Preliminary 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 are based on a discrete Schaefer model [7] of biomass dynamics. In this implementation however, parameter estimates are obtained using Bayesian methods.

Methods

Data

Commercial Catch per Unit Effort (CPUE) data (including Limited Divers landings) from 1980 to 2007, and Recreational and Illegal Catches, were supplied by Angus Mackenzie (Marine and Coastal Management). The illegal catch is broadly considered to be 10% of the combined commercial and recreational catch, with minor modifications in recent years [3, 5]. Illegal catch in the 2006/07 season is assumed to be unchanged from the previous season. A preliminary standardisation of the CPUE series provides an index of population abundance to which the model is fitted. The data available for each zone is shown in Tables 1 and 2, with the catch series given 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 negative log-likelihood lnL (after removal of constants):

$$lnL\left(I, C \mid r, K, q, \sigma\right) = ln\left(\sigma\right) + \frac{\sum_{n=1977}^{2007}\left[ln\left(I_n\right) - ln\left(\hat{I_n}\right)\right]^2}{2\sigma^2}$$

with q obtained analytically from its maximum likelihood value:

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

where,

s is the number of years for which CPUE data is available.

Parameter estimation

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

$$Pr\left(r, K \mid I, C\right) = \frac{1}{Z}L\left(I, C \mid r, K\right)Pr\left(r\right)Pr\left(K\right)$$

where,

Z is an unknown normalising constant.

The distribution of $Pr\,(r, K \mid I, C)$ is approximated by sampling at random from the prior distributions of $Pr(r)$ and $Pr(K)$, calculating the likelihood for each combination of parameters (σ is estimated through a secondary minimisation of the log-likelihood function), 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 [4]. 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, q and σ, 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 are made up to the year 2020. Four different scenarios are assumed using 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.

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 [8], 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 [6, 9]. 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 [2]:

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

with:

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

Results

Zone E

Parameter estimates are reported 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 3. CPUE values predicted by the model are shown in Figure 4 and biomass predictions in Figure 5.

Fit of the model to the CPUE data is poor, particularly in more recent years. Figure 1 shows that the catch series consists mainly of recreational catches. This is the dominant influence on the model and from the poor fit appears to be inconsistent with the commercial CPUE data (assuming that the Schaefer model provides a reasonable representation of population dynamics). Bearing this reservation in mind, the biomass predictions nevertheless indicate the resource to be increasing. This projection is similar for all scenarios considered.

If hyperstability is assumed then fit of the CPUE series appears to marginally improve in more recent years (Figure 6). There is a marked impact on the biomass predictions shown in Figure 7 (assuming unchanged TAC and illegal catch). Although the model prediction regarding recovery of the resource appears to be unchanged, overall biomass is estimated to be substantially lower. This difference is reflected in the resource statistics reported in Table 3 and Figure 8.

Zone G

Parameter estimates are reported in Table 4. Posterior probability densities for r and K are shown in Figure 9. CPUE values predicted by the model are shown in Figures 10 and biomass predictions in Figure 11.

Model fit appears to be poor, again indicating that the catch and CPUE series may be inconsistent. Biomass predictions show the resource to be stable, with an improved chance of recovery should either the TAC or poaching levels be reduced.

If hyperstability is assumed the effect is similar to that for Zone E: fit to the CPUE series improves slightly (Figure 12) and biomass estimates are drastically reduced (Figures 13 and 14). A notable difference is that for Zone G, predictions assuming hyperstability indicate that exploitation is currently unsustainable.

Conclusion

A Schaefer model of biomass dynamics was fitted to 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. 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 and poaching levels remain unchanged. This result is robust to considerations of hyperstability. In Zone G, the abalone population appears to be stable under the current catch regime. This conclusion is however dependent on the relationship between CPUE and population abundance, since under the assumption of hyperstability biomass predictions indicate negative growth.

