Application of the "River Model" to estimate the impact of fishing on the amount of anchovy available to west coast penguin colonies

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A simple approach is used to estimate the extent to which the amount of anchovy recruits of the year which would otherwise have been available to penguin colonies off the West Coast has been reduced by historic levels of fishing. Results suggest that over the past decade the extent of this reduction has been a median of 5-6% and at most some 25%.

Introduction

The availability of anchovy to both the purse-seine fishery and predators off the west coast each year is dominated by the southward "run" of the anchovy recruits of the year down the coast, originating from areas which broadly speaking are immediately to the south of the Orange River and ending on the Agulhas Bank. This run is typically at its height over the April to September period. The "River Model" considers the impact of pelagic fishing on this "river of recruits" and was first implemented by Butterworth and de Moor (2010a, b). This document extends their analyses to include data from the latest anchovy assessment (de Moor and Butterworth 2012). The purpose of the model is to determine for each year the extent to which the fishing for anchovy reduced the densities of these fish that would otherwise have been available to predators.

Data

The data used as input to the model are as follows:

1) $N(y)$ - model predicted anchovy recruitment in November of year y, in billions (from the assessment of de Moor and Butterworth (2012); listed in Table 1);
2) $C(y,m)$ - anchovy catch north of Cape Point during month m, between April and September of year y, in thousands of tons (this catch is dominated by the recruits of the year) - listed in Table 1;
3) $w(y,1)$ - the average anchovy weight-at-age 1 in year y, in grams, from the assessment of de Moor and Butterworth (2012) – listed in Table 1;
3) $wc(y,0.5)$ - the average anchovy catch weight-at-age 6 months in year y, in grams; from the catch weight-at-age in May each year – listed in Table 1; and
4) $M_j = 1.2$ years^{-1} - the rate of natural mortality for juvenile (0-year-old) anchovy in the assessment of de Moor and Butterworth (2012).

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Model

An initial very simple implementation of the "river model" assumes that anchovy recruitment consists of six successive packets of equal size, each remaining within the vicinity of the West Coast islands for a duration of 1 month – thus covering the April to September period typical of the anchovy recruitment run (Butterworth and de Moor 2010a). Pulse fishing is assumed to occur in the middle of each month. The assumption is made that the anchovy available to be taken off the West Coast increase from 6 to 7 months of age during the month they are available to the fishery. The proportion of these anchovy fished in this month, $F(y,m)$, is calculated by solving the following equation:

$$C(y,m) = N(y,m) \times e^{-\frac{6.5}{12}M_j} \times F(y,m) \times w\left(y, \frac{6.5}{12}\right). \qquad (1)$$

The simple implementation thus assumes $N(y,m) = N(y)/6$ and is run both with $C(y,m) = \sum_m C(y,m)\big/6$ to replicate the assumption of uniform monthly catch over the April to September period by Butterworth and de Moor (2010a) ["MODEL1"] and with $C(y,m)$ from Table 1 ["MODEL2"]. The weight of the anchovy at *m* months is calculated assuming linear interpolation between the catch weight-at-age 6 months and the anchovy weight-at-age 1: $w(y,m) = wc(y,0.5) + \frac{m-6}{6} \times (w(y,1) - wc(y,0.5))$.

An extension to this model permits the proportion of anchovy recruitment forming the monthly packet to vary between months. The proportion of recruitment distributed within the vicinity of the West Coast islands can be sampled from a Beta distribution. The estimated proportion of anchovy recruitment from November of year *y*-1 which is in the vicinity of the island during month *m*, is then calculated as follows:

$$p(y,m) = \frac{C(y,m)}{\sum_m C(y,m)} \times Cor + \sqrt{1 - Cor^2}\, p^*(y,m) \qquad (2)$$

where $$p^*(y,m) = \frac{p^{**}(y,m)}{\sum_m p^{**}(y,m)} \quad \text{and} \quad p^{**}(y,m) \sim Beta(v,w)$$

with $$v = \frac{\bar{C}_m^2 (1 - \bar{C}_m)}{Var_m} - \bar{C}_m \qquad \text{and} \quad w = \frac{(1 - \bar{C}_m)(\bar{C}_m (1 - \bar{C}_m) - Var_m)}{Var_m}.$$

$\bar{C}_m$ denotes the average proportion of catch in month *m* over all years and Var_m denotes the variance in the proportion of catch in month *m* over all years. Cor is the estimated correlation between the monthly proportion of anchovy recruitment present close to a colony and the monthly proportion of anchovy catch. The only data currently available to inform this correlation are the small scale surveys around the west coast islands (Robinson and Butterworth 2014 – MARAM/IWS/DEC14/Peng/B6). Appendix A of Butterworth and de Moor (2010b) showed this correlation could be as high as 0.9 based on the 2009 Robben Island surveys, but more recent surveys show the correlation could be almost zero. Thus a range of values for Cor was tested. The number of recruits remaining within the vicinity of the West Coast islands in equation (1) thus becomes $N(y,m)=\frac{p(y,m)}{\sum_m p(y,m)}N(y)$ [1] ["MODEL3"].

