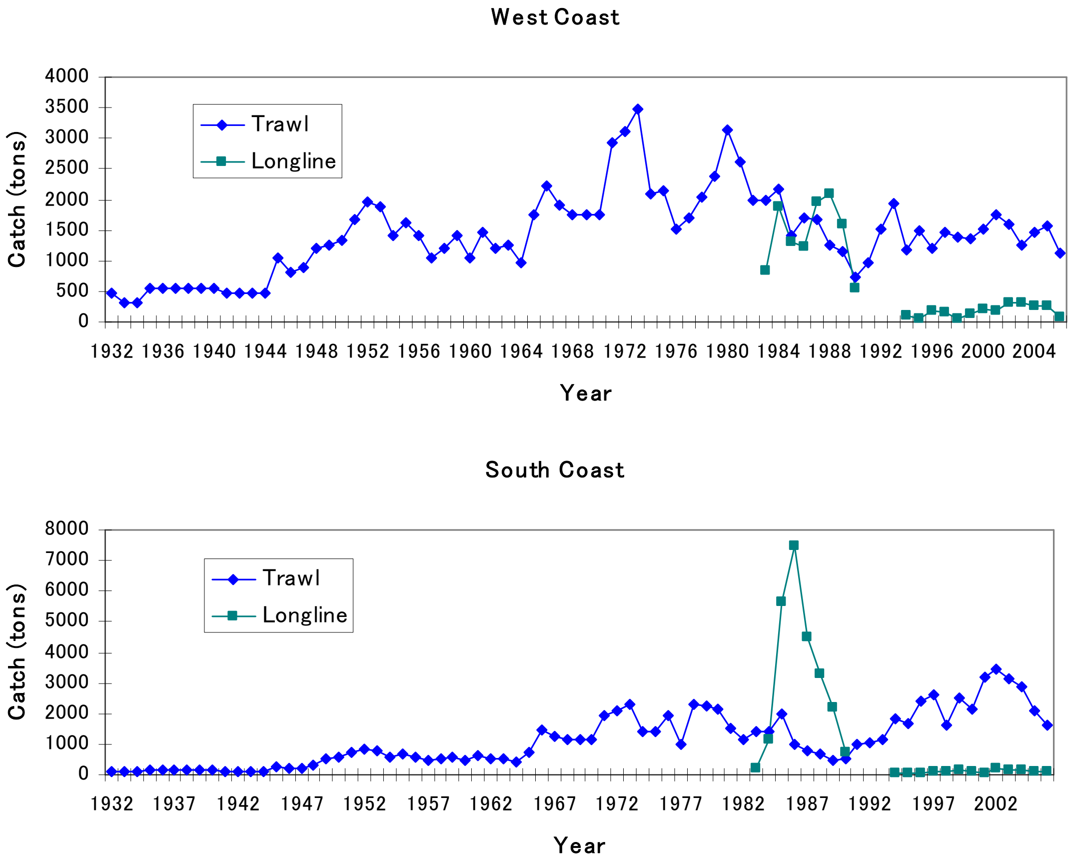


Figure 1. Historical catches of kingklip in the West and South coasts of South Africa separated by gear type (i.e. trawl or longline).

