Schaefer model predictions of Abalone dynamics in Zones E and G based on commercial CPUE data from 1980 to 2007

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Introduction

Here we present the revised predictions of abalone dynamics in Zones E and G. As in the previous assessment [1], predictions were based on a discrete Schaefer model [12] of biomass dynamics. In this implementation however, parameter estimates were obtained using Bayesian methods.

Methods

Data

Commercial Catch per Unit Effort (CPUE) data from 1980 to 2007, plus Commercial, Recreational and Illegal Catches from 1977 onwards, were supplied by Angus Mackenzie (Marine and Coastal Management). Details concerning derivation of the data used in this assessment are given as an Appendix. A standardised CPUE series [2] provided an index of population abundance to which the model was fitted. The data available for each zone is given in Tables 1 and 2, with the catch series shown in Figures 1 and 2.

Model description

The stock assessment for Zones E and G is based on a discrete-time Schaefer model of population dynamics:

$$y_{n+1} = y_n + ry_n\left(1 - \frac{y_n}{K}\right) - C_n^{COMM} - C_n^{REC} - C_n^{ILLEGAL}$$

$$I_n = q\left(\frac{y_n + y_{n+1}}{2}\right)e^{\varepsilon} = \hat{I}_n e^{\varepsilon}$$

where,

n is the Model Year, representing a season of fishing from October in year $n-1$ to September in year n, with $\{n = 1977, 1978, \cdots, 2007\}$

y_n is the population biomass in year n;

r is the intrinsic growth rate;

K is the carrying capacity;

C_n is the annual catch in year n divided into Commerical, Recreational and Illegal sectors;

q is the catchability coefficient; and,

I_n is an index of population size, in this case the CPUE measured in kg per minute dived.

Observation error is assumed to have a log-normal distribution with $\varepsilon \sim N(0, \sigma^2)$. Process error is assumed to be negligible. The fit of this model to observed CPUE values is measured using the likelihood function L:

$$L(\mathbf{I} \mid \hat{\mathbf{I}}, \hat{\sigma}) = \prod_{n=1977}^{2007} \frac{1}{\sqrt{2\pi}\hat{\sigma}} e^{\frac{[ln(I_n) - ln(\hat{I}_n)]^2}{2\hat{\sigma}^2}},$$

with q obtained analytically from its maximum likelihood value:

$$ln(\hat{q}) = \frac{1}{s} \sum \left[ln(I_n) - ln\left(\frac{y_n + y_{n+1}}{2}\right)\right]$$

where, s is the number of years for which CPUE data is available. Calculation of the likelihood involved three steps. First $\hat{\mathbf{I}}$ was calculated (from values of r and K with $\hat{q}$ obtained from the analytical formula above), then $\hat{\sigma}$ was obtained through minimisation of the negative log-likelihood function, followed finally by the calculation of $L(\mathbf{I} \mid \hat{\mathbf{I}}, \hat{\sigma})$.

Parameter estimation

To find values for r and K within a Bayesian framework we estimate the joint posterior probability:

$$Pr(r, K \mid \mathbf{I}, \hat{q}, \hat{\sigma}) = \frac{1}{Z} L(\mathbf{I} \mid r, K, \hat{q}, \hat{\sigma}) Pr(r) Pr(K)$$

where, Z is an unknown normalising constant. The distribution of $Pr(r, K \mid \mathbf{I}, \hat{q}, \hat{\sigma})$ is approximated by sampling at random from the prior distributions of $Pr(r)$ and $Pr(K)$, calculating the likelihood for each combination of parameters, and summing the likelihood contributions over discrete parameter intervals.

Priors were assumed to be uniformly distributed. We assumed the prior for r to be $r \sim U(0.1, 0.3)$ based on estimates from Zones A-D [8]. Prior bounds on K were arbitrarily large and equal for both zones, with $K \sim U(0.1, 3.0)$ in units of 10^3 tonnes.

The prior distributions of $Pr(r)$ and $Pr(K)$ were sampled 100,000 times to estimate the parameter values for r and K in the model. Estimated values were taken as the medians of each marginal posterior probability density. In addition to r, K, $\hat{q}$ and $\hat{\sigma}$, we report additional statistics on the resource, namely current biomass (y_{2007}), biomass at maximum sustainable yield ($MSYL$), depletion relative to K (*depletion*) and sustainable catch (*s.catch*). The sustainable catch is the catch that would keep biomass at a constant level and is calculated as the expected population growth $ry_{2007}(1 - \frac{y_{2007}}{K})$.