References

[1] C. T. T. Edwards and É. E. Plagányi. Schaefer model-based assessment of abalone dynamics in zones e and g. Working Group Document WG/AB/06/Aug/23, Marine and Coastal Management (South Africa), 2006.

[2] S. J. Harley, R. A. Myers, and A. Dunn. Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Science*, 58(9):1760–1772, 2001.

[3] G. Maharaj. Poaching assumptions for zone e and g: Summary of task team meeting on 28th july 2006, 2006.

[4] É. E. Plagányi. Abalone spatial- and age-structured assessment model preliminary results for zones a, b, c and d in 2006. Working Group document WG/AB/06/Aug/17, Marine and Coastal Management (South Africa), 2006.

[5] É. E. Plagányi and A. MacKenzie. Further revisions to catch data for abalone in zones e and g. Working Group Document WG/AB/07/07/13, Marine and Coastal Management (South Africa), 2006.

[6] J. D. Prince and A. Guzmán del Próo. A stock reduction analysis of the mexican abalone (haliotid) fishery. *Fisheries Research*, 16:25–49, 1992.

[7] M. B. Schaefer. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bulletin 1:27-56, Inter-American Tropical Tuna Commission, 1954.

[8] S. A. Shepherd, M. J. Tegner, and A. Guzmán del Próo, editors. *Abalone of the world: biology, fisheries and culture.* Oxford, UK: Fishing News Books, 1992.

[9] M. J. Tegner, P. A. Breen, and C. J. Lennert. Population biology of red abalone (*Haliotis rufescens*) in southern california and management of the red and pink (*H. corrugata*) abalone fisheries. *Fisheries bullettin*, 87:313–339, 1989.

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	16873	0
1979				2000	19685	0
1980		19	1.36	8861	22497	4620
1981		8	1.42	4852	25309	3016
1982				360	28121	2941
1983				278	30934	3121
1984		6	1.66	5447	33746	4325
1985		158	1.47	74563	36558	12416
1986		9	1.41	3681	39370	4330
1987	20000	42	1.25	11840	42182	5916
1988	20000	16	1.18	4975	44994	5092
1989	20000	42	1.35	17820	47806	6770
1990	20000	19	1.07	4572	50619	5538
1991	10000	35	1.03	6591	53431	6007
1992	0			0	62800	6280
1993	0			0	121300	12130
1994	0			0	79900	7990
1995	0			0	78000	7800
1996	0			0	67600	6760
1997	0			0	74400	7440
1998	5000			0	37200	3970
1999	5000	24	1.12	3303.4	12400	4000
2000	5000	30	1.08	4964.2	13000	4000
2001	5300	24	0.99	4057.2	14000	4000
2002	13000	73	0.79	10136.9	29100	4080
2003	13000	43	0.86	5963	18500	2000
2004	15000	138	0.78	14353	0	1290
2005	15000	127	0.77	14110	0	1510
2006	12000	112	0.81	11962	0	1400
2007	12000	69	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	5433	0
1979				11000	6339	0
1980		9	1.33	4587	7244	1624
1981		10	1.58	5293	8150	3515
1982		18	1.44	13669	9055	3806
1983		8	1.24	3926	9961	1389
1984				206	10867	1107
1985				502	11772	1227
1986		89	1.43	41729	12678	5441
1987	30000	76	1.41	30652	13583	4424
1988	30000	95	1.27	32539	14489	4703
1989	30000	98	1.13	22653	15394	3805
1990	0			0	16300	1630
1991	0			0	17205	1721
1992	0			0	15900	1590
1993	0			0	47400	4740
1994	0			0	48500	4850
1995	0			0	78300	7830
1996	0			0	59800	5980
1997	0			0	57600	11520
1998	15000	91	1.04	6182	39600	9649
1999	15000	17	1.24	2232	6600	4000
2000	15000	38	0.99	5381	6300	4000
2001	15000	95	0.84	12359.7	6000	4000
2002	25500	106	1.01	20469.7	6600	5587
2003	25000	116	1.03	17378.5	6400	8000
2004	27000	151	0.79	19947	0	8000
2005	27000	173	0.77	22302	0	8000
2006	22000	155	0.8	18633	0	8000
2007	18000	54	0.92	3935	0	8000