The biomass entering the West Coast at the start of the fishing month is then:

$$B^{start}(y,m)=N(y,m)\times e^{-\frac{6}{12}M_j}\times w\left(y,\frac{6}{12}\right) \tag{3}$$

and leaving at the end of the same month is:

$$B^{end}(y,m)=N(y,m)\times e^{-\frac{6.5}{12}M_j}\times(1-F(y,m))\times e^{-\frac{0.5}{12}M_j}\times w\left(y,\frac{7}{12}\right). \tag{4}$$

The density of anchovy as experienced by the penguins is proportional to:

$$D(y,m)=\frac{B^{start}(y,m)+B^{end}(y,m)}{2}. \tag{5}$$

The quantity of interest is how much this density was decreased by fishing, i.e. the "reduction":

$$R(y,m)=\frac{D(y,m)}{D|_{F(y,m)=0}(y,m)}. \tag{6}$$

Results

The median monthly fishing proportion (*F*) and reduction (*R*) quantities calculated are listed in Table 2. The time series of *R* is plotted over time in Figures 1 and 2 for MODEL1 and MODEL2, respectively, while Figure 3 shows the medians and lower 2.5 percentiles for *R* for MODEL3.

Discussion

This update to the original simple implementation of the River Model has shown that over the past decade (which encompasses the period of substantial decline in penguin abundance), fishing decreased the amount of anchovy that would otherwise have been available to the penguin colonies off the West Coast by at most 10%, unchanged from that reported by Butterworth and de Moor (2010a), with a median[2] reduction of 6%. This median reduction becomes 5%, with the largest reduction having been 25% when monthly catches are used while assuming equal "packets" of recruits moving down the coast (MODEL2). Furthermore, the extent of this reduction after 1997 was typically less than before that time.

The introduction of stochasticity (MODEL3) does not change these results qualitatively in median terms. The lower 2.5 percentile values can drop quite low for low values of Cor. However such results should not be over-interpreted, given the intentionally simple nature of this exercise. An analysis incorporating stochasticity

[1] The simple manner in which the stochasticity in recruitment is introduced does allow the possibility of the monthly catch exceeding the number of recruits available. In these cases $F(y,m)$ was capped at 1. In calculations, however, this occurred in 6% of cases when $Cor=0.0$, less than 1% of cases when $Cor=0.5$, and never when $Cor=0.9$. Thus it does not influence the median results reported here.

[2] Median over years 2000 to 2011.

in a fully self-consistent manner would be very complex, given the conditioning on the catches actually made, as explicit account has to be taken of the fact that such catches cannot have exceeded the biomass present during the interval concerned. (This same issue arises in taking process error – in the form of variability about stock-recruitment relationships - into account in simulation testing of assessment methods for specific fish stocks – see ICES (2012) for more details on how this can be addressed.) The temporal correlation structure is also less than straightforward to accommodate as different time scales apply to catches (monthly as considered here), the island surveys (integrating in some sense over a few days) and penguin impact which depends on the foraging trip duration distribution. This would likely require an assessment model structured at perhaps even a daily time step, which would require a substantial investment of analytical resources.

Butterworth and de Moor (2010a) also considered sensitivity analyses to the assumptions for the rate of juvenile natural mortality and the duration of stay of the anchovy recruits on the West Coast (two months instead of one in equation (1)). As their results then were very similar to those for their base case analyses, they have not been repeated here.

The inferences drawn above could be biased if much of the anchovy recruitment passed by well offshore, where it is not available to either the fishery or to the penguins. However Appendix A shows distribution plots from the annual recruitment surveys which indicate that most anchovy off the West Coast to occur within about 25 to 30 n. miles from the shore, in close proximity to the penguin breading colonies, and almost all anchovy is caught within that same distance of the coast (van der Westhuizen pers. comm.). As breeding penguins can forage to such distances, this potential bias would therefore not appear to be substantial.

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Table 1. The annual numbers of model predicted anchovy recruits (in billions), $N(y)$, observed monthly anchovy catch north of Cape Point between April and September (in thousands of tons), $C(y,m)$, annual model estimated weight-at-age 1, $w(y,1)$, and catch weight-at-age 6 months, $wc(y,0.5)$ (in grams).