Biomass projections

Biomass projections were made up to the year 2020. Six different scenarios were assumed including every combination of an unchanged and zero future TAC, and unchanged and zero poaching levels. The unchanged (current) values are given in Tables 1 and 2. In addition to these, we investigated a scenario with unchanged poaching and a TAC twice the current values, and a scenario with zero TAC but with poaching increased to twice the current TAC. This final scenario was intended to accommodate the perceptions of industry representatives that poaching would increase were the fishery to be closed.

Hyperstability

The above model (referred to as the Reference case) assumes our population index, CPUE, to be linearly related to biomass. This is unlikely to be the case for a benthic resource such as abalone [13], particularly in the sparsely populated Zones E and G, and there are several examples from elsewhere in the world of the problems this assumption can cause [11, 14]. Because the resource is not uniformly distributed, the system may exhibit hyperstability, so that CPUE remains high but then drops rapidly at lower abundance. We therefore repeated our analyses assuming a convex relationship of the type recommended in the literature [6]:

$$I_n = \sqrt{\hat{I}_n} e^{\varepsilon}$$

with:

$$ln\left(q\right) = \frac{2}{s} \sum \left[ln\left(I_n\right) - \frac{1}{2} ln\left(\frac{y_n + y_{n+1}}{2}\right)\right]$$

Investigating the impact of hyperstability tests the sensitivity of biomass projections under the reference model to assumptions made by that model regarding the relationship between CPUE and resource biomass.

Results

Zone E

Fit of the model to the CPUE data is poor, particularly in more recent years. In order for the model to provide a more accurate reflection of recent biomass dynamics, and thus improve the reliability of projections, we repeated the model fit using only CPUE data from 1999 onwards. This led to a negligible improvement (Figure 3). We nevertheless report results obtained from fitting to the most recent years only. Parameter estimates are given in Table 3, along with Highest Posterior Density (HPD) intervals, which contain 90% of the posterior distribution. Posterior probability densities for r and K are shown in Figure 4 and biomass predictions in Figure 5.

If hyperstability is assumed then there is a marked impact on the biomass predictions shown in Figure 6 (assuming unchanged TAC and illegal catch), with overall biomass estimated to be substantially lower. This difference is reflected in the resource statistics reported in Table 3 and Figure 7.

Zone G

Model fit to the CPUE data was again poor (Figure 8), and in an effort to improve the reliability of projections only CPUE data from 1998 onwards was used. Parameter estimates are reported in Table 4. Posterior probability densities for r and K are shown in Figure 9, with biomass predictions in Figure 10.

If hyperstability is assumed then biomass estimates are drastically reduced and a negative resource projection is observed (Figures 11). Resource statistics are given in Figure 12.

Conclusion

A Schaefer model of biomass dynamics was fitted to standardised CPUE data from Zones E and G to predict future resource dynamics. Model fit was poor in both cases, indicating that the model and data inputs are inconsistent. This may be due to deficiencies in the model as a representation of the population, or inaccuracies in the data (or both). For example the model assumes that recruitment to the fishery is constant over time, which is unlikely to be accurate. Similarly, the reliability of recreational and illegal catches could be questioned, since these are a dominating influence on the model (Figures 1 and 2). It must therefore be emphasised that any conclusions drawn from model predictions are not well supported by the data.

Predictions indicate that abalone in Zone E will continue to increase in abundance even if the commercial TAC increases and poaching levels remain unchanged (Scenario 5). This result is robust to considerations of hyperstability, although application of this sensitivity test indicates that the Reference model in its current form may overestimate population biomass. In Zone G, the abalone population appears to be stable under the current catch regime, although a negative trajectory would likely result from any increases in total catch (Scenarios 5 and 6). Furthermore, the sensitivity test applied here indicates that the Reference model may be over optimistic in its predictions concerning the potential for resource recover.

References

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Appendix: Catch data

Here we outline the sources of data used in this assessment.