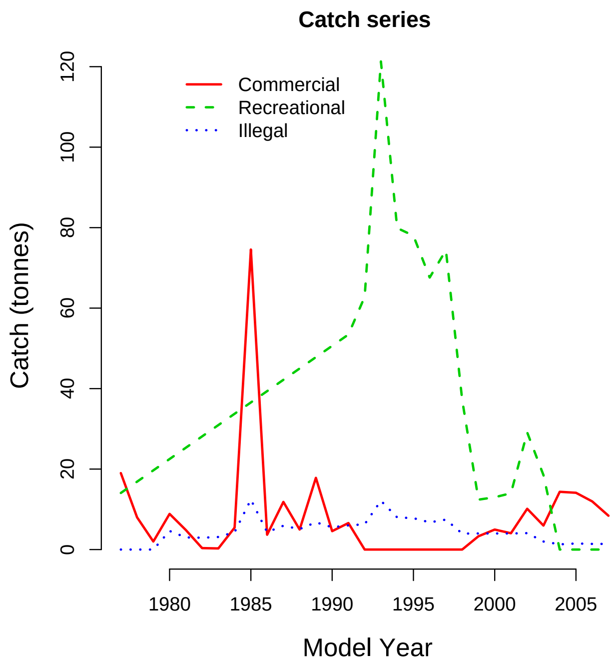

Figure 1: Catch series: **Zone E**.

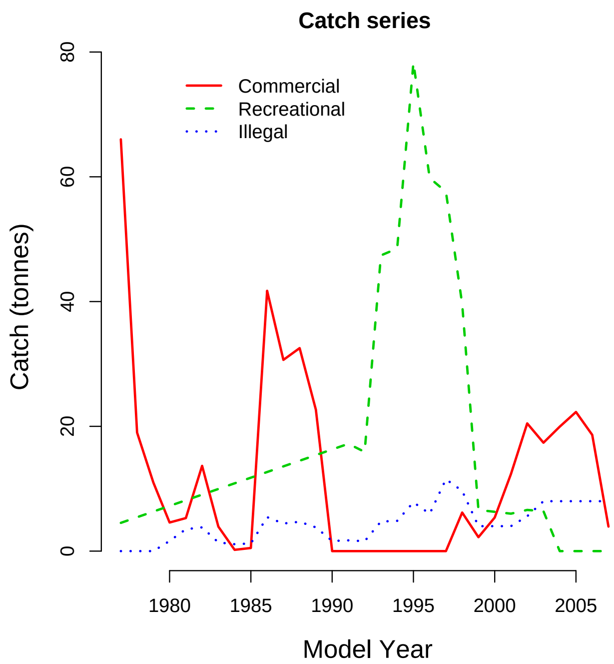

Figure 2: Catch series: **Zone G**.

Table 3: Model outputs: **Zone E**. Median of the posterior density and lower and upper HPD intervals are given for the reference case and assuming hyperstability.

Output	Reference			Hyperstability		
	Median	Lower	Upper	Median	Lower	Upper
K	1547	1284	1911	1192	974	1340
r	0.11	0.10	0.15	0.12	0.10	0.17
q	1.03E-06	7.47E-07	1.32E-06	1.96E-06	1.51E-06	2.55E-06
σ	0.14	0.14	0.17	0.13	0.12	0.15
y_{2007}	954	734	1384	440	313	646
$sust.catch$	41	38	44	33	26	42
$MSYL$	774	642	956	596	487	670
$depletion$	0.62	0.54	0.74	0.38	0.28	0.50

Table 4: Model outputs: **Zone G**. Median of the posterior density and lower and upper HPD intervals are given for the reference case and assuming hyperstability.