Year	$N(y)$	$C(y,4)$	$C(y,5)$	$C(y,6)$	$C(y,7)$	$C(y,8)$	$C(y,9)$	$w(y,1)$	$wc(y,0.5)$
1986	436.798								
1987	405.082	41.125	12.987	50.680	76.506	67.440	23.695	10.468	6.228
1988	73.169	3.327	42.391	73.922	60.515	70.107	38.843	11.985	6.168
1989	211.003	56.067	70.481	39.057	12.584	0.000	0.000	11.623	7.309
1990	660.100	35.880	35.026	59.514	0.559	0.216	0.035	10.270	3.818
1991	433.739	36.416	22.424	43.882	5.928	0.872	0.018	9.375	7.406
1992	187.336	51.476	58.769	34.909	43.564	55.954	25.807	9.909	4.942
1993	113.529	42.818	13.730	1.181	10.822	67.137	38.827	11.526	6.555
1994	219.056	17.731	40.973	17.403	0.264	30.101	2.817	12.310	3.723
1995	45.757	21.751	12.867	34.109	32.313	38.732	1.591	6.807	3.070
1996	228.994	3.765	10.004	13.060	0.000	0.001	0.002	7.834	5.149
1997	245.484	0.021	1.169	0.758	18.001	10.760	20.963	13.998	6.519
1998	459.754	18.314	21.366	41.932	12.262	3.702	3.603	12.182	4.676
1999	1336.396	8.378	19.383	26.179	20.114	33.045	50.440	12.029	6.398
2000	1729.574	26.998	37.415	14.414	47.511	52.565	33.846	9.371	5.877
2001	656.840	34.116	32.407	44.128	10.084	30.393	50.400	7.016	5.759
2002	693.254	21.069	6.026	48.717	48.223	33.508	43.361	9.355	6.277
2003	316.918	15.875	23.742	77.744	47.758	16.268	40.211	9.987	3.715
2004	577.183	18.490	37.755	20.077	65.017	20.257	12.233	12.326	5.508
2005	306.907	41.796	53.221	16.312	40.065	24.191	39.675	9.923	5.081
2006	673.270	2.144	4.225	28.756	33.515	19.253	18.748	12.703	4.303
2007	1035.275	17.582	55.979	28.409	31.829	36.179	42.851	8.670	5.988
2008	606.414	5.449	33.863	21.023	25.635	55.484	27.853	7.054	5.554
2009	300.131	9.163	15.588	7.147	36.984	32.546	27.282	10.053	3.660
2010	176.016	24.230	13.324	39.259	63.848	34.272	4.927	11.468	5.122
2011		12.879	21.299	16.988	39.055	12.432	0.006	11.880	4.820

Table 2. The estimated median (for MODEL3) proportion fished, $F(y,m)$, and "reduction", $R(y,m)$.

		MODEL1		MODEL2		MODEL3					
						$Cor=0.0$		$Cor=0.5$		$Cor=0.9$	
Year	Month	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$
1987	4	0.18	0.91	0.16	0.92	0.22	0.89	0.20	0.90	0.19	0.90
	5			0.05	0.97	0.05	0.97	0.07	0.96	0.10	0.95
	6			0.20	0.90	0.18	0.91	0.18	0.91	0.18	0.91
	7			0.31	0.85	0.30	0.85	0.24	0.88	0.21	0.90
	8			0.27	0.86	0.28	0.86	0.24	0.88	0.21	0.90
	9			0.09	0.95	0.15	0.92	0.16	0.92	0.17	0.91
1988	4	0.21	0.89	0.01	0.99	0.02	0.99	0.03	0.99	0.05	0.98
	5			0.18	0.91	0.18	0.91	0.19	0.90	0.20	0.90
	6			0.32	0.84	0.27	0.86	0.24	0.88	0.22	0.89
	7			0.26	0.87	0.26	0.87	0.24	0.88	0.22	0.89
	8			0.30	0.85	0.32	0.84	0.26	0.87	0.23	0.88
	9			0.17	0.92	0.29	0.85	0.25	0.87	0.23	0.88
1989	4	0.61	0.70	1.15	0.43	1.00	0.50	0.98	0.51	0.76	0.62
	5			1.44	0.28	1.00	0.50	0.95	0.53	0.75	0.63
	6			0.80	0.60	0.71	0.65	0.67	0.67	0.64	0.68
	7			0.26	0.87	0.25	0.88	0.32	0.84	0.41	0.79
	8			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
	9			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
1990	4	0.27	0.85	0.45	0.76	0.59	0.68	0.42	0.78	0.33	0.82
	5			0.44	0.76	0.44	0.77	0.36	0.81	0.31	0.83
	6			0.74	0.60	0.65	0.65	0.43	0.77	0.34	0.82
	7			0.01	1.00	0.01	1.00	0.01	0.99	0.02	0.99
	8			0.00	1.00	0.00	1.00	0.00	1.00	0.01	1.00
	9			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
1991	4	0.04	0.98	0.08	0.96	0.11	0.95	0.07	0.97	0.05	0.97
	5			0.05	0.97	0.05	0.97	0.05	0.98	0.04	0.98
	6			0.10	0.95	0.09	0.96	0.06	0.97	0.05	0.98
	7			0.01	0.99	0.01	0.99	0.02	0.99	0.02	0.99
	8			0.00	1.00	0.00	1.00	0.00	1.00	0.01	1.00
	9			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
1992	4	0.22	0.89	0.25	0.87	0.34	0.82	0.29	0.85	0.25	0.87
	5			0.29	0.85	0.29	0.85	0.26	0.87	0.24	0.88
	6			0.17	0.91	0.15	0.92	0.17	0.91	0.19	0.90
	7			0.22	0.89	0.22	0.89	0.22	0.89	0.22	0.89
	8			0.28	0.86	0.29	0.85	0.26	0.87	0.24	0.88
	9			0.13	0.93	0.20	0.90	0.21	0.89	0.21	0.89
1993	4	0.26	0.87	0.38	0.81	0.49	0.75	0.37	0.82	0.30	0.85
	5			0.12	0.94	0.12	0.94	0.15	0.92	0.19	0.90
	6			0.01	0.99	0.01	1.00	0.01	0.99	0.03	0.99
	7			0.10	0.95	0.09	0.95	0.12	0.94	0.16	0.92
	8			0.59	0.70	0.65	0.67	0.42	0.79	0.32	0.84
	9			0.34	0.83	0.58	0.71	0.40	0.80	0.31	0.84
1994	4	0.42	0.77	0.40	0.78	0.55	0.70	0.49	0.73	0.45	0.75
	5			0.93	0.48	0.90	0.50	0.63	0.65	0.50	0.72
	6			0.40	0.78	0.34	0.81	0.37	0.80	0.39	0.78
	7			0.01	1.00	0.01	1.00	0.01	0.99	0.02	0.99
	8			0.69	0.62	0.76	0.58	0.58	0.67	0.49	0.73
	9			0.06	0.96	0.10	0.94	0.14	0.92	0.21	0.88
1995	4	0.37	0.81	0.34	0.82	0.43	0.77	0.41	0.79	0.39	0.80
	5			0.20	0.90	0.20	0.89	0.24	0.87	0.29	0.85
	6			0.53	0.72	0.47	0.75	0.43	0.78	0.39	0.79
	7			0.50	0.74	0.49	0.74	0.44	0.77	0.40	0.79
	8			0.60	0.69	0.65	0.66	0.51	0.74	0.43	0.78
	9			0.02	0.99	0.04	0.98	0.05	0.97	0.09	0.95

