A Very Simple Implementation 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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Abstract

A very simple approach is used to estimate the extent to which the amount of anchovy recruits of the year available to penguin colonies off the west coast has been reduced by historic levels of fishing. This suggests that over the past decade the extent of this reduction has at most been some 10%.

Inroduction

The availability of anchovy to both fishery and predators off the west coast each year is dominated by the southward "run" of anchovy recruits of the year down the coast originating from areas to the south of the Orange river. The run is typically at its height over the April to September period. These calculations model this annual anchovy recruitment process very coarsely as six packets each containing 1/6 of the year's recruits. They follow each other successively, each spending one month in the west coast fishing region – thus covering the April to September period typical of the anchovy recruitment run. We assume pulse fishing in the middle of each month, and the catch taken uniformly over the six months. The purpose of the exercise 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 the penguins.

Data

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

1) $N(y)$ - model predicted anchovy recruitment in November of year $y-1$, in billions (from the assessment of de Moor and Butterworth 2009);

2) $C(y)$ - anchovy catch north of Cape Point between April and September of year y, in thousands of tons (this catch is dominated by the recruits of the year);

3) $w(a)$ - the average anchovy weight at age a, in grams; and

4) $M_j = 0.9$ - the rate of natural mortality for juvenile (0-year-old) anchovy in the assessment of de Moor and Butterworth (2009), in years^{-1}.

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$N(y)$ and $C(y)$ are listed in Table 1. The average weight at age was calculated using a linear interpolation between the average catch weight at age 0 (assumed to correspond to an age of 0.5 years, or 6 months) of 4.86g and the average weight at age 1 in the November survey of 9.72g. This gives a weight at age 7 months of 5.67g and a weight at age 8 months of 6.48g.

Model

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 is calculated by solving the following equation:

$$\frac{C(y)}{6}=\frac{N(y)}{6}\times e^{-\frac{6.5}{12}M_j}\times F(y)\times w\left(\frac{6.5}{12}\right).$$

The biomass entering the west coast at the start of the fishing month is then:

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

and leaving at the end of the same month is:

$$B^{end}(y)=\frac{N(y)}{6}\times e^{-\frac{6.5}{12}M_j}\times(1-F(y))\times e^{-\frac{0.5}{12}M_j}\times w\left(\frac{7}{12}\right).$$

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

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

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

$$R(y)=\frac{D(y)}{D\big|_{F(y)=0}(y)}.$$

Two sensitivities to these calculations are pursued:

A) An increased value of juvenile natural mortality of $M_j=1.2$; (note that the assessment is also re-run for this assumption, leading to a different set of recruitment values $N(y)$) and

B) The recruits are assumed to remain on the west coast for 2 months instead of 1 month. The relevant equations then become:

$$\frac{C(y)}{3}=\frac{N(y)}{3}\times e^{-\frac{7}{12}M_j}\times F(y)\times w\left(\frac{7}{12}\right)$$

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

$$B^{end}(y)=\frac{N(y)}{3}\times e^{-\frac{7}{12}M_j}\times(1-F(y))\times e^{-\frac{1}{12}M_j}\times w\left(\frac{8}{12}\right).$$

Results

The average monthly fishing mortality and reduction quantities calculated are listed in Table 1 for the basic model and for the two sensitivities, and the value of the "reduction" over time is plotted in Figure 1.

Discussion

The results suggest that over the last decade (which encompasses the period of a substantial drop in penguin abundance), fishing decreased the amount of anchovy that would otherwise have been available to the penguins by at most some 10%.

This inference 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 Coetzee (pers. commn) advises that the recruitment surveys show most anchovy off the west coast to occur within about 25 to 30 n. miles from the shore, and almost all anchovy is caught within that same distance of the coast (van der Westhuizen pers. commn). As breeding penguins can forage to such distances, this potential bias does not appear to be substantial.