Output	Reference			Hyperstability		
	Median	Lower	Upper	Median	Lower	Upper
K	1075	830	1400	773	577	899
r	0.12	0.10	0.17	0.13	0.10	0.21
q	1.46E-06	9.97E-07	1.99E-06	3.07E-06	2.29E-06	4.31E-06
σ	0.13	0.13	0.16	0.12	0.11	0.14
y_{2007}	653	464	1016	255	169	398
$sust.catch$	30	27	34	22	17	29
$MSYL$	537	415	700	386	289	450
$depletion$	0.61	0.52	0.74	0.34	0.25	0.47

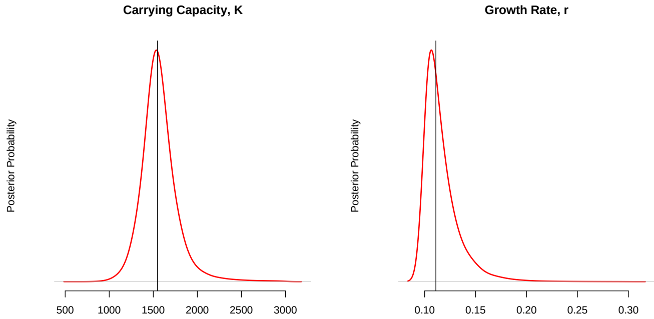

Figure 3: Posterior Density estimates (with median) for r and K: **Zone E**.

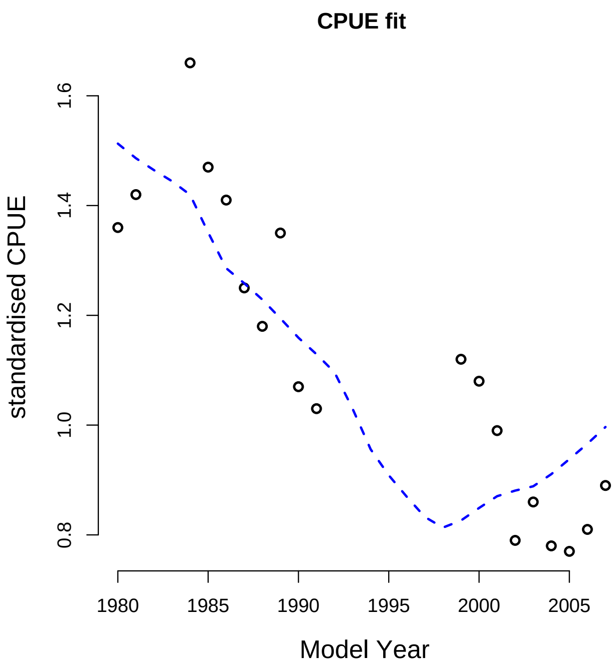

Figure 4: CPUE fit: **Zone E**.

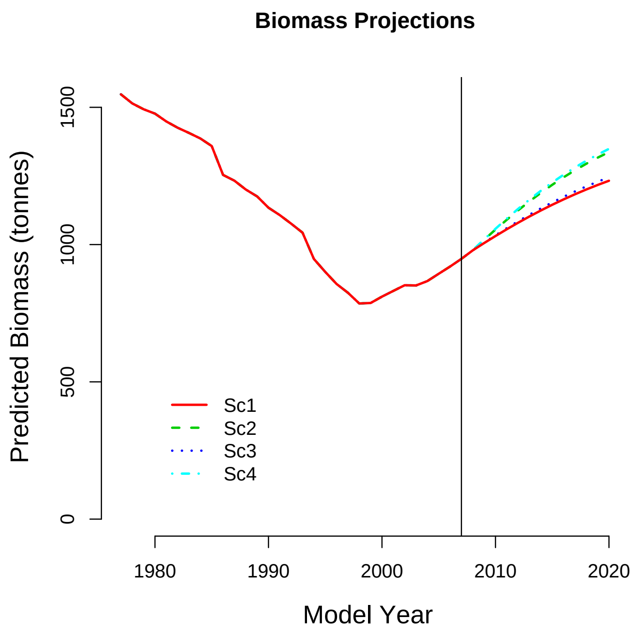

Figure 5: Biomass projections: **Zone E**. Scenario 1: TAC unchanged, Poaching unchanged; Scenario 2: TAC zero, Poaching unchanged; Scenario 3: TAC unchanged, Poaching zero; Scenario 4: TAC zero, Poaching zero.