Table 2 (continued).

		MODEL1		MODEL2		MODEL3					
						$Cor = 0.0$		$Cor = 0.5$		$Cor = 0.9$	
Year	Month	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$
1996	4	0.21	0.90	0.18	0.91	0.24	0.88	0.23	0.89	0.22	0.89
	5			0.47	0.77	0.46	0.77	0.32	0.84	0.25	0.87
	6			0.61	0.70	0.53	0.74	0.34	0.83	0.26	0.87
	7			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
	8			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
	9			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
1997	4	0.06	0.97	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
	5			0.01	1.00	0.01	1.00	0.01	0.99	0.02	0.99
	6			0.01	1.00	0.00	1.00	0.01	1.00	0.01	0.99
	7			0.13	0.93	0.12	0.94	0.09	0.95	0.07	0.96
	8			0.08	0.96	0.08	0.96	0.07	0.96	0.07	0.97
	9			0.15	0.92	0.24	0.88	0.11	0.94	0.08	0.96
1998	4	0.15	0.92	0.16	0.91	0.21	0.89	0.18	0.90	0.16	0.91
	5			0.19	0.90	0.19	0.90	0.17	0.91	0.16	0.91
	6			0.37	0.80	0.31	0.83	0.22	0.88	0.18	0.90
	7			0.11	0.94	0.11	0.94	0.12	0.94	0.13	0.93
	8			0.03	0.98	0.04	0.98	0.05	0.97	0.07	0.96
	9			0.03	0.98	0.05	0.97	0.07	0.96	0.09	0.95
1999	4	0.10	0.95	0.03	0.98	0.04	0.98	0.05	0.97	0.07	0.97
	5			0.07	0.96	0.07	0.97	0.08	0.96	0.08	0.96
	6			0.10	0.95	0.08	0.96	0.09	0.96	0.09	0.95
	7			0.07	0.96	0.07	0.96	0.08	0.96	0.09	0.96
	8			0.12	0.94	0.13	0.94	0.11	0.94	0.10	0.95
	9			0.18	0.91	0.29	0.85	0.17	0.91	0.12	0.94
2000	4	0.05	0.98	0.04	0.98	0.05	0.98	0.05	0.98	0.05	0.98
	5			0.05	0.97	0.05	0.97	0.05	0.97	0.05	0.97
	6			0.02	0.99	0.02	0.99	0.02	0.99	0.03	0.98
	7			0.07	0.97	0.06	0.97	0.06	0.97	0.05	0.97
	8			0.07	0.96	0.08	0.96	0.07	0.97	0.06	0.97
	9			0.05	0.98	0.08	0.96	0.06	0.97	0.06	0.97
2001	4	0.04	0.98	0.04	0.98	0.05	0.98	0.05	0.98	0.04	0.98
	5			0.04	0.98	0.04	0.98	0.04	0.98	0.04	0.98
	6			0.05	0.98	0.04	0.98	0.04	0.98	0.04	0.98
	7			0.01	0.99	0.01	0.99	0.02	0.99	0.02	0.99
	8			0.03	0.98	0.04	0.98	0.04	0.98	0.04	0.98
	9			0.06	0.97	0.09	0.96	0.06	0.97	0.05	0.98
2002	4	0.09	0.96	0.06	0.97	0.07	0.96	0.08	0.96	0.08	0.96
	5			0.02	0.99	0.02	0.99	0.02	0.99	0.04	0.98
	6			0.13	0.94	0.12	0.94	0.10	0.95	0.10	0.95
	7			0.13	0.94	0.13	0.94	0.11	0.94	0.10	0.95
	8			0.09	0.96	0.10	0.95	0.09	0.95	0.09	0.95
	9			0.12	0.94	0.18	0.91	0.13	0.93	0.11	0.95
2003	4	0.14	0.92	0.06	0.97	0.08	0.95	0.10	0.95	0.12	0.94
	5			0.09	0.95	0.09	0.95	0.11	0.94	0.12	0.93
	6			0.30	0.84	0.26	0.86	0.20	0.89	0.17	0.91
	7			0.19	0.90	0.19	0.90	0.17	0.91	0.16	0.92
	8			0.06	0.97	0.07	0.96	0.09	0.95	0.11	0.94
	9			0.16	0.92	0.24	0.87	0.19	0.90	0.17	0.91
2004	4	0.17	0.91	0.11	0.94	0.14	0.93	0.15	0.92	0.16	0.92
	5			0.23	0.88	0.23	0.88	0.20	0.89	0.19	0.90
	6			0.12	0.94	0.10	0.95	0.12	0.94	0.14	0.93
	7			0.39	0.80	0.40	0.79	0.27	0.86	0.21	0.89
	8			0.12	0.94	0.13	0.93	0.14	0.93	0.15	0.92
	9			0.07	0.96	0.11	0.94	0.13	0.93	0.15	0.92