Commercial catch and CPUE data was obtained from database records [4, 5, 3]. Limited divers landings were included. All catches from False Bay were excluded although catches recorded ambiguously as from Cape Point were retained. Inclusion and exclusion of ambiguous entries from Cape Point has been shown previously to have a negligible impact on model projections [1]. Standardisation of the CPUE series is detailed elsewhere [2]. Two CPUE values (1982 and 1983) from Zone E and two from Zone G (1984 and 1985) were excluded as unreliable due to the small number of records for those years.

Recreational catches between 1992 and 2003 were estimated from a telephonic survey of numbers caught, conducted by Marine and Coastal Management. Abalone caught were assumed to weigh 0.95kg and 0.75kg from Zones E and G respectively [9]. Historic recreational catches were assumed to have increased linearly from 1977 until 1992, with 1977 catches as given in Tables 1 and 2.

Illegal catches in Zone E were assumed to be equal to 10% of the combined recreational and commercial catches for the majority of years [9, 10]. Illegal catches from 1999 and 2000 were scaled up to 4000kg to better reflect the perceptions of industry representatives [7]. For the same reason illegal catches in 2006 were set equal to 1400kg, and kept unchanged for 2007.

Illegal catches in Zone G were assumed to be equal to 10% of the combined recreational and commercial catches prior to 1997 and 20% thereafter [9, 10]. After consultation with industry representatives [7], illegal catches from 1999 and 2000 were scaled up to 4000kg and since 2003 have been assumed constant at 8000kg.

Table 1: Catch data: **Zone E**. All catches are in kilograms.

Model Year	TAC	no. datapoints	CPUE	Comm. Catch	Rec. Catch	Illegal Catch
1977				19000	14061	0
1978				8000	17314	0
1979				2000	20567	0
1980		19	1.38	8861	23821	3268
1981		8	1.42	4852	27074	3193
1982		2		360	30327	3069
1983		1		278	33580	3386
1984		8	1.64	5447	36834	4228
1985		160	1.44	74563	40087	11465
1986		9	1.43	3681	43340	4702
1987	20000	43	1.23	11840	46593	5843
1988	20000	16	1.18	4975	49847	5482
1989	20000	42	1.32	17820	53100	7092
1990	20000	19	1.09	4572	56353	6093
1991	10000	42	1.04	6591	59606	6620
1992	0			0	62860	6286
1993	0			0	121384	12138
1994	0			0	79929	7993
1995	0			0	77999	7800
1996	0			0	67633	6763
1997	0			0	74466	7447
1998	5000			0	37234	3723
1999	5000	25	1.11	3303	12368	4000
2000	5000	32	1.08	4964	34525	3949
2001	5300	28	0.98	4057	14031	4000
2002	13000	73	0.77	10137	29170	3931
2003	13000	43	0.86	5963	18523	2449
2004	15000	141	0.78	14353	0	1435
2005	15000	132	0.76	14110	0	1411
2006	12000	114	0.79	11962	0	1400
2007	12000	70	0.89	8406	0	1400

Table 2: Catch data: **Zone G**. All catches are in kilograms.

Model Year	TAC	no. datapoints	CPUE	Comm. Catch	Rec. Catch	Illegal Catch
1977				66000	4528	0
1978				19000	5291	0
1979				11000	6055	0
1980		9	1.37	4587	6818	1141
1981		11	1.54	5293	7582	1287
1982		18	1.5	13669	8345	2201
1983		9	1.24	3926	9109	1303
1984		1		206	9872	1008
1985		1		502	10636	1114
1986		89	1.43	41729	11399	5313
1987	30000	76	1.41	30652	12163	4281
1988	30000	95	1.26	32539	12926	4547
1989	30000	99	1.16	22653	13690	3634
1990	0			0	14453	1445
1991	0			0	15217	1522
1992	0			0	15980	1598
1993	0			0	47388	4739
1994	0			0	48467	4847
1995	0			0	78346	7835
1996	0			0	59870	5987
1997	0			0	57660	11532
1998	15000	91	0.98	6182	39685	9173
1999	15000	17	1.23	2232	6698	4000
2000	15000	39	0.92	5381	27512	6579
2001	15000	98	0.84	12360	6007	4000
2002	25500	109	0.99	20470	6624	5419
2003	25000	118	1.01	17379	6443	8000
2004	27000	152	0.79	19947	0	8000
2005	27000	175	0.76	22302	0	8000
2006	22000	155	0.78	18633	0	8000
2007	18000	59	0.88	3935	0	8000

