Revised Age-Compositions for the B-C-B Bowhead Whales

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ABSTRACT
The method for estimating the age-composition of harvests of bowhead whales developed by Schweder and Ianelli (2000) is applied to updated data on age-at-length and catch-at-length to produce revised age-compositions by sex. The results indicate a smaller proportion of very old (100+) animals and a greater incidence of very old males in catches since 1974 than estimated by Schweder and Ianelli (2000).

INTRODUCTION

Schweder and Ianelli (2000) constructed age-compositions for the B-C-B bowhead whales by first modeling the relationship between length and age based on data for 42 bowhead whales reported in George *et al.* (1999), and then allocating the observed lengths in the catch between 1973–92 (Braham, 1995) to ages using this relationship. The uncertainty associated with these age-compositions was determined by bootstrapping the construction of the age-at-length data.

Punt (2006) noted some concerns with the basis for the age-composition information provided by Schweder and Ianelli (2000):

- Schweder and Ianelli (2000) ignored sex when constructing their age-compositions because George *et al*. (1999) did not identify a statistically significant difference between male and female growth. However, the sample size available to George *et al.* (1999) to estimate growth (42 animals) was small in comparison to the age-length data set on which the analyses of this paper are based. This larger sample size supports different growth curves for males and females (Punt, 2006; Lubetkin and Zeh, 2006). One consequence of ignoring sex when creating the age-composition data was that the fraction of very old (100+ years) animals was over-estimated (all animals aged to be 100+ years were males; the two oldest females in George *et al*.'s data set were 38 and 69 years respectively).
- Schweder and Ianelli (2000) mis-interpreted the meaning of animals in George *et al*. (1999) that had negative standard errors.

This paper therefore updates the age-compositions reported by Schweder and Ianelli (2000) using the most recent age-at-length data as well as using updated information on catch-at-length.

METHODS

Data

The data on which the analyses of this paper are based (provided in the Excel spreadsheet "8Feb 07All Ages.XLS") are the pooled age estimates and lengths for 179 (non-foetal) whales. The details of how ages were assigned to whales using various methods of age-determination and the process for pooling ages when multiple age estimates are available for the same whale are provided in Lubetkin and Zeh (2006). The data set contains age-length pairs for 75 males 104 females. The data on whale lengths for 1974-2005 (data for 2006 are preliminary and were ignored for the purposes of this study) were supplied by Craig George (Dept. of Wildlife, Alaska). The catch-at-length data on which the analyses are based are restricted to animals harvested by hunters (code "H"). Data for foetuses, strandings and biopsied animals were therefore ignored.

Analysis approach

The approach taken in this paper to calculating the age-composition of the catch follows that adopted by Schweder and Ianelli (2000). Specifically, the data in Figure 1 were modeled using a log-linear model of the form:

$$A_j = \exp\left(\alpha + \sum_{i=1}^{n} \beta_i (L_j)^i\right) + \varepsilon_j \qquad \varepsilon_j \sim N(0;\delta_j^2) \tag{1}$$

where A_j is the age of the j^th animal,

L_j is the length of the j^th animal,

α , β_i are parameters,

ε_j is a random error with mean 0 and variance $\delta_j^2 = \sigma_j^2 + (\tau_{A_j} \hat{A}_j)^2$,

$\hat{A}_j$ is the estimate of the age of the j^th animal based on the deterministic component of Equation 1,

σ_j is the standard error of the estimate of the age of the j^th animal (see Lubetkin and Zeh (2006) for details), and

τ_{A_j} is the coefficient of variation of the age of the j^th animal.

The results of fitting the age-length data can be used to the estimate the age-composition corresponding to set of lengths $\{L_k : k = 1,..,m\}$ using the formula:

$$p(A=a) = \tfrac{1}{m}\sum_{k=1}^{m} \int_{a-0.5}^{a+0.5} \frac{1}{\sqrt{2\pi}\tau_{A_k}\hat{A}_k} \exp\left(-\frac{(\phi - \hat{A}_k)^2}{2(\tau_{A_k}\hat{A}_k)^2}\right) d\phi \tag{2}$$

where $\hat{A}_k$ is the estimate of the age of the k^th animal for which a length is available based on the deterministic component of Equation 1.

