Demography of an ice-obligate mysticete in a region of rapid environmental change

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Appendix I

Estimating proportion of mature females using undifferentiated sample of animals of known length

Estimating the pregnancy rate requires knowledge of the proportion of females that are mature and the proportion pregnant. However, the hormonal dataset does not provide us with that information because it does not distinguish between immature females and mature non-pregnant females. The proportion of mature females can be calculated from our undifferentiated by sex length data provided we can estimate the probability that an animal at a given length is both female and mature. Commercial whaling data on sex, length and pregnancy of Antarctic minke whales (AMW) are available from the International Whaling Commission (IWC) data base, and these data were extracted for all the catches in the region 55°W to 70°W longitude from 1972-1987, which encompasses the tip of the Antarctic Peninsula. Records of 513 AMW females and AMW 509 males were available from this region. 393 females were pregnant, but the maturity state of the non-pregnant females is not recorded in the IWC database. Standard lengths of these animals was recorded to the nearest 0.1 m.

The following logistic function was fitted to the female catch data to estimate the proportion mature in each 0.1m length interval (l):

$$p_f\left(l\right) = \alpha\left(1 + \mathrm{e}^{\beta\left(l - l_{m,50}\right)}\right)^{-1} \qquad (0.1)$$

Where:

α is the asymptotic proportion of females pregnant at higher lengths,

β is a rate parameter determining the length span over which maturation occurs, and

$l_{m,50}$ is the length at which 50% are pregnant.

To calculate the maturity ogive we assume that the logistic function with α set to unity then describes the proportion of females mature at each length. We estimated the parameters using a Monte Carlo Markov Chain (MCMC) assuming that the proportions pregnant in each length interval have binomial distributions.

The catch data (figure 6A) shows that the sex-ratio of animals of greater than 9m in length approaches 100% females, but males dominate the sex-ratio at around 8m. Below 8m the sex ratio at length is highly variable because of the small sample sizes. To allow for the high variability in the sex ratio of smaller animals we estimate the probability by fitting the product of two logistic functions so that the female sex ratio for large animals can approach unity, with a dip around 8m, where the smaller males dominate, while being free to accommodate a range of shapes at smaller lengths. However, because the probability of maturity of females under 8m is low, uncertainty in the sex ratio at smaller sizes will not have much effect on the estimates of the proportion mature. The fitted function for the proportion of males in each length interval, l is:

$$p_m(l) = \omega\left(\left(1+e^{\gamma(l-\nu)}\right)^{-1} \times \left(1+e^{\eta(l-\phi)}\right)^{-1} \Big/ \sup\left(\left(1+e^{\gamma(l-\nu)}\right)^{-1} \times \left(1+e^{\eta(l-\phi)}\right)^{-1}\right)\right) \qquad (0.2)$$

where:

ω is the estimated maximum proportion of males

γ, ν, η, ϕ are parameters to be estimated

The proportion of females in length interval l is thus $1-p_m(l)$.

The expected number of females, both mature and otherwise, in our length sample is:

$$N_f = \sum_{i=1}^{n}\left(1-p_m(l_i)\right) \qquad (0.3)$$

The expected number of mature females in our length sample is:

$$N_M = \sum_{i=1}^{n}\left(\left(1-p_m(l_i)\right)p_f(l_i)\right) \qquad (0.4)$$

Hence, the proportion of mature females in the length samples is N_M/N_f. This proportion is then applied to the number of females identified from the biopsies, so that the calculated pregnancy rate (P) is:

$$P = \frac{n_p}{n_f N_M / N_f} \qquad (0.5)$$

Where:

n_p is the number of pregnant females from our hormone analyses and

n_f is the total number of females identified.

A MCMC of length 6 million was used to generate a set of 1999 parameters for the two functions that describe the proportion of females at length and the proportion pregnant at length using binomial likelihood functions. A distribution of pregnancy rate was calculated using all instances from the set of posterior parameters. The prior distributions for each parameter and the basic statistics of their posterior distributions are given in the Table S1.

Table S1. The prior distributions for the parameter used to calculate the sex ratio and maturity functions from the commercial catch data and the basic statistics of their posterior distributions

Function	Parameter	Prior		Posterior	
		Distribution		Median	95% credible interval
Maturity function	Pregnant asymptote α	Uniform	0.85 – 0.999	0.957	0.909 – 0.995
	Rate of maturation β	Uniform	2.0 – 9.0	4.768	3.494 – 7.040
	Length at 50% mature $l_{m,50}$	Normal	$\mu = 8.21$ $\sigma = 0.5$	8.198	8.111 – 8.280
Proportion male	Max. male proportion ω	Uniform	0.60 – 0.85	0.742	0.686 – 0.825
	γ	Uniform	-7.0 – -2.0	-4.75	-6.57 – -3.27
	ν	Uniform	0.0 – 7.0	3.07	0.14 – 6.06
	η	Uniform	3.0 – 7.0	4.89	3.63 – 6.58
	ϕ	Uniform	8.4 – 9.0	8.72	8.53 – 8.84