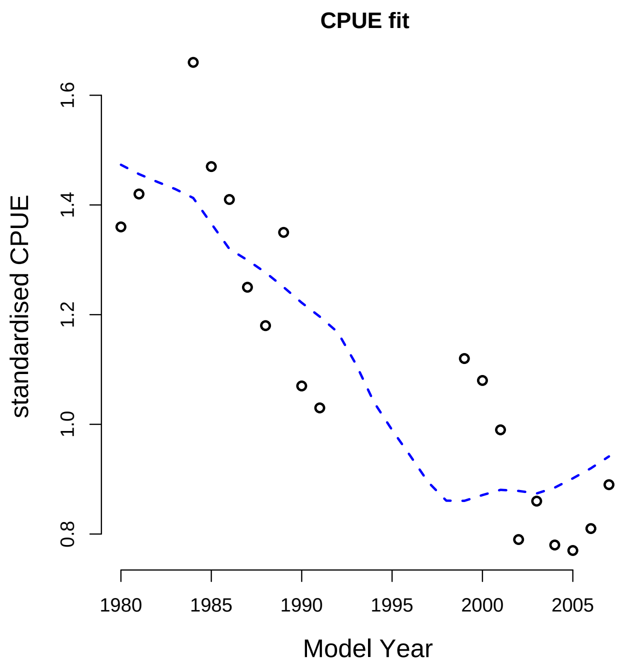

Figure 6: CPUE fit assuming hyperstability: **Zone E**.

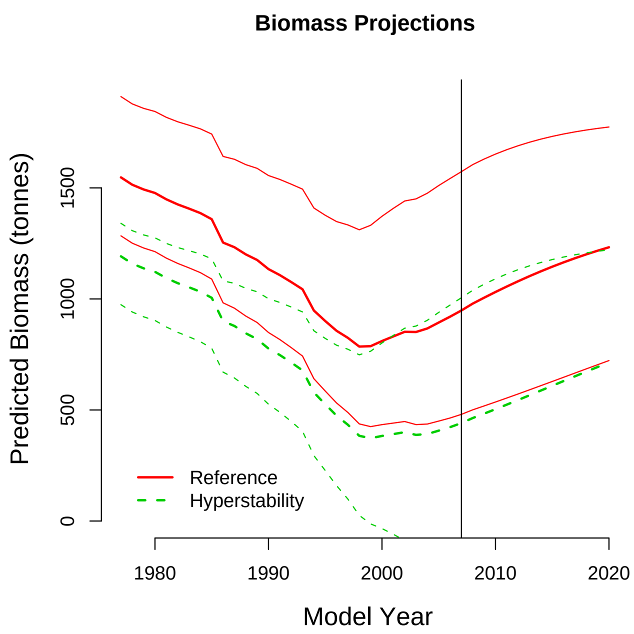

Figure 7: Biomass projections assuming hyperstability. HPD intervals are shown: **Zone E**.

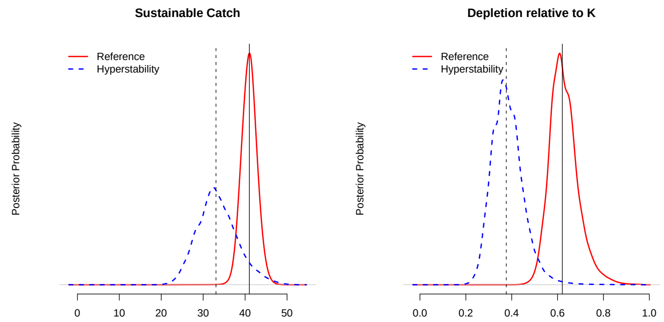

Figure 8: Resource Statistics: **Zone E**.