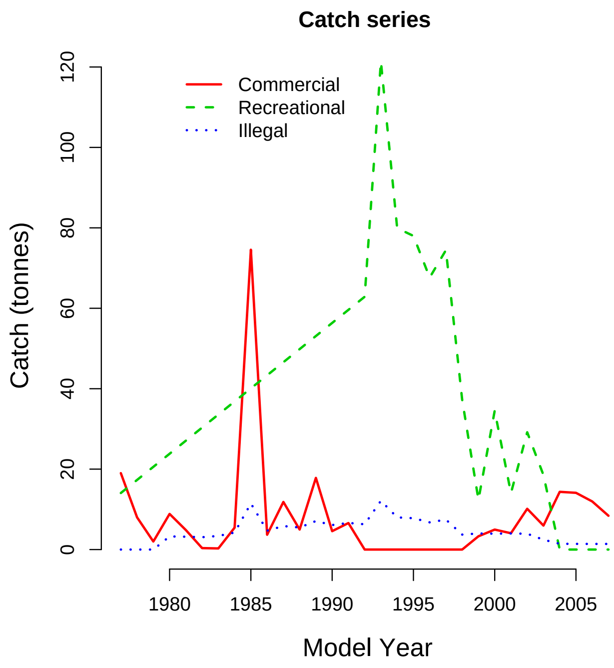

Figure 1: Catch series: **Zone E**.

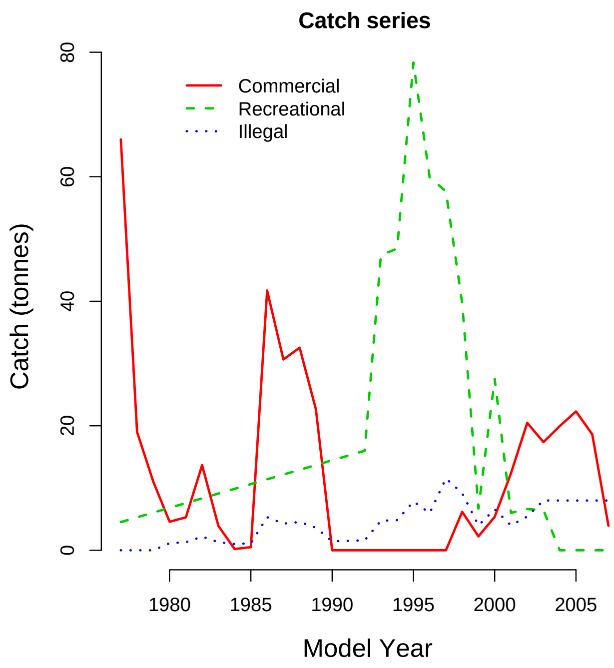

Figure 2: Catch series: **Zone G**.

Table 3: Model outputs: **Zone E**. Median of the posterior density and lower and upper HPD intervals are given for the reference case and sensitivity test. Biomass values are given in tonnes.

Output	Reference			Sensitivity		
	Median	Lower	Upper	Median	Lower	Upper
K	1793	1221	2834	1264	946	2611
r	0.13	0.10	0.26	0.13	0.10	0.26
$\hat{q}$	7.96E-07	4.32E-07	1.38E-06	1.70E-06	5.11E-07	2.74E-06
$\hat{\sigma}$	0.211	0.176	0.263	0.171	0.143	0.254
$y.2007$	1326	699	2541	550	263	2339
$sust.Catch$	43	29	46	37	25	47
$MSYL$	897	610	1417	632	473	1306
$depletion$	0.75	0.53	0.95	0.45	0.25	0.93

Table 4: Model outputs: **Zone G**. Median of the posterior density and lower and upper HPD intervals are given for the reference case and sensitivity test. Biomass values are given in tonnes.