Table 2 (continued).

		MODEL1		MODEL2		MODEL3					
						$Cor = 0.0$		$Cor = 0.5$		$Cor = 0.9$	
Year	Month	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$	$F(y,m)$	$R(y,m)$
2005	4	0.13	0.93	0.15	0.92	0.20	0.90	0.17	0.91	0.15	0.92
	5			0.19	0.90	0.19	0.90	0.16	0.92	0.14	0.93
	6			0.06	0.97	0.05	0.97	0.07	0.97	0.09	0.96
	7			0.15	0.93	0.15	0.93	0.14	0.93	0.13	0.93
	8			0.09	0.96	0.10	0.95	0.11	0.95	0.12	0.94
	9			0.14	0.93	0.24	0.88	0.18	0.91	0.15	0.92
2006	4	0.13	0.93	0.02	0.99	0.02	0.99	0.03	0.98	0.05	0.97
	5			0.03	0.98	0.03	0.98	0.04	0.98	0.07	0.96
	6			0.22	0.88	0.19	0.90	0.16	0.91	0.15	0.92
	7			0.25	0.86	0.24	0.87	0.18	0.90	0.16	0.92
	8			0.14	0.92	0.16	0.91	0.15	0.92	0.14	0.92
	9			0.14	0.92	0.22	0.88	0.18	0.90	0.15	0.92
2007	4	0.10	0.95	0.05	0.98	0.07	0.97	0.07	0.96	0.08	0.96
	5			0.15	0.92	0.15	0.93	0.13	0.94	0.11	0.95
	6			0.08	0.96	0.07	0.97	0.08	0.96	0.09	0.96
	7			0.09	0.96	0.08	0.96	0.09	0.96	0.09	0.95
	8			0.10	0.95	0.10	0.95	0.10	0.95	0.10	0.95
	9			0.12	0.94	0.19	0.90	0.14	0.93	0.12	0.94
2008	4	0.06	0.97	0.01	0.99	0.01	0.99	0.02	0.99	0.03	0.99
	5			0.07	0.97	0.06	0.97	0.06	0.97	0.06	0.97
	6			0.04	0.98	0.04	0.98	0.04	0.98	0.05	0.98
	7			0.05	0.98	0.05	0.98	0.05	0.97	0.05	0.97
	8			0.11	0.95	0.12	0.94	0.08	0.96	0.07	0.97
	9			0.05	0.97	0.08	0.96	0.07	0.97	0.06	0.97
2009	4	0.10	0.95	0.04	0.98	0.05	0.97	0.07	0.96	0.08	0.96
	5			0.07	0.96	0.07	0.96	0.08	0.96	0.09	0.95
	6			0.03	0.98	0.03	0.98	0.04	0.98	0.05	0.97
	7			0.17	0.91	0.16	0.91	0.13	0.93	0.11	0.94
	8			0.15	0.92	0.16	0.91	0.13	0.93	0.11	0.94
	9			0.12	0.93	0.19	0.90	0.14	0.92	0.12	0.94
2010	4	0.20	0.89	0.16	0.91	0.22	0.89	0.21	0.89	0.21	0.89
	5			0.09	0.95	0.09	0.95	0.11	0.94	0.14	0.92
	6			0.27	0.86	0.23	0.88	0.22	0.88	0.21	0.89
	7			0.43	0.77	0.44	0.77	0.31	0.84	0.25	0.87
	8			0.23	0.88	0.25	0.87	0.23	0.88	0.22	0.89
	9			0.03	0.98	0.06	0.97	0.08	0.96	0.11	0.94
2011	4	0.21	0.89	0.16	0.92	0.21	0.89	0.21	0.89	0.21	0.89
	5			0.26	0.86	0.26	0.86	0.24	0.87	0.22	0.88
	6			0.21	0.89	0.18	0.91	0.19	0.90	0.20	0.90
	7			0.47	0.75	0.47	0.75	0.32	0.83	0.25	0.87
	8			0.15	0.92	0.16	0.91	0.18	0.91	0.19	0.90
	9			0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00