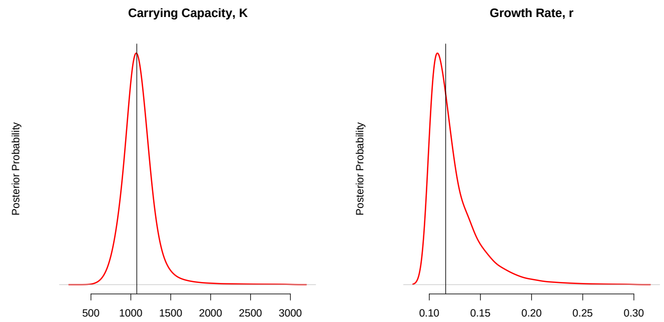

Figure 9: Posterior Density estimates (with median) for r and K: **Zone G**.

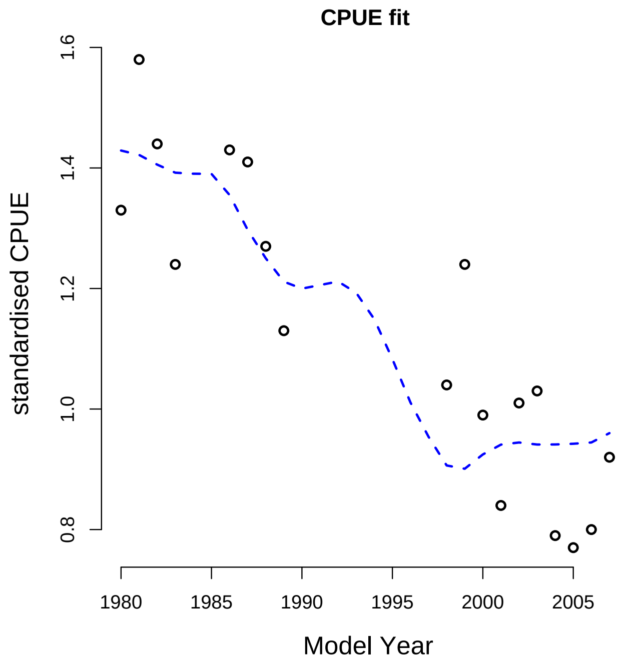

Figure 10: CPUE fit: **Zone G**.

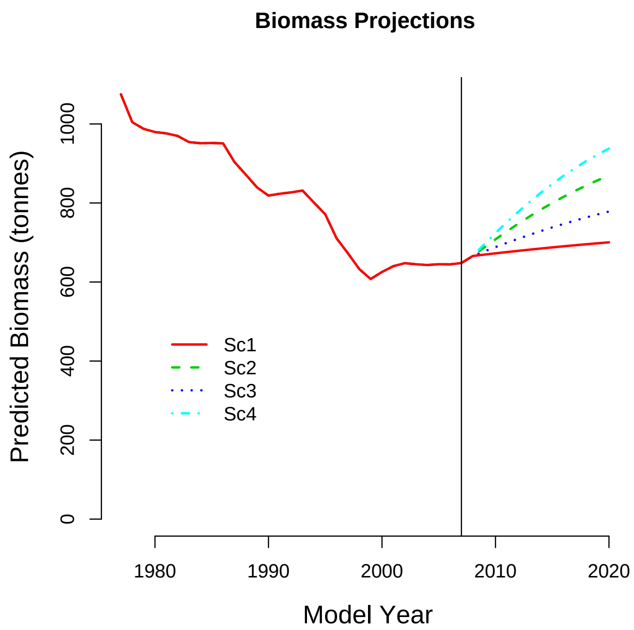

Figure 11: Biomass projections: **Zone G**. Scenario 1: TAC unchanged, Poaching unchanged; Scenario 2: TAC zero, Poaching unchanged; Scenario 3: TAC unchanged, Poaching zero; Scenario 4: TAC zero, Poaching zero.