Output	Reference			Sensitivity		
	Median	Lower	Upper	Median	Lower	Upper
K	1096	739	2554	741	516	1671
r	0.13	0.10	0.25	0.14	0.10	0.26
$\hat{q}$	1.38E-06	4.63E-07	2.34E-06	3.22E-06	8.11E-07	5.07E-06
$\hat{\sigma}$	0.163	0.138	0.220	0.126	0.115	0.215
$y.2007$	695	365	2312	222	117	1419
$sust.Catch$	32	26	35	22	15	35
$MSYL$	548	370	1277	371	258	836
$depletion$	0.65	0.46	0.92	0.31	0.20	0.86

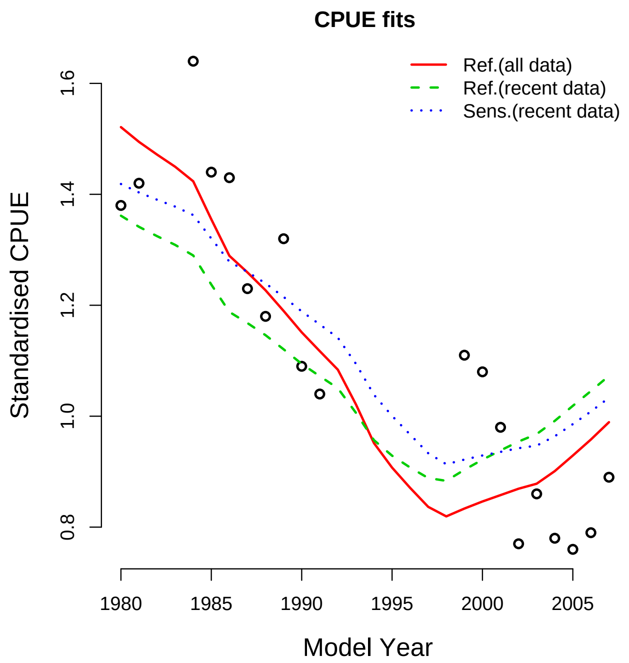

Figure 3: CPUE fit: **Zone E**.

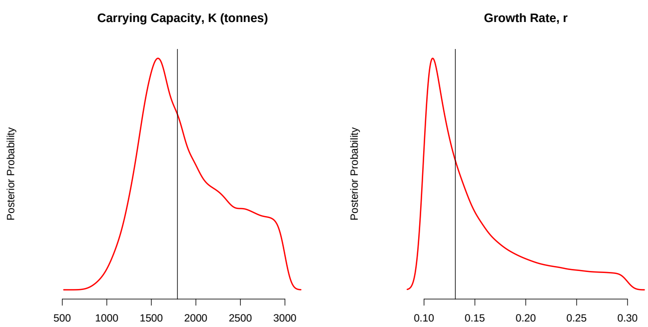

Figure 4: Posterior Density estimates (with median) for r and K: **Zone E**.

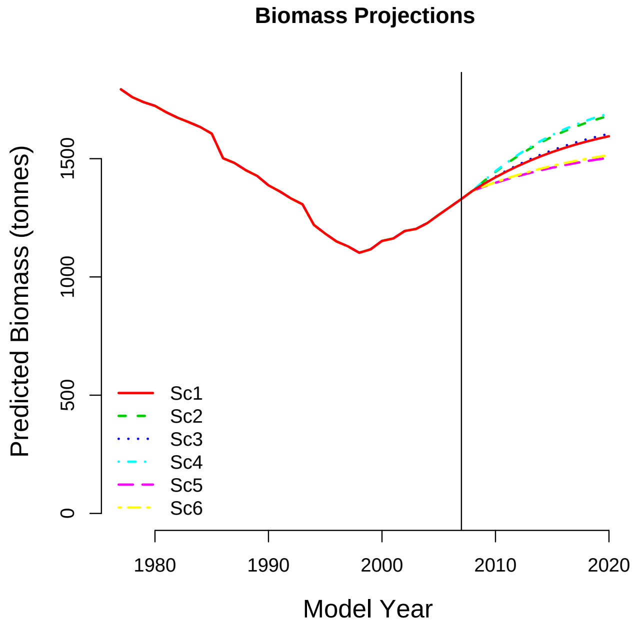

Figure 5: Biomass projections: **Zone E**. Scenario 1: TAC unchanged, Poaching unchanged; Scenario 2: TAC zero, Poaching unchanged; Scenario 3: TAC unchanged, Poaching zero; Scenario 4: TAC zero, Poaching zero; Scenario 5: TAC doubled, Poaching unchanged; Scenario 6: TAC zero, Poaching equal to twice the current TAC.