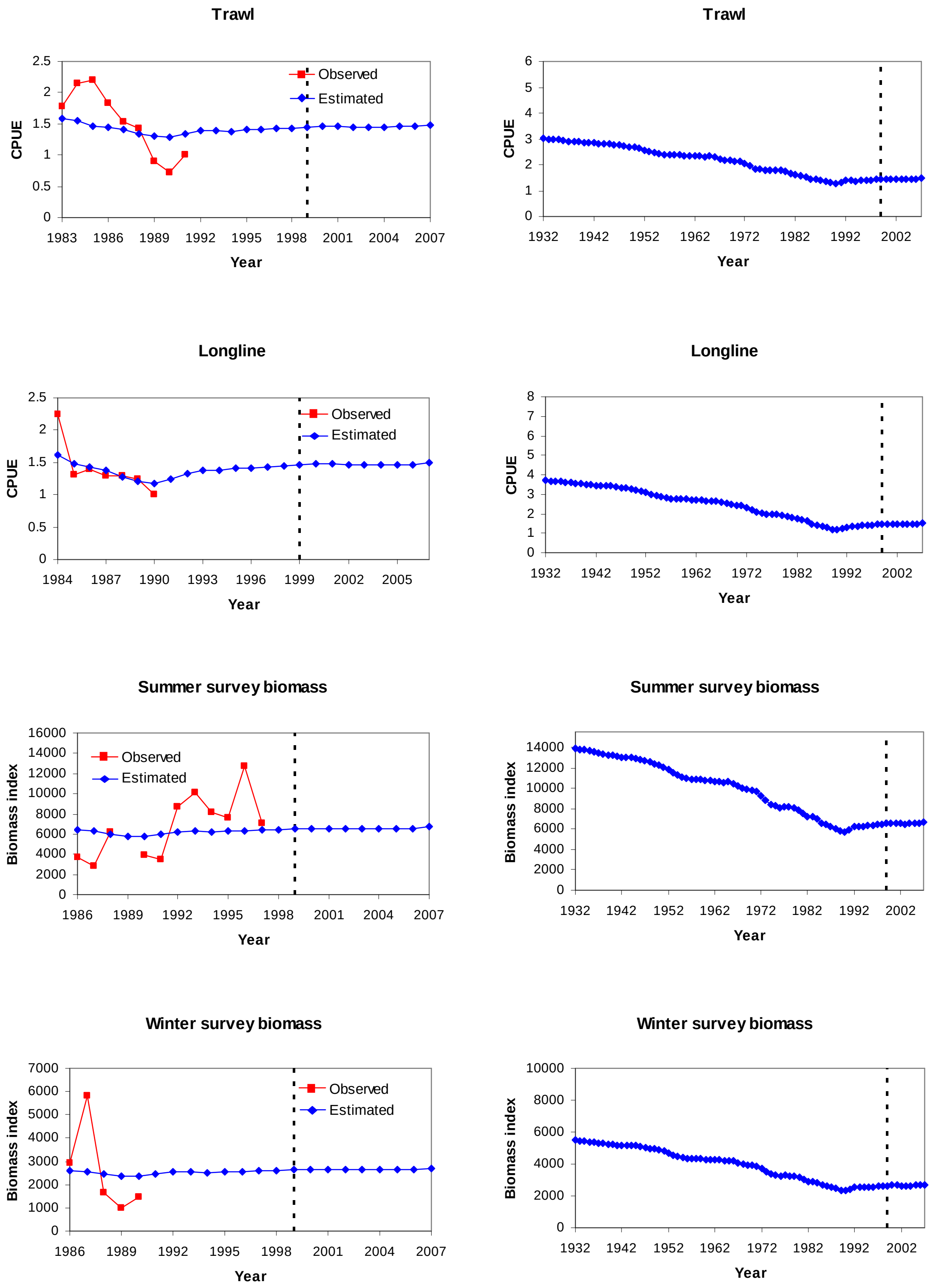


Figure 2a. Observed and estimated trend of abundance indices for the base case model (h = 0.5) fitted to data up to 1999 for the West coast of South Africa. Values on and after the dotted vertical line are projections for each series under subsequent catches.

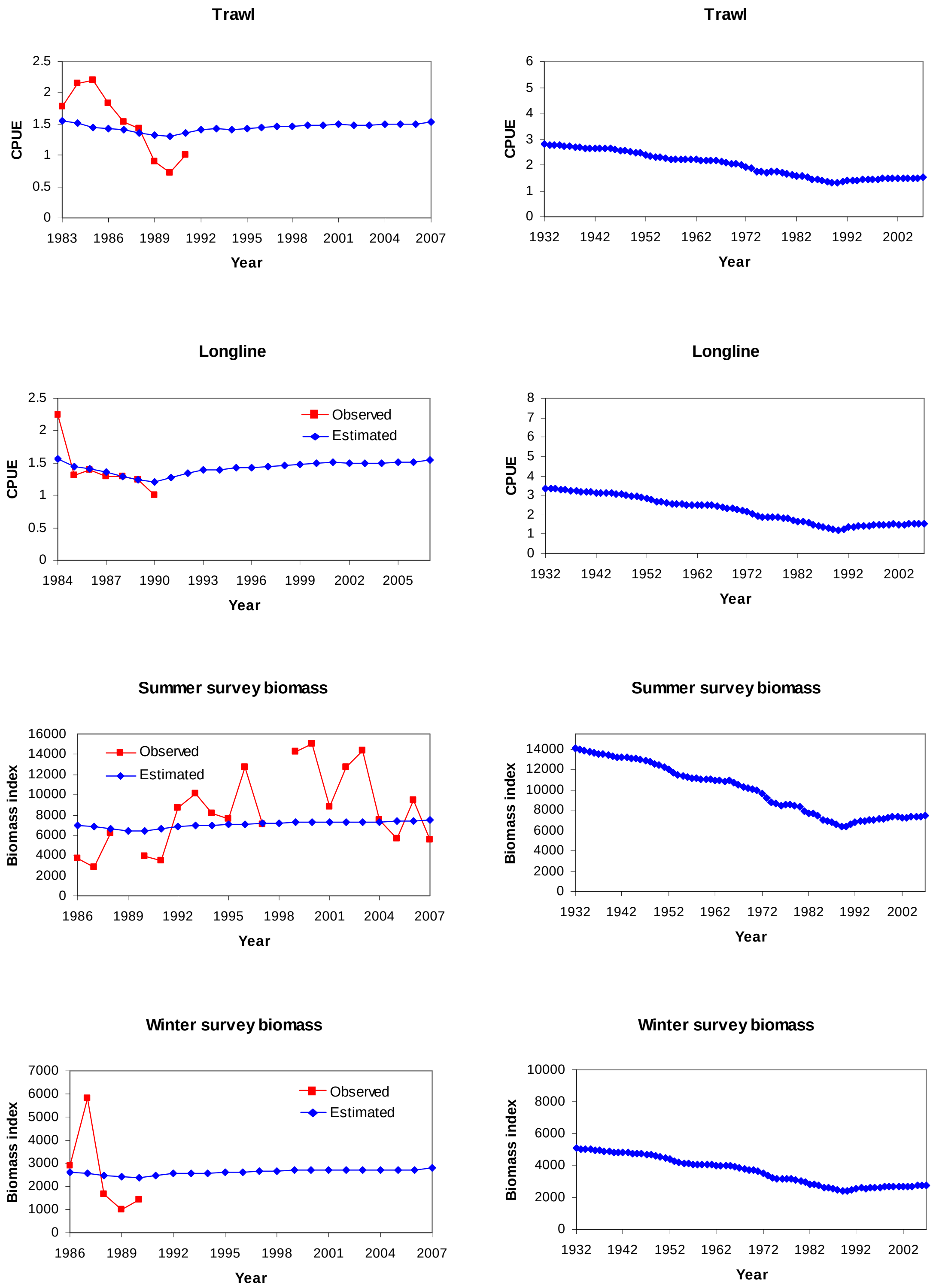


Figure 2b. Observed and estimated trend of abundance indices for the base case model (h = 0.5) fitted to data up to 2007 for the West coast of South Africa.