The precision of the age-composition data is determined using a bootstrap procedure. This involved constructing 1000 pseudo age-length data sets by sampling age-length pairs with replacement from the original data set, fitting Equation 1 and then applying Equation 2. The sampling was done separately by sex.

RESULTS AND DISCUSSION

Unlike Schweder and Ianelli (2000), the bulk of the results in this paper are based on fitting model (1) to the data for each sex separately. This is because there is strong evidence (p<0.01) for differences in growth rates between the sexes using a larger data set on age-at-length (179 rather than 42 data points). Support for sex-specific analyses is also provided by Punt (2006) and Lubekin and Zeh (2006) who analysed the data on length-at-age for the B-C-B bowhead whales.

Estimation of a relationship between length and age

A variety of alternative models (choices for the number of β_i terms in Equation 1 and choices for the relationship between the coefficient of variation and the expected age) were examined. Models with n > 1 led to fits that were preferred under AIC. However, these models also produced pathological behaviour (e.g. expected age decreasing with increasing length for very large animals). Given that the application of Equation 2 involved extrapolation beyond the range of the lengths for which age-at-length information is available, it was decided to base the analyses on a model with n=1. This is the same model that Schweder and Ianelli (2000) used. Slight improvements in goodness-of-fit can be obtained by allowing the square of the coefficient of variation to change (generally decrease) linearly with age. However, the small improvement in AIC, the potential for pathological behaviour (very low coefficients of variation for very large animals), and desire for comparability with approach applied by Schweder and Ianelli (2000) led to the decision to base the analyses on a model with a constant coefficient of variation. Consequently, the model applied in this study is identical to that applied by Schweder and Ianelli (2000), except that the analyses were generally conducted separately by sex.

The fit of the model to the data (Figure 1) indicates that the simple (3-parameter) model captures the nature of the data, except possibly for the largest animals, adequately. However, there are few of these very large animals and they often have very large age-estimation standard errors, resulting in the fit to the large animals being given fairly low weight when the parameters of model 1 are estimated.

Estimation of age-composition

Table 1 lists the estimates of the age-composition for the catches of males and females and of both sexes combined. Two sets of results are presented for the sex-combined case: one set in which the results by sex are combined (weighting the catch-at-age for each sex by the catch-at-length for that sex) and one in which results are based on fitting Equation 1 to sex-aggregated data. The latter analysis was conducted because there is no information on sex for 38 animals for which there is information on length. Results are shown in Table 1 for the period 1974-1992 as well as for the period 1974-2005. The former results are presented to allow comparisons to be made with the results in Schweder and Ianelli (2000). Table 2 lists the results of the boostrapping exercise for the entire period.

The results for 1974-2005 are similar to those for 1974-1992. This is perhaps not surprising given the longevity of the species, the lack of substantial variation in birth and calf survival rates, the fact that 384 of the 874 animals in the 1974-2005 sample are also in the 1974-2005 sample, and the fact that the same age-at-length relationship is applied to the catch-at-length data for both periods.

The results in Table 1 for the period 1974-1992 differ in fairly noteworthy ways from the results obtained by Schweder and Ianelli (2000). Specifically, the estimated proportion of very old (100+) animals is lower in this study (point estimates of 0.04-0.05 rather than 0.06), the estimated proportion of very old males is higher (0.07 compared to 0.03), and estimated proportion of very old females is lower (0.02 compared to 0.09). The latter result is consistent with the age-at-length data. All of the oldest animals in the age-at-length data set are males (the oldest female is estimated to be 121.3yr (SE 25.3yr) whereas four of the males are older than this). Also, females tend to be larger than males for the same age (Lubetkin and Zeh, 2006) so a sex-aggregated age-at-length relationship will tend to assign older ages to females than to males even if they are the same age just because of the difference in growth rates.

General discussion

The estimates of age-composition in Table 1 provide the most up-to-date information about the age-structure of the recent (1974-2005) harvests of bowhead whales. These estimates are more comparable with the expectations from the current method of stock assessment (fewer older animals, more younger animals). It should be noted, however, that this paper (and Schweder and Ianelli (2000)) are essentially using a single age-length key to calculate catch age-compositions over a long period. This approach is known to lead to biased estimates of catch age-composition owing to the impact of changes in population age-structure over time (Ricker, 1975). While this effect may be fairly minor for bowheads, we prefer to include age information in assessments using the approach outlined by Punt (2006).