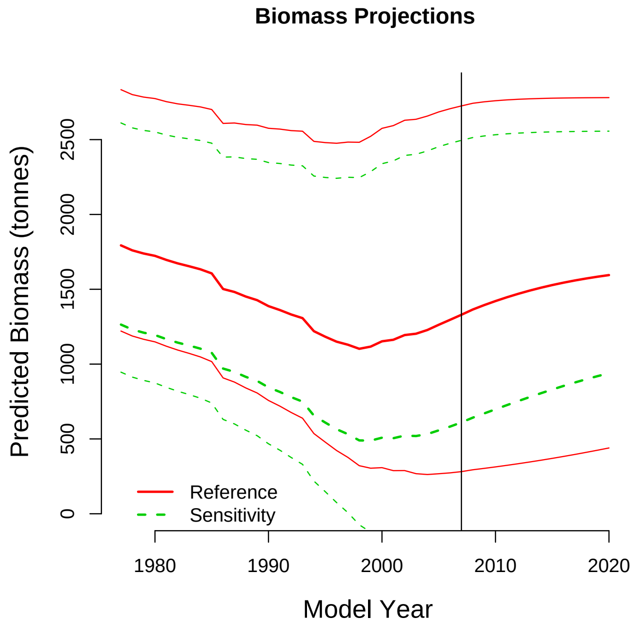

Figure 6: Biomass projections assuming hyperstability: **Zone E**. HPD intervals are shown. Catch Scenario 1 is assumed.

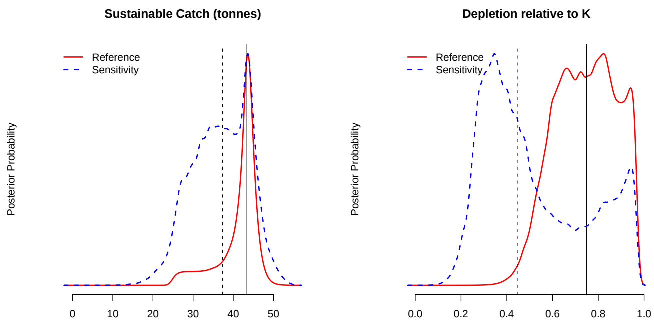

Figure 7: Resource Statistics: **Zone E**.

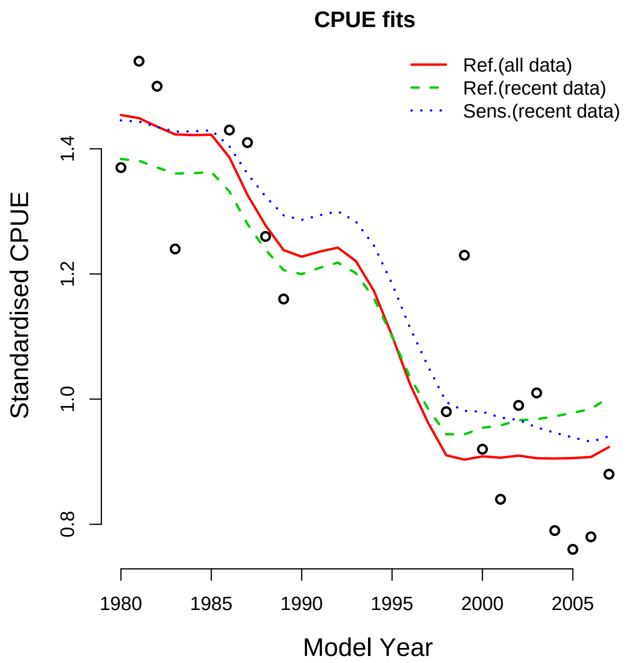

Figure 8: CPUE fit: **Zone G**.

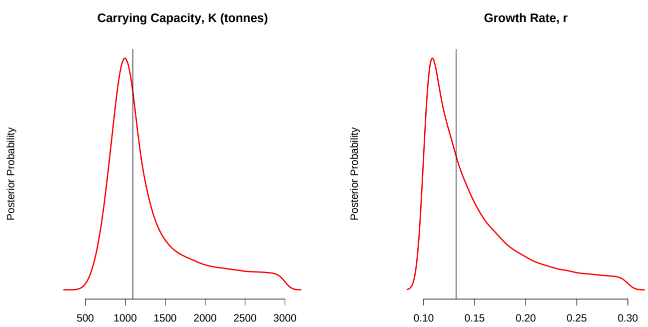

Figure 9: Posterior Density estimates (with median) for r and K: **Zone G**.