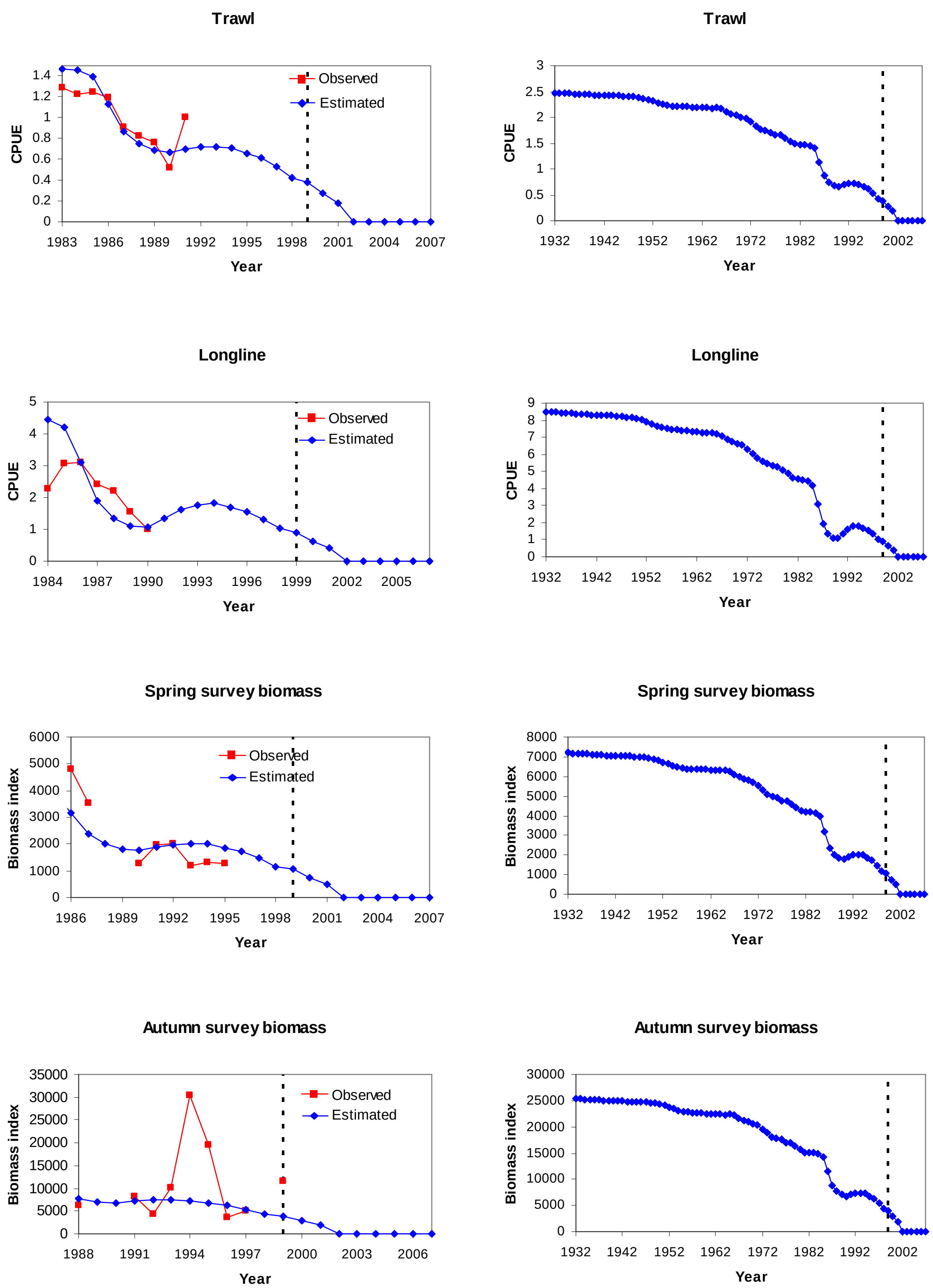


Figure 3a. Observed and estimated trend of abundance indices for the base case model (h = 0.5) fitted to data up to 1999 for the South coast of South Africa. Values on and after the dotted vertical line are projections for each series under subsequent catches.

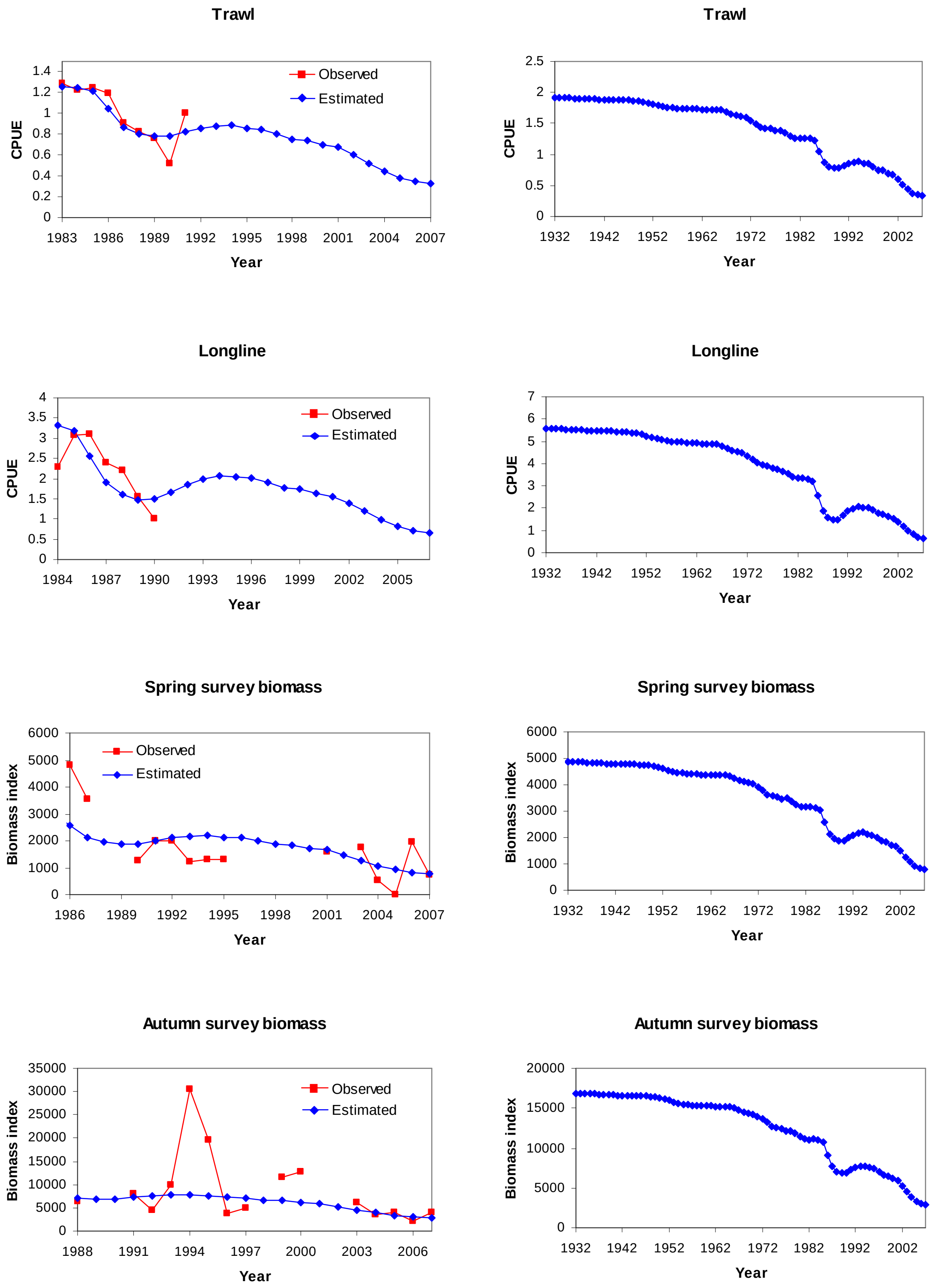


Figure 3b. Observed and estimated trend of abundance indices for the base case model (h = 0.5) fitted to data up to 2007 for the South coast of South Africa.