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Table 1
Point estimates of breakdown of the catch of B-C-B bowheads by age-class.

	1974-1992				1974-2005			
Age	Male	Female	All	All*	Male	Female	All	All*
0-20	674	679	677	699	672	703	688	708
20-40	99	134	117	114	112	131	122	120
40-60	75	93	84	76	73	77	75	69
60-80	51	48	49	45	47	42	44	39
80-100	32	23	27	26	30	23	26	24
100+	69	23	46	41	66	24	44	40

* Based on all lengths and a version of Eqn 1 in which the parameters are independent of sex.

Table 2
Bootstrap means, bootstrap standard errors and bootstrap correlation matrices for the age-compositions by sex (1974-2005).

			Correlation matrix					
	Mean	SD	0-20	20-40	40-60	60-80	80-100	100+
(a) Males								
0-20	673	13	1	0.6	0.03	-0.96	-0.95	-0.8
20-40	114	9		1	0.8	-0.46	-0.78	-0.95
40-60	73	3			1	0.16	-0.25	-0.61
60-80	46	2				1	0.91	0.67
80-100	29	3					1	0.9
100+	64	17						1
(b) Females								
0-20	700	10	1	-0.09	-0.72	-0.81	-0.53	-0.36
20-40	133	10		1	0.62	-0.48	-0.79	-0.88
40-60	77	3			1	0.33	-0.1	-0.33
60-80	42	3				1	0.9	0.75
80-100	23	3					1	0.95
100+	25	9						1

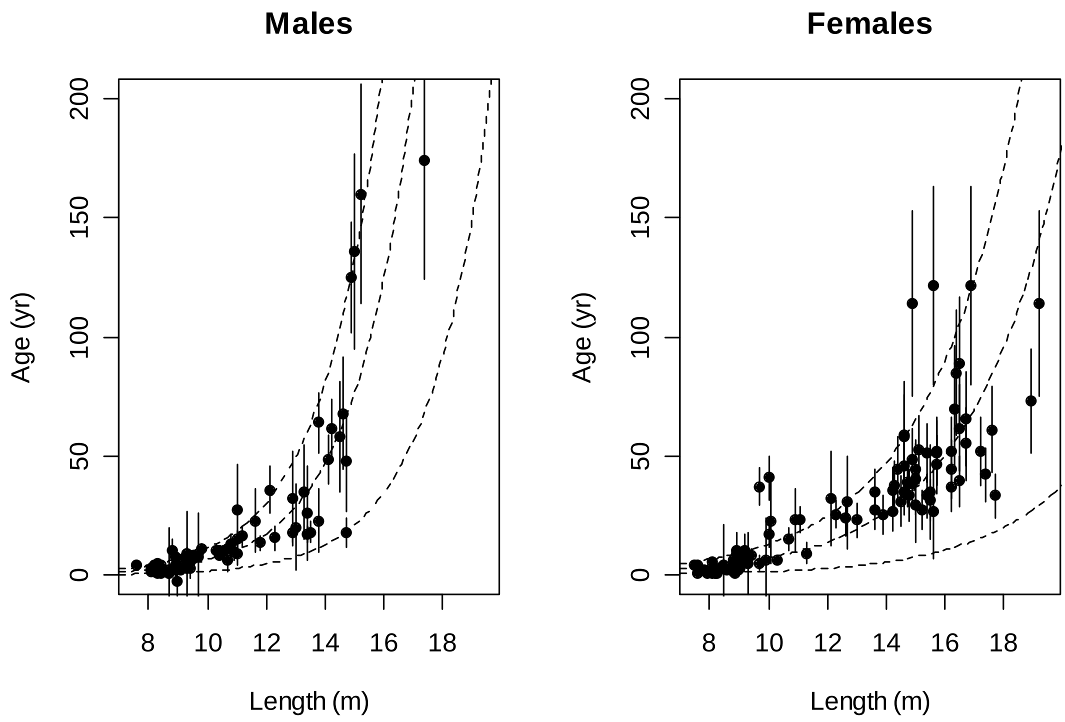

Figure 1
The age-at-length data on which the analyses of this paper are based. The dashed lines denote the fit of model 1 and the 90% intervals for age-at-length.