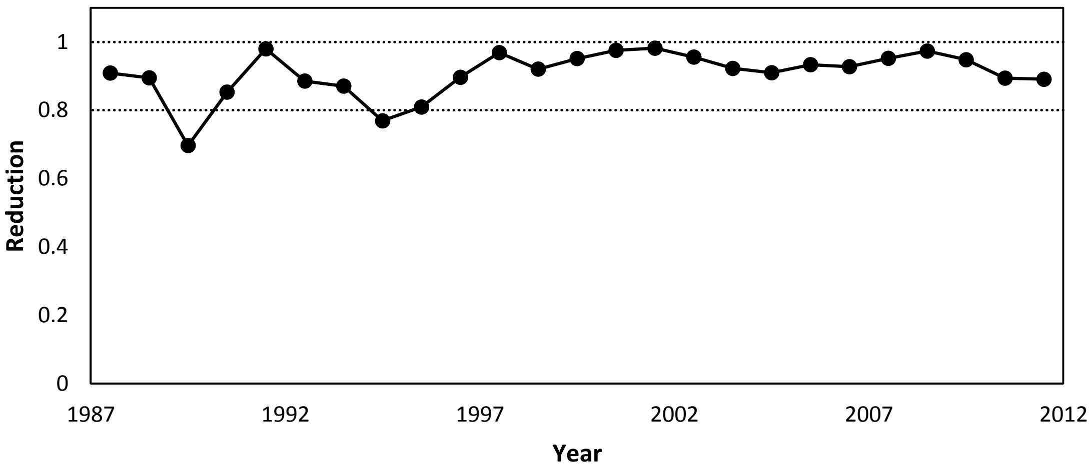

Figure 1. Annual reduction of anchovy, showing the proportion to which the amount of anchovy that would otherwise have been available to the penguins was decreased by fishing for MODEL1.

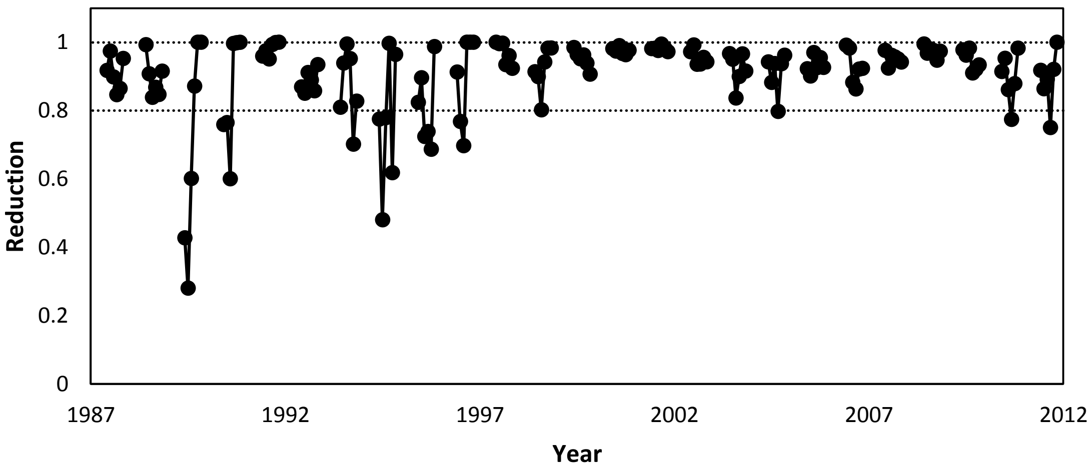

Figure 2. Monthly reduction of anchovy, showing the proportion to which the amount of anchovy that would otherwise have been available to the penguins was decreased by fishing for MODEL2.