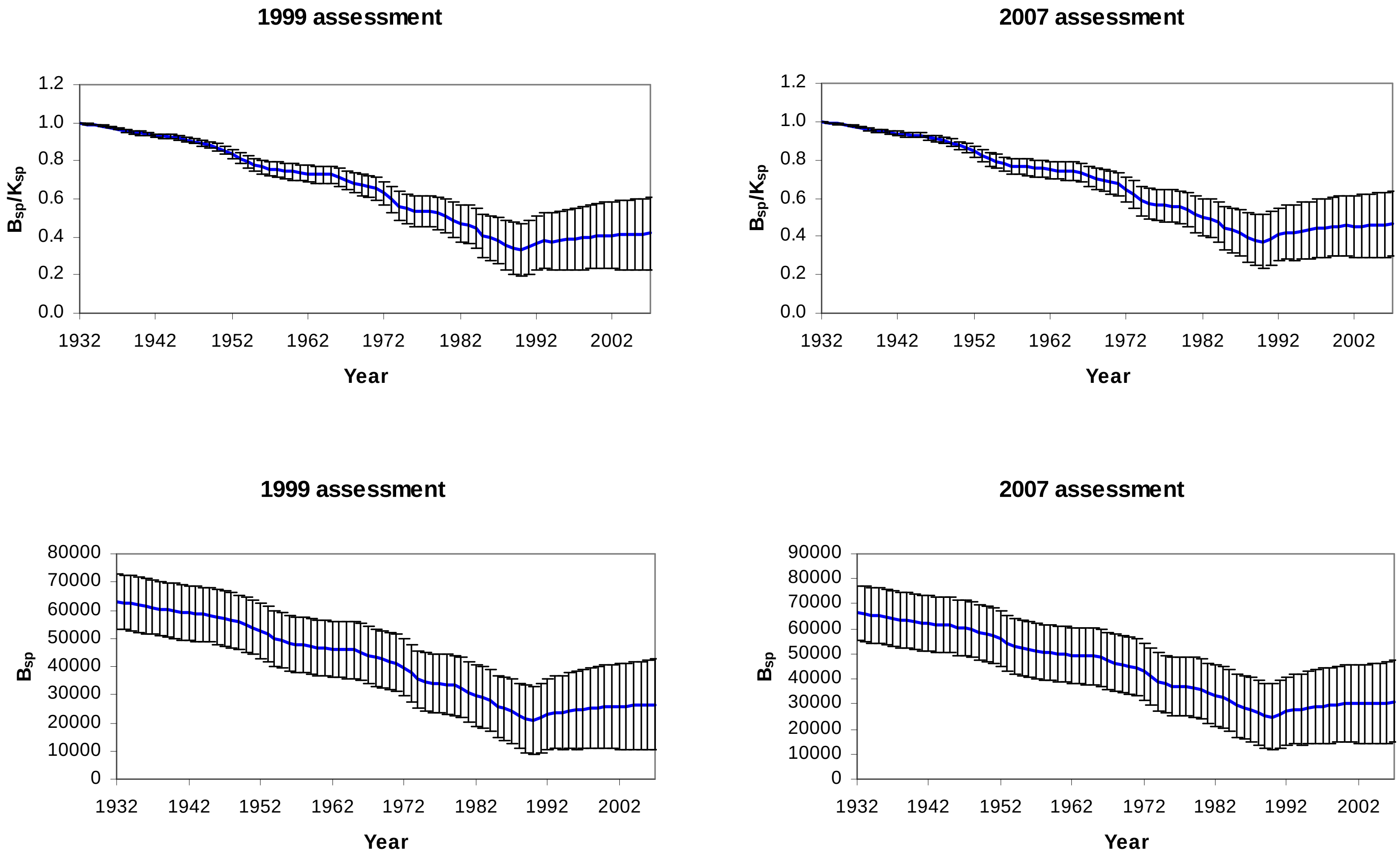


Figure 4a. Trajectories of spawning stock depletion (B_{sp}/K_{sp}) and spawning biomass (B_{sp}) estimates for kingklip for the West coast of South Africa for the base case model (h = 0.5), when the model is fitted to data up to 1999 (left hand side) and to data up to 2007 (right hand side). The error bars represent the 95% confidence intervals calculated from the Hessian matrix.