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Reference

de Moor, C.L., and Butterworth, D.S. 2009. Updated Anchovy Assessment. MCM Document MCM/2009/SWG-PEL/31. 10pp

Table 1. The annual numbers of anchovy recruits (in billions), $N(y)$, the anchovy catch between April and September (in thousands of tons), $C(y)$, and the estimated proportion fished, $F(y)$, and "reduction", $R(y)$, for the basic model and the two sensitivities. Note that recruitment $N(y)$ differs for the sensitivity to an alternative value for juvenile natural mortality M_j.

	Base Case Model				$M_j = 1.2$			2 month stay on west coast	
Year	$N(y)$	$C(y)$	$F(y)$	$R(y)$	$N(y)$	$F(y)$	$R(y)$	$F(y)$	$R(y)$
1987	256.7	271.1	0.33	0.83	340.8	0.29	0.85	0.31	0.83
1988	208.2	285.0	0.42	0.78	269.9	0.38	0.80	0.41	0.78
1989	64.2	172.4	0.83	0.57	81.8	0.77	0.61	0.80	0.57
1990	138.3	130.5	0.29	0.85	177.2	0.27	0.86	0.28	0.85
1991	384.6	109.4	0.09	0.95	509.7	0.08	0.96	0.08	0.95
1992	211.1	265.2	0.39	0.80	270.1	0.36	0.82	0.37	0.80
1993	119.5	173.7	0.45	0.77	154.4	0.41	0.79	0.43	0.77
1994	61.4	106.5	0.54	0.72	77.5	0.50	0.74	0.52	0.72
1995	141.5	140.6	0.31	0.84	182.8	0.28	0.86	0.30	0.84
1996	47.4	26.7	0.17	0.91	62.4	0.16	0.92	0.17	0.91
1997	151.0	50.7	0.10	0.95	199.5	0.09	0.95	0.10	0.95
1998	169.7	101.2	0.18	0.90	223.6	0.16	0.92	0.18	0.91
1999	292.5	156.8	0.17	0.91	386.2	0.15	0.92	0.16	0.91
2000	846.9	210.7	0.08	0.96	1132.2	0.07	0.97	0.07	0.96
2001	841.6	201.0	0.07	0.96	1120.2	0.07	0.97	0.07	0.96
2002	396.1	200.6	0.16	0.92	525.3	0.14	0.93	0.15	0.92
2003	360.7	220.4	0.19	0.90	476.0	0.17	0.91	0.18	0.90
2004	215.1	165.1	0.24	0.88	282.6	0.21	0.89	0.23	0.88
2005	288.5	212.7	0.23	0.88	380.3	0.20	0.90	0.22	0.88
2006	169.2	102.6	0.19	0.90	222.4	0.17	0.91	0.18	0.90
2007	427.3	209.9	0.15	0.92	566.6	0.13	0.93	0.15	0.92
2008	639.2	160.2	0.08	0.96	851.4	0.07	0.96	0.07	0.96
2009	450.4	125.2	0.09	0.96	594.6	0.08	0.96	0.08	0.96

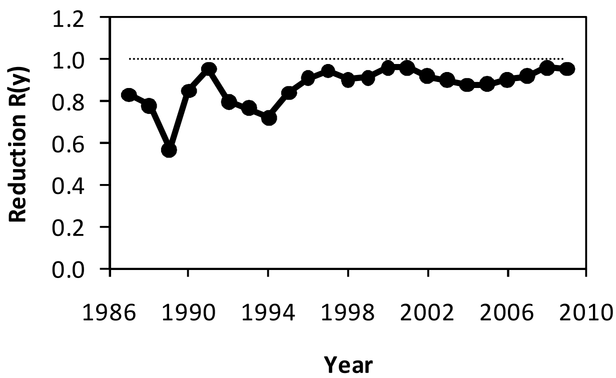

Figure 1. Annual reduction of anchovy, showing the proportion to which the amount of anchovy that would otherwise have been available to the penguins was decreased by fishing. The plot for the two sensitivities is indistinguishable from this for the basic model.