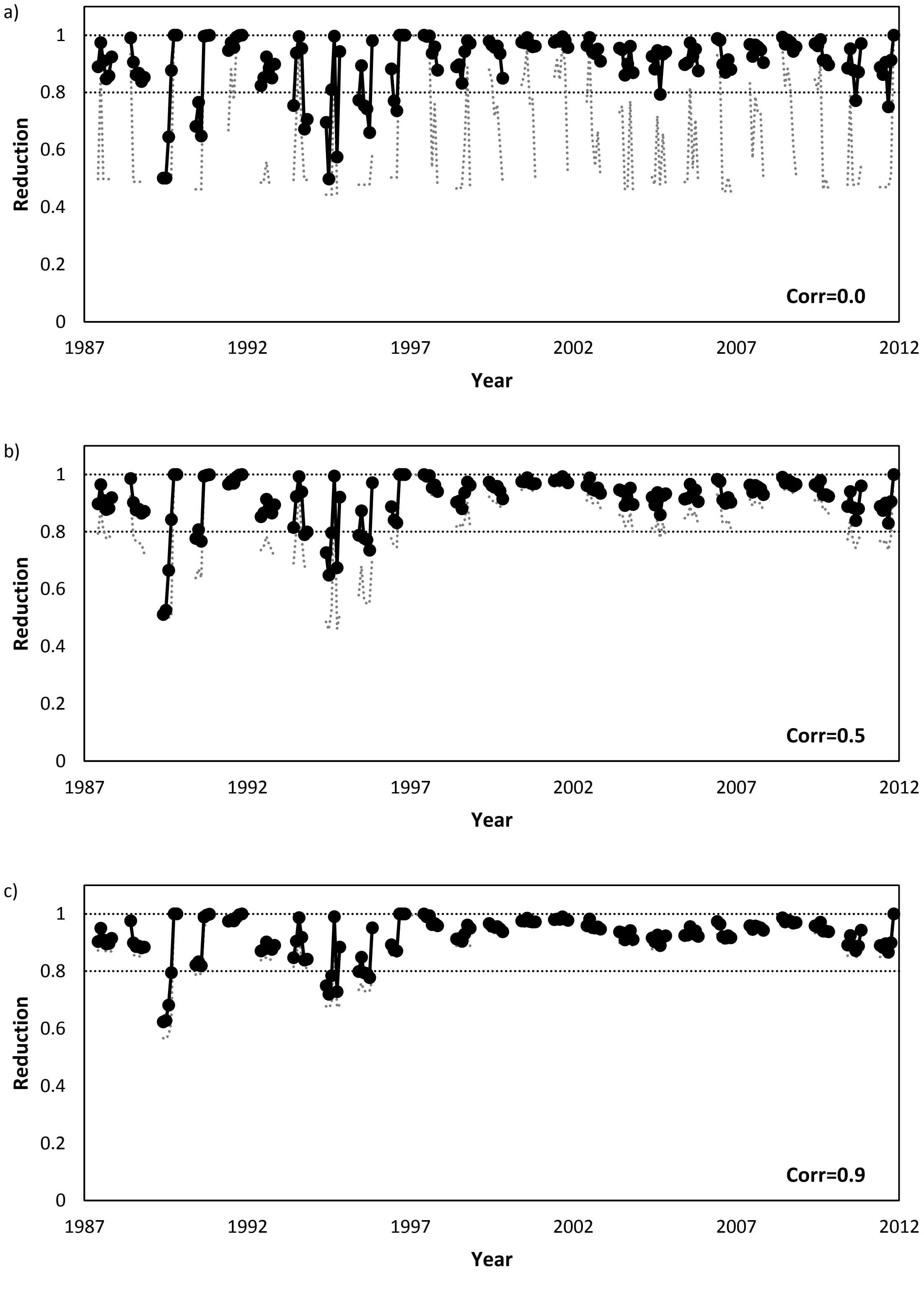

Figure 3. Monthly median reduction of anchovy, showing the proportion to which the amount of anchovy that would otherwise have been available to the penguins was decreased by fishing for MODEL3, assuming a) $Cor = 0.0$, b) $Cor = 0.5$, and c) $Cor = 0.9$. The lower 2.5 percentiles are shown joined by the dotted lines.

Appendix A: Distribution of anchovy off the west coast, from recruitment surveys (originally Appendix B from Butterworth and de Moor (2010b), provided by Janet Coetzee and Dagmar Merkle)

Figure A.1 shows the distribution of anchovy recruitment off the west coast of South Africa during the May hydroacoustic surveys from 2000 to 2010. This shows that most of the recruit density was found close inshore and within a distance of 25 nmi from the coast in the area between Cape Columbine and Cape Point. The highest densities consistently passed southward in close proximity to the two West Coast Islands situated in this area.