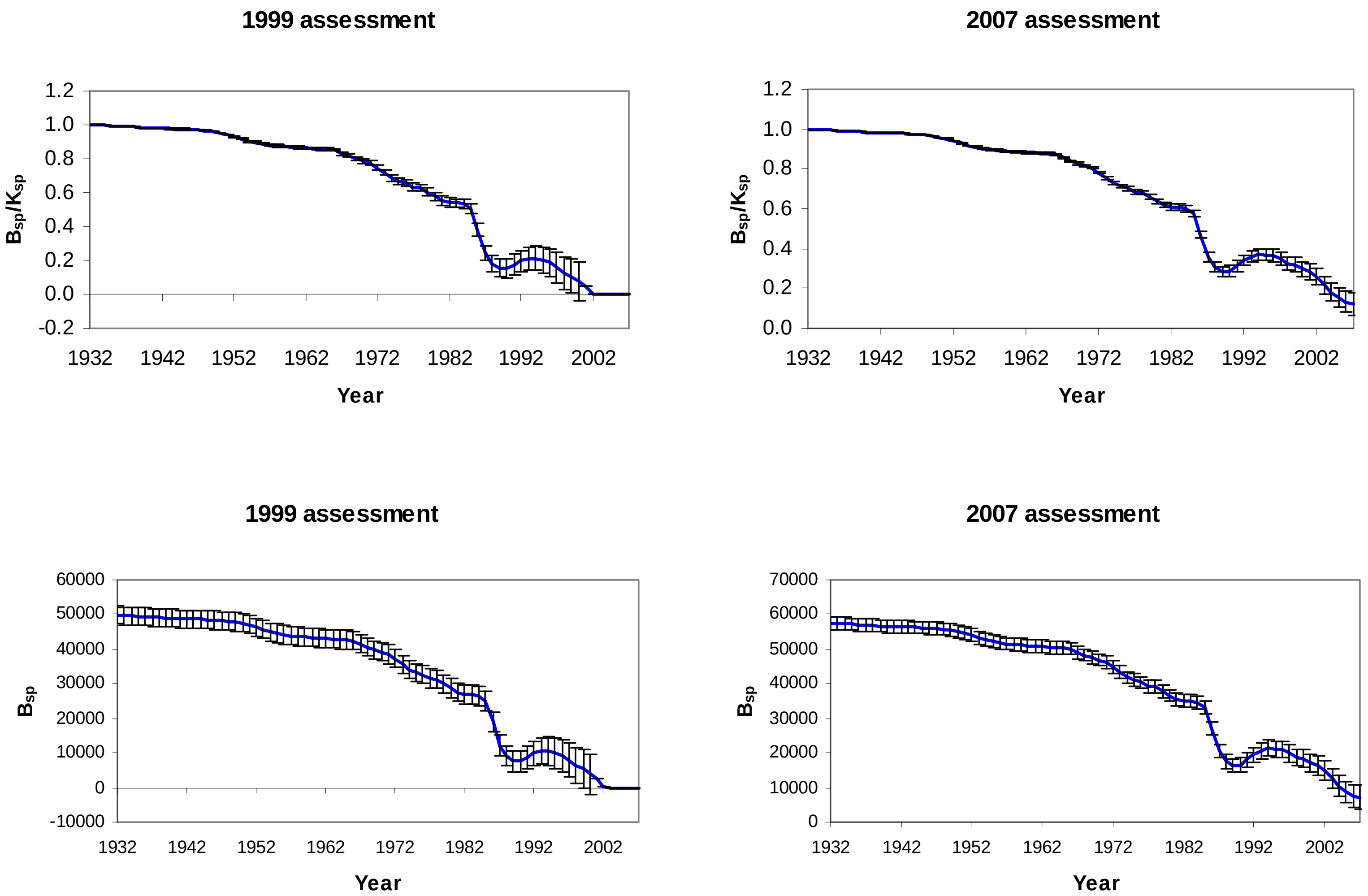


Figure 4b. Trajectories of spawning stock depletion (B_{sp}/K_{sp}) and spawning biomass (B_{sp}) estimates for kingklip for the South coast of South Africa for the base case model (h = 0.5), when the model is fitted to data up to 1999 (left hand side) and to data up to 2007 (right hand side). The error bars represent the 95% confidence intervals calculated from the Hessian matrix.

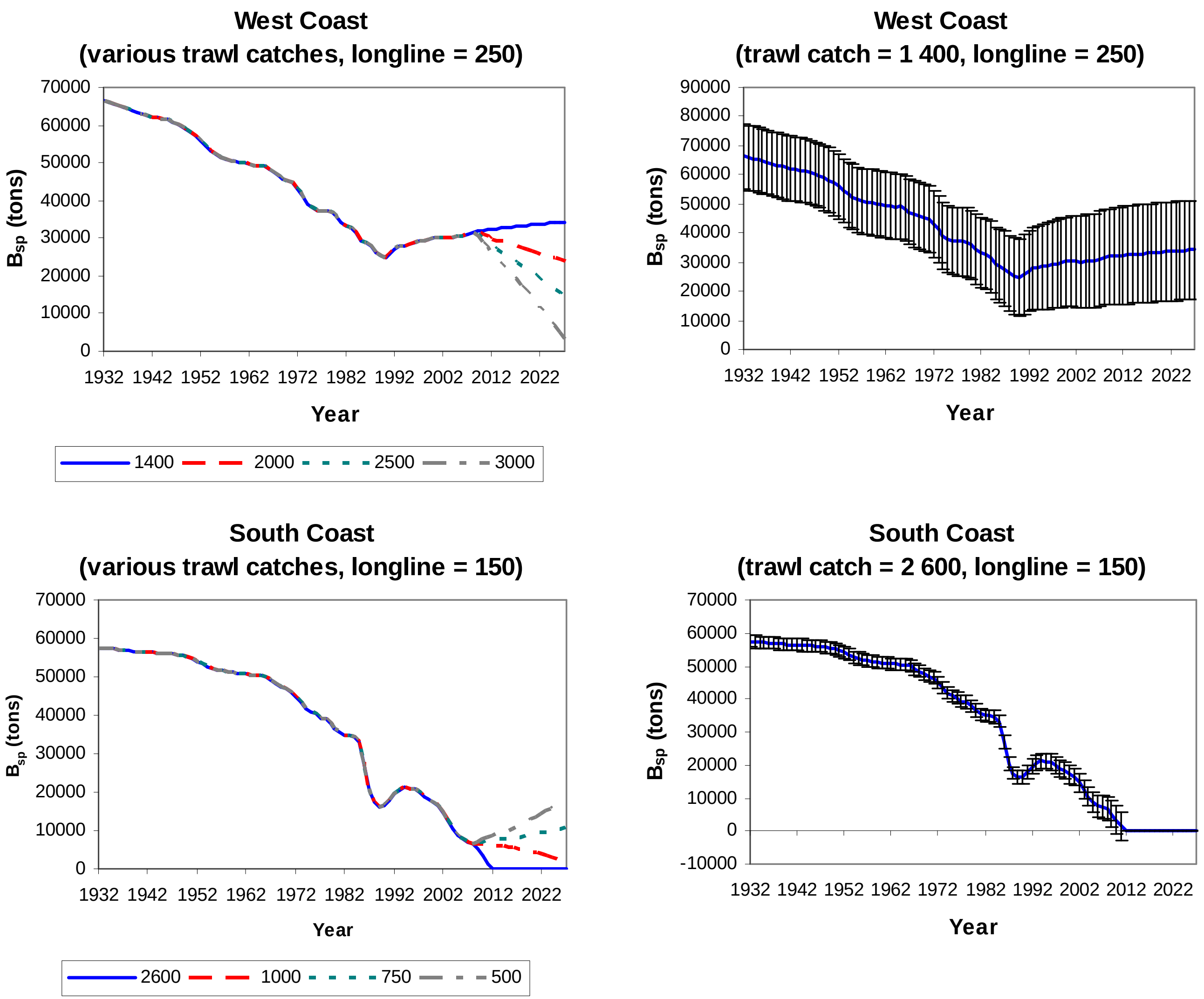
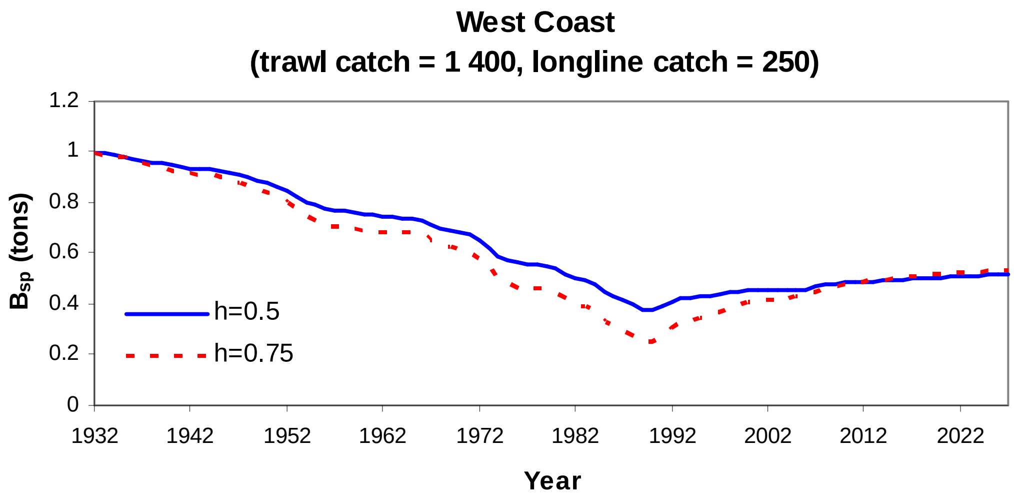


