A NOTE ON POSSIBLE CHANGE IN THE MEAN CALVING INTERVAL FOR SOUTHERN RIGHT WHALES OFF SOUTH AFRICA

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A simple approach has been applied to investigate whether resightings of female right whales with calves on annual aerial surveys off South Africa provide any evidence for a change in calving interval over the period from 1979 to 2006 for which data are now available.

Updated data, including some corrections to the data from 1979 to 2003 that were considered in previous reports (Best *et al*., 2001, 2005), are shown in Table 1. The methodology applied is that of Cooke *et al*. (1993), and is set out in the Appendix. Two possible parameterisations of a change in calving interval probabilities are considered, as reflected in Equations (7) and (8) of that Appendix.

The results obtained are shown in Tables 2 and 3, which first reflect the small impact of three further years data on estimates of unchanging calving interval probabilities. The estimation of the additional parameters required to estimate a change in the calving interval frequencies is statistically justified in terms of AIC. For either model considered, there is an indication that a decrease in the mean calving interval from 3.2 to 3.1 years occurred somewhere between about 1985 and 1990. This corresponded to an increase in the proportion of calvings at 3-year intervals from about 0.84 to 0.90, with a corresponding decrease from about 0.14 to 0.08 in the proportions of longer intervals.

The biological significance of such a change is uncertain, but the overall increasing trend in calf production has continued at about 7% a year. Further work will examine these data for evidence of any change in the annual survival rate.

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Table 1. Observed right whale cow-calf pairs on the south coast of South Africa between 1979 and 2006. Number of calvings recorded in each year as well as the number of females that have been resighted with a calf in later years are shown.

a) The number of females recorded to calve both in year *i* and in year *j* (n_{ij}), where $i < j$.

Year *i* (*i* < *j*)	**Year *j* (*i* < *j*)**																										
	80	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**
1979	0	1	17	2	4	14	2	2	10	3	5	8	4	4	6	6	3	4	4	6	4	6	6	6	3	7	5
1980		0	0	22	2	2	15	4	3	17	5	3	15	3	3	16	6	3	10	6	3	12	4	4	11	4	5
1981			0	2	31	0	4	27	2	5	15	8	6	12	5	4	17	6	5	14	3	10	14	4	8	10	4
1982				0	1	28	3	2	24	4	3	18	5	4	14	5	4	12	3	7	10	5	7	10	3	7	9
1983					0	2	21	5	4	23	8	4	17	6	5	18	4	3	15	7	5	17	7	5	12	5	7
1984						0	1	42	5	4	30	8	6	25	7	6	26	10	7	21	7	11	18	7	9	20	8
1985							0	2	34	4	3	28	4	5	28	6	6	19	6	9	14	8	10	17	7	9	17
1986								0	1	31	2	4	22	3	3	19	5	4	13	9	7	17	8	6	12	2	7
1987									0	3	43	5	4	34	4	7	36	8	9	28	5	14	30	7	11	30	10
1988										0	1	38	3	4	35	5	7	30	4	9	21	8	10	24	7	9	22
1989											0	2	47	7	4	39	8	10	31	7	13	34	6	10	23	9	14
1990												0	0	39	1	5	37	4	5	32	3	10	32	6	8	31	9
1991													0	2	47	5	6	39	7	9	32	10	8	31	10	5	29
1992														0	1	51	12	4	39	9	8	37	13	10	27	14	11
1993															0	1	50	6	6	44	7	10	41	9	8	34	15
1994																0	1	58	3	5	48	7	11	43	7	9	37
1995																	0	1	56	6	4	50	9	10	37	10	12
1996																		0	3	77	7	11	63	12	16	54	21
1997																			0	2	67	9	7	57	9	11	49
1998																				0	0	69	9	9	56	11	13
1999																					0	1	91	8	8	75	23
2000																						0	2	91	6	5	80
2001																							0	2	95	10	10
2002																								0	2	104	25
2003																									0	0	106
2004																										0	1
2005																											0

b) Number of calvings recorded in each year *i* (n_i).