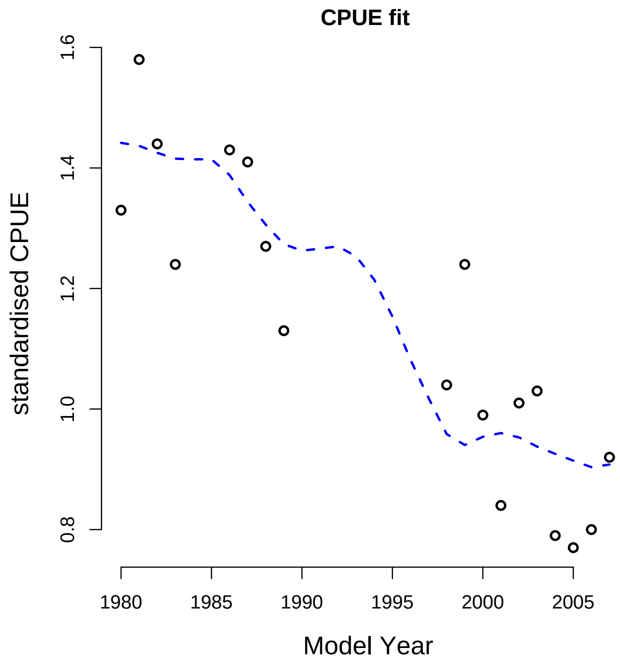

Figure 12: CPUE fit assuming hyperstability: **Zone G**.

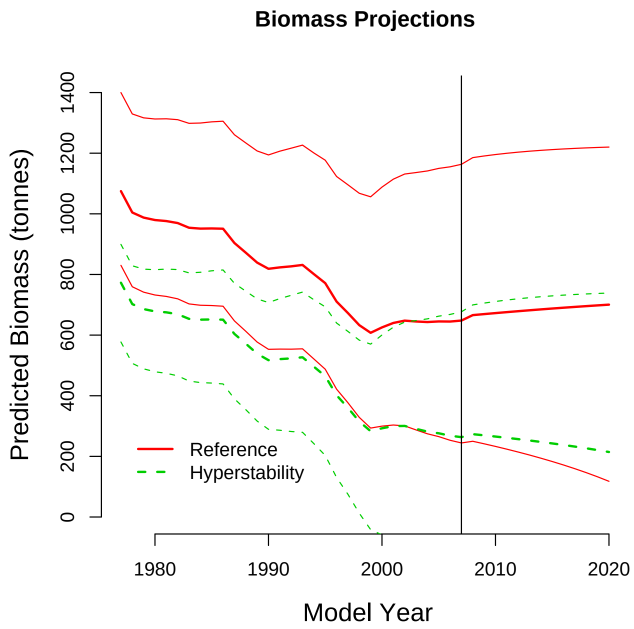

Figure 13: Biomass projections: **Zone G**. Scenario 1: TAC unchanged, Poaching unchanged; Scenario 2: TAC zero, Poaching unchanged; Scenario 3: TAC unchanged, Poaching zero; Scenario 4: TAC zero, Poaching zero.

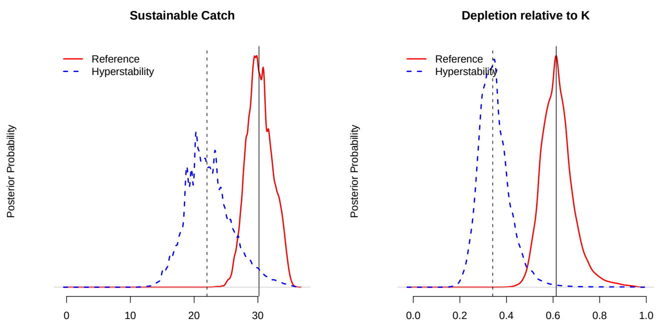

Figure 14: Resource Statistics: **Zone G**.