Figure 5. Twenty year projections for kingklip for the West and the South coasts of South Africa for the base case model (*h* = 0.5). Results for various levels of future constant catches for the trawl fishery are shown on the left hand side. Plots on the right hand side give the projections when future constant catches for each coast are set to be the average of the past five years (2002–2006) of each fishery, together with 95% CIs.



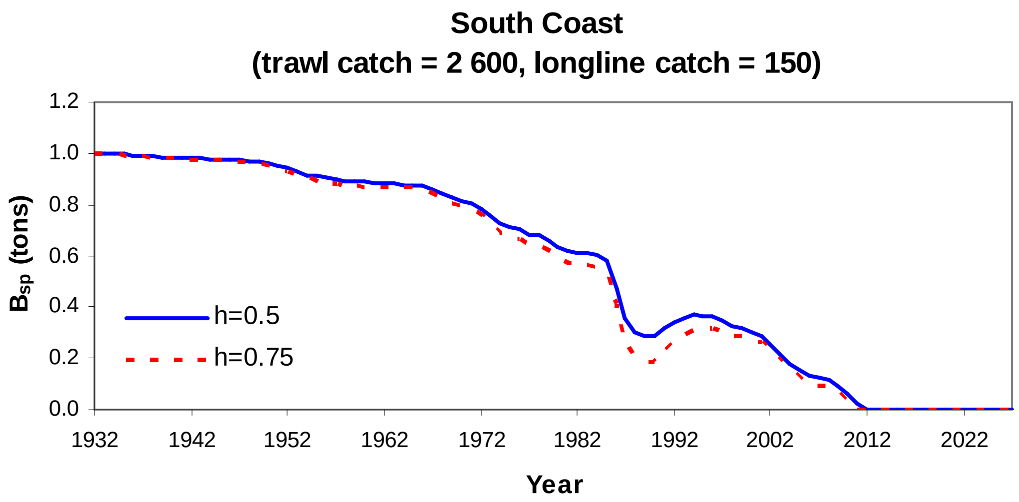


Figure 6. Twenty year projections for kingklip for the West and the South coasts of South Africa for the base case model (h = 0.5) and a sensitivity test on the steepness parameter (h = 0.75). Future constant catches for each coast are set to be the average of the past five years (2002–2006) of each respective fishery.

APPENDIX

THE AGE-STRUCTURED PRODUCTION MODEL FOR KINGKLIP

THE POPULATION DYNAMICS

The kingklip population dynamics are represented by:

$$\begin{aligned}
N_{y+1,a} &= R_{y+1} && \text{if } a=0 \\
N_{y+1,a} &= (N_{y,a-1}e^{-\frac{M_{a-1}}{2}} - C_{y,a-1})e^{-\frac{M_{a-1}}{2}} && \text{if } 1 \le a < x \\
N_{y+1,a} &= (N_{y,a}e^{-\frac{M_a}{2}} - C_{y,a})e^{-\frac{M_a}{2}} + (N_{y,a-1}e^{-\frac{M_{a-1}}{2}} - C_{y,a-1})e^{-\frac{M_{a-1}}{2}} && \text{if } a=m
\end{aligned} \quad \text{(A.1)}$$

where:

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

$C_{y,a}$ is the number of kingklip of age *a* taken by the fishery (both longline and trawl) in year *y*,

R_y is the number of 0 year olds at the start of year *y*,

M_a is the instantaneous rate of natural mortality of kingklip of age *a* (assumed to be age invariant with a value of 0.2 yr^{-1}), and

m is the largest age considered (i.e. the "plus group", taken to be 30 years).

Note that in the interests of simplicity this approximates the fishery as a pulse fishery at the start of the year. Given that kingklip is relatively long-lived with low natural mortality, such an approximation would seem adequate.

For a two-gear (or "fleet", trawl and longline) fishery, the total predicted number of fish of age *a* caught in year *y* is given by:

$$C_{y,a} = \sum_{f=1}^{2} C^f_{y,a} , \quad \text{(A.2)}$$

where:

$$C^f_{y,a} = N_{y,a} e^{-\frac{M_a}{2}} S^f_a F^f_y \quad \text{(A.3)}$$

and:

F^f_y is the proportion of the resource above age *a* harvested in year *y* by fleet *f*, and

S^f_a is the commercial selectivity at age *a* for fleet *f*.