Year	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**
n_i	27	33	50	40	43	65	53	44	75	68	78	75	76	84	90	90	96	134	119	111	153	152	169	193	180	186	210	230

Table 2. Estimates of the probability distribution of calving intervals (h_j), mean calving interval (yr) and annual survival rate (S) for right whales off South Africa for a maximum calving interval (j_{max}), of five years, based on the Payne *et al*. (1990) model of Equations (1) to (6) of the Appendix. The change in calving intervals is modelled by Equation (7). Where applicable the estimates for the two time periods are shown. Results in brackets represent 95% confidence intervals based on the Hessian matrix (in the case where a change in the calving intervals has been assumed, these confidence intervals refer to estimates for the first period).

Parameter	**Data up to 2003**	**Data up to 2006**	**Change in 1985**	**Change in 1990**	**Change in 1995**
h_1	0.00	0.00	0.00	0.00	0.00
h_2	0.023 (0.015; 0.031)	0.020 (0.013; 0.026)	0.018 (0.012; 0.024)	0.018 (0.012; 0.025)	0.019 (0.013; 0.026)
h_3	0.853 (0.843; 0.864)	0.853 (0.844; 0.862)	0.826; 0.884 (0.809; 0.842)	0.842; 0.918 (0.831; 0.852)	0.850; 0.925 (0.841; 0.860)
h_4	0.073 (0.065; 0.080)	0.075 (0.068; 0.081)	0.087; 0.058 (0.078; 0.096)	0.079; 0.041 (0.072; 0.086)	0.075; 0.038 (0.069; 0.081)
h_5	0.051 (0.038; 0.064)	0.053 (0.042; 0.064)	0.070; 0.040 (0.057; 0.083)	0.061; 0.023 (0.050; 0.072)	0.056; 0.019 (0.045; 0.067)
S	0.990 (0.983; 0.996)	0.990 (0.985; 0.996)	0.991 (0.986; 0.997)	0.989 (0.983; 0.994)	0.990 (0.985; 0.996)
Mean calving interval	3.149 (3.116; 3.182)	3.158 (3.131; 3.185)	3.205; 3.118 (3.171; 3.240)	3.179; 3.066 (3.151; 3.207)	3.165; 3.054 (3.137; 3.192)
Δ	—	—	0.059 (0.028; 0.089)	0.076 (0.035; 0.118)	0.075 (-0.015; 0.164)
Log-likelihood	7746.8	11207.8	11214.9	11214.0	11209.0

Table 3. Estimates of the probability distribution of calving intervals (h_j), mean calving interval (yr) and annual survival rate (S) for right whales off South Africa for a maximum calving interval (j_{max}), of five years, based on the Payne *et al*. (1990) model of Equations (1) to (6) of the Appendix. The change in calving intervals is modelled by Equation (8). Where applicable the estimates for the two time periods are shown. Results in brackets represent 95% confidence intervals based on the Hessian matrix (in the case where a change in the calving intervals has been assumed, these confidence intervals refer to estimates for the first period).

Parameter	Data up to 2006	Change in 1985	Change in 1990	Change in 1995
h_1	0.00	0.00	0.00	0.00
h_2	0.020 (0.013; 0.026)	0.019 (0.013; 0.026)	0.019 (0.013; 0.026)	0.019 (0.012; 0.025)
h_3	0.853 (0.844; 0.862)	0.828; 0.883 (0.811; 0.845)	0.843; 0.916 (0.832; 0.853)	0.854; 0.907 (0.845; 0.863)
h_4	0.075 (0.068; 0.081)	0.097; 0.048 (0.084; 0.110)	0.083; 0.011 (0.075; 0.091)	0.076; 0.000 (0.069; 0.082)
h_5	0.053 (0.042; 0.064)	0.056; 0.048 (0.039; 0.073)	0.055; 0.054 (0.043; 0.067)	0.052; 0.075 (0.041; 0.063)
S	0.990 (0.985; 0.996)	0.992 (0.987; 0.997)	0.989 (0.983; 0.994)	0.990 (0.984; 0.995)
Mean calving interval	3.158 (3.131; 3.185)	3.188; 3.127 (3.149; 3.226)	3.171; 3.098 (3.142; 3.200)	3.158; 3.128 (3.131; 3.185)
Δ	—	0.055 (0.028; 0.089)	0.073 (0.032; 0.114)	0.053 (-0.047; 0.152)
ξ	—	-0.022 (-0.039; -0.004)	-0.036 (-0.063; -0.008)	-0.049 (-0.118; 0.019)
Log-likelihood	11207.8	11217.8	11217.2	11211.5