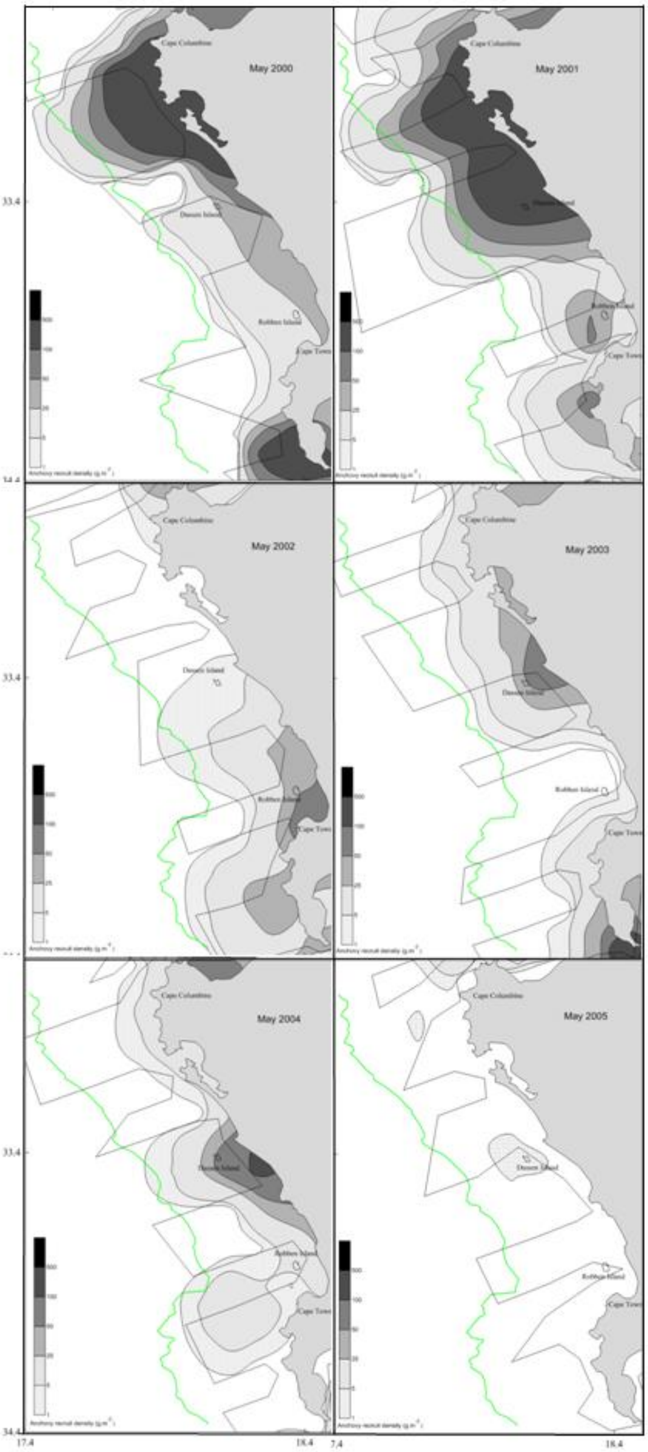

Figure A.1. Recruit densities between Cape Columbine and Cape Point for anchovy, from 2000 to 2010. The green line depicts a distance of 25 nmi from the coast.

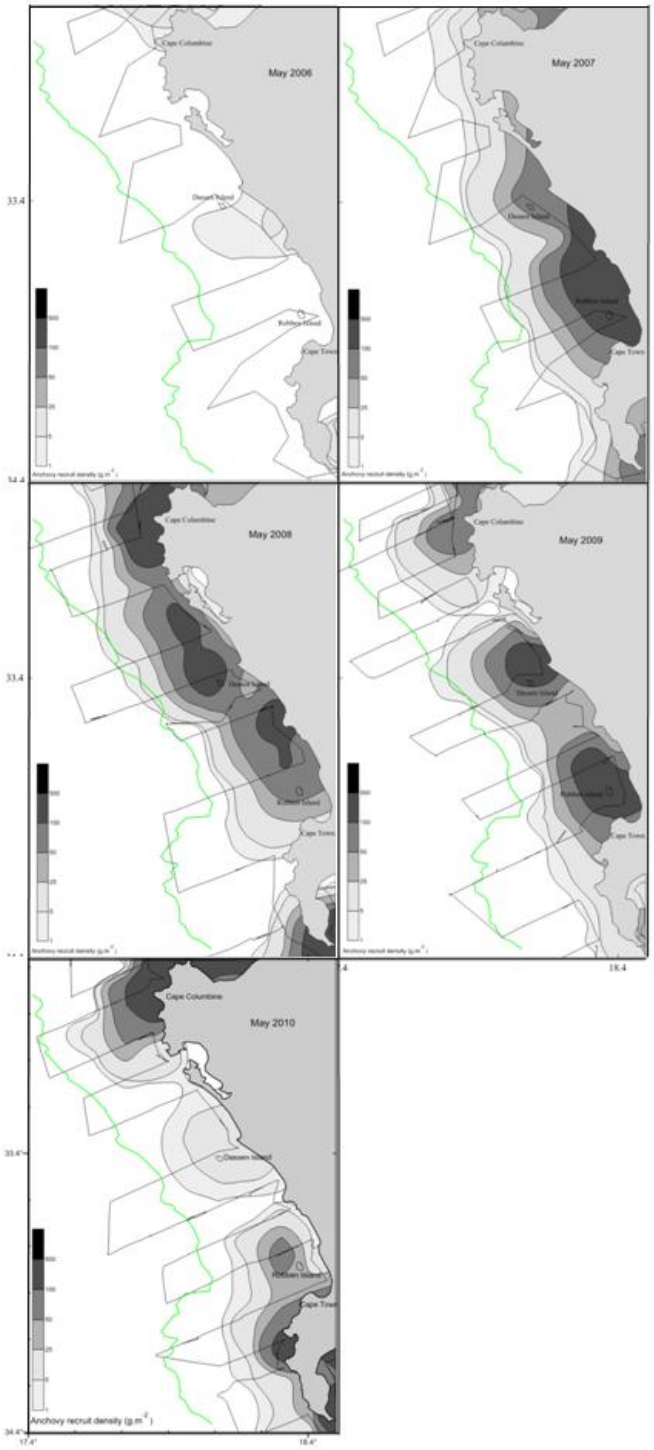

Figure A.1 (continued).