The mass-at-age is given by the combination of a von Bertalanffy growth equation $\ell(a)$ defined by constants ℓ_∞, κ and t_0 and a relationship relating length to mass. Note that ℓ refers to standard length.

$$\ell(a) = \ell_\infty [1 - e^{-\kappa(a-t_0)}] \quad \text{(A.4)}$$

$$w_a = c\left[\ell(a)\right]^d \quad \text{(A.5)}$$

where:

w_a is the mass of a fish at age a, and

c, d are the mass-length relationship parameters.

The fleet-specific total catch by mass in year y is given by:

$$C_y^f = \sum_{a=0}^{m} w_{a+0.5} C_{y,a}^f = \sum_{a=0}^{m} w_{a+0.5} S_a^f F_y^f N_{y,a} e^{-\frac{M_a}{2}} \tag{A.6}$$

which can be re-written as:

$$F_y^f = \frac{C_y^f}{\sum_{a=0}^{m} w_a S_{y,a}^f N_{y,a} e^{-\frac{M_a}{2}}} = \frac{C_y^f}{B_y^{\exp,f}}, \tag{A.7}$$

where $B_y^{\exp,f}$ is the is the fleet-specific exploitable component of the biomass.

FISHING SELECTIVITY

The fleet-specific commercial fishing selectivity, S_a^f, is assumed to be of the same form as in Punt and Japp (1994). For the longline this is given by:

$$S_a^L = \left\{1 + \exp\left[-\left(a - a_{50}^L\right)/\delta^L\right]\right\}^{-1} \tag{A.8}$$

and for the trawl fishery by:

$$S_a^T = \begin{cases} \left\{1 + \exp\left[-\left(a - a_{50}^T\right)/\delta^T\right]\right\}^{-1} & \text{if } a \le a_{50}^T \\ \dfrac{\exp\left[-\gamma\left(a - a_{50}^T\right)\right]}{\left\{1 + \exp\left[-\left(a - a_{50}^T\right)/\delta^T\right]\right\}^{-1}} & \text{if } a > a_{50}^T \end{cases} \tag{A.9}$$

where:

$a_{50}^{L/T}$ is the age-at-50% selectivity for the longline/trawl fishery,

$\delta^{L/T}$ is the parameter which determines the width of the age-specific selectivity function for the longline/trawl fishery, and

γ is (approximately) the negative of the slope of the selectivity function for large ages.

STOCK-RECRUITMENT RELATIONSHIP

The spawning biomass in year y is given by:

$$B_y^{sp} = \sum_{a=1}^{m} w_a f_a N_{y,a} = \sum_{a=a_m}^{m} w_a N_{y,a} \tag{A.10}$$

where:

f_a is the proportion of fish of age a that are mature (assumed to be knife-edge at age a_m).

The number of recruits at the start of year y is assumed to relate to the spawning biomass at the start of year y, B_y^{sp}, by a Beverton-Holt stock-recruitment relationship (assuming deterministic recruitment):

$$R(B_y^{sp}) = \frac{B_y^{sp}}{\alpha + \beta B_y^{sp}}. \qquad \text{(A.11)}$$

The values of the parameters α and β can be calculated given the unexploited equilibrium (pristine) spawning biomass K^{sp} and the steepness of the curve h, using equations (A.12)–(A.13) below. If the pristine recruitment is $R_0 = R(K^{sp})$, then steepness is the recruitment (as a fraction of R_0) that results when spawning biomass is 20% of its pristine level, i.e.:

$$hR_0 = R(0.2K^{sp}) \qquad \text{(A.12)}$$

from which it can be shown that:

$$h = \frac{0.2(\alpha + \beta K^{sp})}{\alpha + \beta 0.2K^{sp}} \qquad \text{(A.13)}$$

and hence:

$$\begin{aligned} \alpha &= K^{sp}(1-h)/(4hR_0) \\ \beta &= (5h-1)/(4hR_0) \end{aligned} \qquad \text{(A.14)}$$

The model estimate of the mid-year exploitable component of the biomass for each fleet is given by:

$$B_{y,mid}^{\exp,f} = \sum_{a=0}^{m} w_{a+0.5} S_a^f N_{y,a} e^{-M/2}, \qquad \text{(A.15)}$$

where:

$w_{a+0.5}$ is the mid-year weight of kingklip of age a.

The model estimate of the start of the year exploitable component of the biomass for each fleet is given by:

$$B_{y,st}^{\exp,f} = \sum_{a=0}^{m} w_a S_a^f N_{y,a} \qquad \text{(A.16)}$$

PAST STOCK TRAJECTORY AND FUTURE PROJECTIONS

Given a value for the pre-exploitation equilibrium spawning biomass (K^{sp}) of kingklip, and the assumption that the initial age structure is at pre-exploitation equilibrium, it follows that:

$$K^{sp} = R_0 \left(\sum_{a=1}^{m-1} w_a f_a e^{-Ma} + \frac{w_m f_m e^{-Mm}}{1-e^{-M}} \right) \quad \text{(A.15)}$$

which can be solved for R_0.

The resource is assumed at its unexploited equilibrium when catches start in 1932 for the West and South coasts. The initial numbers at each age a for the trajectory calculations, corresponding to the deterministic equilibrium, are given by:

$$N_{1932,a} = R_0 n_a \,, \quad \text{(A.16)}$$

where:

$$n_a = \begin{cases} 1 & \text{if } a = 0 \\ \exp\left(-\sum_{a'=0}^{a-1} M_{a'} \right) & \text{if } 1 \le a < m \\ \exp\left(-\sum_{a'=0}^{m-1} M_{a'} \right) \Big/ \left(1 - \exp\left(-M_m\right)\right) & \text{if } a = m \end{cases} \quad \text{(A.17)}$$

Numbers-at-age for subsequent years are then computed by means of equations (A1.1)-(A1.3) and (A1.6)-(A1.10) under the series of annual catches given.