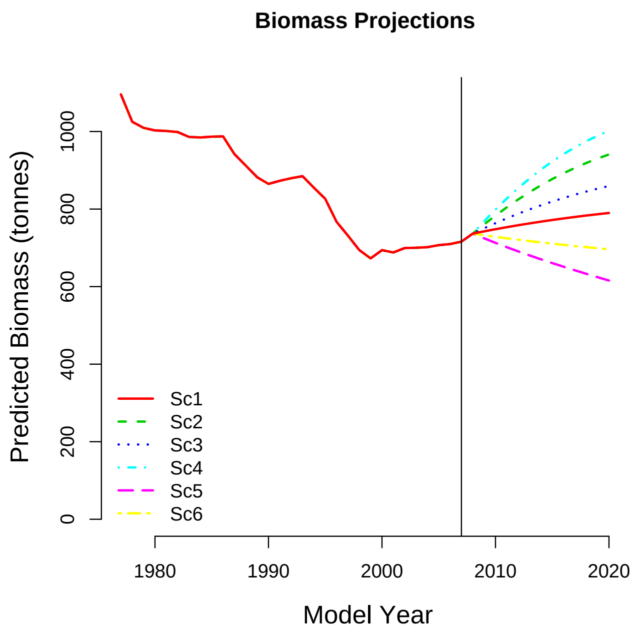

Figure 10: Biomass projections: **Zone G**. Scenario 1: TAC unchanged, Poaching unchanged; Scenario 2: TAC zero, Poaching unchanged; Scenario 3: TAC unchanged, Poaching zero; Scenario 4: TAC zero, Poaching zero; Scenario 5: TAC doubled, Poaching unchanged; Scenario 6: TAC zero, Poaching equal to twice the current TAC.

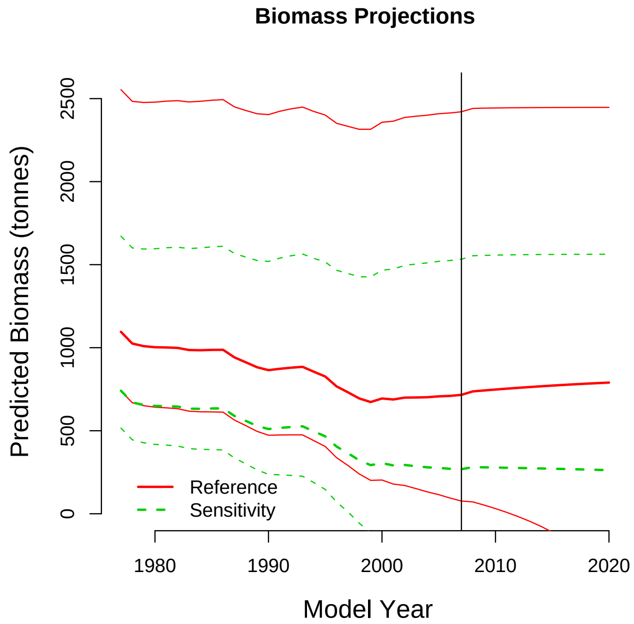

Figure 11: Biomass projections assuming hyperstability: **Zone G**. HPD intervals are shown. Catch Scenario 1 is assumed.

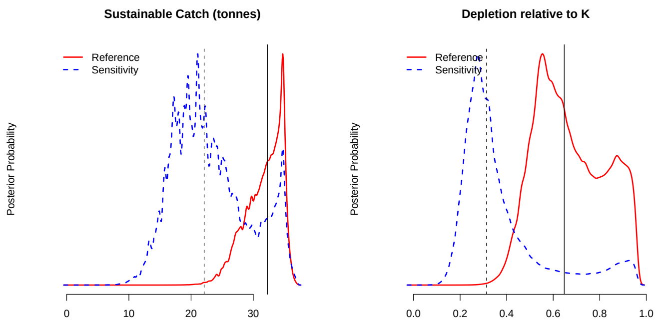

Figure 12: Resource Statistics: **Zone G**.