APPENDIX

Calving interval and survival rates

Observed calving intervals are biased representations of the true calving frequency, because *inter alia* cows on longer intervals are under-represented in the sample (having a greater proportion of incomplete calving intervals), and no allowance is made for missed calvings. In reality, a cow calving in a particular year might not be photographed because (a) the calf died before the survey, or was born after the survey, or (b) the cow plus calf were outside the survey area at the time of the survey, or were in the survey area but were overflown. To estimate the true calving interval, the maximum likelihood approach adopted in Payne *et al.* (1990) and developed further by Cooke *et al.* (1993) has been used. Their models are summarised below. For a more detailed discussion of these models the reader is referred to the above references.

The same notation as Payne *et al.* (1990) is adopted:

p_j = the probability that a calving in year j is recorded
h_j = probability that a female calving in year m has her next calf in year $m+j$, given that she has survived to year $m+j$
q_j = the probability that a female calving in year m has a calf in year $m+j$, given that she has survived to year $m+j$
n_i = number of calvings recorded in year i
n_{ij} = number of females recorded to calve both in year i and in year j, where $i < j$
j_{max} = the maximum calving interval, where possible values considered are j_{max} = 4, 5, and 6
s_j = the probability that a female that calved in year m survives to year $m+j$
n = total number of years in which calvings have been recorded.

The probabilities q_j are related to the probabilities h_j by the following equation:

$$q_j = \sum_{i=1}^{j} h_i q_{j-i} \ , \tag{1}$$

where q_0 = 1 and the h_i satisfy the condition:

$$\sum_{i=1}^{j_{\max}} h_i = 1. \tag{2}$$

The n_{ij} are assumed to follow a Poisson distribution with expected value given by:

$$\mu_{ij} = n_i s_{j-i} q_{j-i} p_j \quad (i < j)\,, \tag{3}$$

so that the likelihood function is then given by:

$$L(n_{ij}; p_j, h_i, S) = \prod_{j=1}^{n} \prod_{i=0}^{j-1} \frac{e^{-\mu_{ij}} \mu_{ij}^{n_{ij}}}{n_{ij}!}\,, \tag{4}$$

where S is the annual survival rate of females (assumed constant), so that $s_j = S^j$.
The mean calving interval is given by:

$$\sum_{j=1}^{j\max} j h_j s_j \Big/ \sum_{j=1}^{j\max} h_j s_j . \tag{5}$$

This model also provides estimates for p_j given by:

$$\hat{p}_j = \sum_{i=o}^{j-1} n_{ij} \Big/ \sum_{i=0}^{j-1} n_i q_{j-i} s_{j-i} \tag{6}$$

and these in turn yield estimates of the number of calvings in each year ($\hat{N}_j$, where $\hat{N}_j = n_j / \hat{p}_j$). Confidence intervals for the parameter estimates are based on the Hessian matrix.

Change in the probability distribution of calving intervals

Two methods have been used to model a change in the probability distribution of calving intervals after a specified year x where x = 1985, 1990 or 1995. The change in the probabilities h_j apply to calving intervals of 3, 4 and 5 years as (no change is assumed for calving intervals of one and two years):

a) $h_3 \to h_3 + \Delta; \quad h_4 \to h_4 - \Delta/2; \quad h_5 \to h_5 - \Delta/2$. (7)

b) $h_3 \to h_3 + \Delta; \quad h_4 \to h_4 - \Delta/2 + \xi; \quad h_5 \to h_5 - \Delta/2 - \xi$. (8)