THE LIKELIHOOD FUNCTION

The age-structured production model (ASPM) is fitted to the fleet-specific CPUE data and to season-specific (i.e. summer or winter) survey series. The likelihood is calculated assuming that the observed abundance indices are lognormally distributed about their expected values:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \qquad \text{or} \qquad \varepsilon_y^i = \ln\left(I_y^i\right) - \ln\left(\hat{I}_y^i\right)$$

where:

I_y^i is the abundance index of type i for year y, where for example, $i = CPUE_{trawl}$, when dealing with the CPUE index for the trawl fishery, or $i = Survey_{summer}$ when dealing with the abundance index from the summer survey, and so on,

$\hat{I}_y^i = \hat{q}_i \hat{B}_{y,s}^{\exp,f}$ is the corresponding model estimated value, where $B_{y,s}^{\exp,f}$ is the model value for exploitable resource biomass for fishery f ($f = T$ for trawl or $f = L$ for longline fishery) and time of the year s ($s = mid$ for mid-year or $s = st$ for the start of year),

$\hat{q}_i$ is a constant of proportionality for abundance index *i*, and

ε^i_y is normally distributed with mean zero and standard deviation σ^i_y.

Survey abundance data

The surveys are assumed to have the same selectivity as the trawl fishery, and the time of year when the survey took place is taken into account. Thus, for the summer survey, the corresponding model estimated exploitable resource biomass is given by equation (A.16) and for the winter survey, $B^{\exp,f}_{y,s}$ is given by equation (A.15), with the corresponding selectivity function being that for the trawl fishery.

The contribution of the survey abundance data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ln L_{survey} = \sum_i \sum_y \left[\ln \sigma^i_y + \left(\varepsilon^i_y\right)^2 \Big/ 2\left(\sigma^i_y\right)^2 \right] \quad \text{(A.18)}$$

where:

σ^i_y are given by $\ln\left(1+\left(CV^i_y\right)^2\right)$, where the CV^i_y are the coefficients of variation of the resource abundance estimate for index *i* for year *y*. These CVs are input and are given in Table 2.

The catchability coefficient q_i for the survey abundance index *i* is estimated by its maximum likelihood value and is given by:

$$\ln \hat{q}_i = \frac{\sum_y \left\{ \ln I^i_y - \ln \hat{B}^{\exp,T}_{y,s} \right\} \left(1 \Big/ \left(\sigma^i_y\right)^2 \right)}{\sum_y 1 \Big/ \left(\sigma^i_y\right)^2} .$$

CPUE abundance data

The contribution to the negative of the log-likelihood function (after removal of constants) by the trawl and longline CPUE abundance data is given by:

$$-\ln L_{CPUE} = \sum_i \sum_y \left[\ln \sigma^i_y + \left(\varepsilon^i_y\right)^2 \Big/ 2\left(\sigma^i_y\right)^2 \right], \quad \text{(A.19)}$$

where the model estimate of exploitable resource biomass is given by equation (A.15) and homocesdasticity of residuals is assumed, so that $\sigma^i_y = \sigma^i$ and this is estimated by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{\frac{1}{n_i} \sum_y \left(\ln I^i_y - \ln \hat{q}_i \hat{B}^{\exp,f}_{y,mid} \right)^2} ,$$

where:

n_i is the number of data points for the abundance series *i*,

and the maximum likelihood estimate of q_i is given by:

$$\ln \hat{q}_i = \frac{1}{n_i} \sum_y \left\{ \ln I_y^i - \ln \hat{B}_{y,s}^{\exp,T} \right\}.$$

ADJUSTMENT TO INCORPORATE ADDITIONAL VARIANCE

To incorporate additional variance in the survey abundance indices, Equation (A.18) is modified to:

$$-\ln L_{survey} = \sum_i \sum_y \left[\ln\left(\sqrt{\left(\sigma_y^i\right)^2 + \left(\sigma_{add}^i\right)^2} \right) + \left(\varepsilon_y^i\right)^2 \Big/ 2\left(\left(\sigma_y^i\right)^2 + \left(\sigma_{add}^i\right)^2 \right) \right] \quad \text{(A.20)}$$

where:

σ_{add}^i is the square root of the additional variance for abundance series *i*, and is treated as an estimable parameter.

ADJUSTMENT TO INCORPORATE SURVEY VESSEL OR GEAR DIFFERENCES

The base case model does not differentiate between survey abundance indices that were obtained using either the old or the new gear on the *Africana*, nor whether the *Africana* or the *Nansen* was used for the survey. To differentiate between gear type and between vessels, the term ε_y^i in Equation (A.18) is modified to:

$$\varepsilon_y^i = \ln\left(I_y^i\right) - \ln\left(\hat{q}_i^* \hat{B}_{y,s}^{\exp,T}\right)$$

where:

$\hat{q}_i^*$ is a constant of proportionality for abundance index *i*, where

$$\hat{q}_i^* = \begin{cases} \hat{q}_i^{old} & \text{if index } i \text{ in year } y \text{ is from } \textit{Africana} \text{ with old gear} \\ \hat{q}_i^{old}\hat{q}_i^{d} & \text{if index } i \text{ in year } y \text{ is from } \textit{Africana} \text{ with new gear} \\ \hat{q}_i^{old}\hat{q}_i^{d2} & \text{if index } i \text{ in year } y \text{ is from } \textit{Nansen} \end{cases}.$$

The maximum likelihood estimate of q_i^{old} is given by:

$$\ln \hat{q}_i^{old} = \frac{\sum_y X_y^i \left(1 \big/ \left(\sigma_y^i\right)^2 \right)}{\sum_y 1 \big/ \left(\sigma_y^i\right)^2}$$

where:

$$X_y^i = \begin{cases} \ln I_y^i - \ln \hat{B}_{y,s}^{\exp,T} & \text{if index } i \text{ in year } y \text{ is from } \textit{Africana} \text{ with old gear} \\ \ln I_y^i - \ln\left(\hat{q}_i^d \hat{B}_{y,s}^{\exp,T}\right) & \text{if index } i \text{ in year } y \text{ is from } \textit{Africana} \text{ with new gear} \\ \ln I_y^i - \ln\left(\hat{q}_i^{d2} \hat{B}_{y,s}^{\exp,T}\right) & \text{if index } i \text{ in year } y \text{ is from } \textit{Nansen} \end{cases}$$

and q_i^d and q_i^{d2} are estimated in the non-linear search.