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Preliminary Estimates of Bowhead Whale Body Mass and Length from Yankee Commercial Oil Yield Records

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ABSTRACT

Oil yield-blubber, blubber-weight, and weight-length data are analysed to develop a preliminary approach for estimating the relationship between oil yield (in barrels of oil) and length (in m). This relationship was then used to estimate the length-frequency distribution for whales harvested during the historic period. Parameter uncertainty, estimated using a bootstrap procedure, indicates that considerable uncertainty remains regarding the predicted length-frequencies. It should be possible to reduce this source of uncertainty given additional data. Whalemen were not selective in their catch, however the length-frequencies from oil data suggest that the average size of whales during commercial whaling was somewhat larger than the average size of whales in the B-C-B population today based on photogrammetry. These data also suggest that whales taken early in the fishery were somewhat larger than those taken later. Further refinement of this analysis may help determine if age/lengths structure shifts occurred through the fishery.

INTRODUCTION

Information on the length-structure of a harvest can be used to estimate the harvest selection pattern, a necessary parameter when estimating how the age structure of a population may have changed through time. Age structure shifts are included in stock assessments and hence determine, in part, population size and trends, and present status relative to reference points such as *MSYL*. The selection pattern of the historical harvest is also needed if changes in the genetic structure of the population are to be modelled (e.g. using the methods of Martien *et al*. (2007)).

Whalemen recorded oil yields in barrels (31.5 US gallons) for several hundred whales killed between 1848 and 1919, during the Yankee pelagic bowhead fishery in the western Arctic (Bockstoce and Botkin, 1983; Bockstoce, 1986)). Although careful records were kept of oil and baleen yields, the whalemen rarely measured the body length of the whales they caught, so there are few data available in the logbooks for directly converting the oil yields to whale size or length. In fact, we found data on body lengths and oil yields for only two whales (reported by Scammon (1874)). However, the approximate size for whales with oil yield data can be estimated by analysing data on whale length, whale mass, and oil rendering.

This paper therefore outlines an approach for estimating whale length (in m) from oil yields (in barrels of oil) based on contemporary information. The approach is then applied to the data on oils yields for 1848-1919 collated by Bockstoce and Botkin (1983). The uncertainty of the resulting estimates is quantified using a bootstrap approach. Partial validation of the method is attempted using the data on oil yields and whale lengths reported by Scammon (1874).

METHODS

General approach

The length, *L*, of an animal which produced *V* barrels of oil can be estimated using the formula:

$$L = a + b\ell n\left(\alpha 31.5\mathrm{V}/\beta\right) \quad (1)$$

where α is the ratio of blubber weight (in kg) to oil (in gallons),

β is the ratio of blubber weight to total weight, and

a, b are the parameters of the relationship between length (in m) and weight (in kg), i.e. $W = e^{b(L-a)}$.

Equation (1) is based on the assumption that each barrel of oil contained 31.5 gallons of oil (the standard oil barrel from the Yankee fishery; Bockstoce (1986)) and that there is no (substantial or systematic) variation (over the period 1849-1905 and over months during year) in the relationships between weight and length, between blubber weight and total weight, and between blubber weight and oil yield.

Parameter estimation

The value for the parameter β is estimated as the mean (over animals) of the ratio of blubber weight to total weight for the given animals (Table 1a) while the value of α is the estimate of mean (over animals) of the ratio of oil yield (in gallons) to blubber weight for four samples (Table 1b). The data in Table 1b were obtained from four sections of blubber from two whales that were weighed to the nearest gram and then rendered into oil by boiling for several hours at 150°C. Mass measurements were made at each stage of the rendering process. As a last step, the “rind” or connective tissue was removed and the volume of the resulting oil measured.

The bowhead weight data are from earlier published estimates (George *et al.*, 1988, 1990, 1992). The values for the parameters of weight-length relationship were determined by fitting the model $L = a + b\ell n(W) + \varepsilon$ to the data on lengths and weights of six bowhead whales landed at Barrow (Table 1c)[1].

Variance-estimation

Application of Equation 1 is subject to several sources of uncertainty, including among-barrel variation in oil content, changes over time in biological parameters, and whether the relationship between weight and length is actually governed by the equation $W = e^{b(L-a)}$. However, this study is restricted to considering the impact of parameter uncertainty. The uncertainty associated with the estimate of the length of animal which produced *V* barrels of oil is determined using a bootstrap procedure. This bootstrap

[1] For the largest animal (89B6) only the blubber mass was weighed, so the whale’s mass was scaled up by 1/0.44, all other whales were weighed in sections and/or directly.

procedure involves replicating the estimation of the parameters of Equation 1. The steps in the bootstrap procedure are:

1. Sample five animals at random (and with replacement) from Table 1a and compute an estimate for β.
2. Sample four data points at random (and with replacement) from Table 1b and compute an estimate for α
3. Sample values for a and b from the variance-covariance matrix obtained by fitting the model $L = a + b\ell n(W) + \varepsilon$ to the data in Table 1c.

RESULTS AND DISCUSSION

Estimation of catch length-frequency

The point estimates of α, β, a, and b are 0.441, 6.138, -23.826, and 3.569 respectively, i.e. roughly 44% of the body mass of a bowhead is blubber, and roughly 193.4 kg of blubber is needed to produce one barrel of whale oil.

Figure 1 shows the distributions for the oil yield data (392 animals) for 1850-59 (when the bulk of the catches occurred), for 1860-69, for 1870+, and for all years combined. Figure 2 shows the best estimates of the length-frequencies by time-period while Figure 3 also displays the 90% intervals for the proportions by 1m-class. Figure 3 indicates that there is considerable uncertainty associated with the assignment of animals to length-classes. Results (not shown) here indicate that uncertainty about the relationship between length and log-weight constitutes the bulk of this uncertainty. The primary reason for the high uncertainty is the small sample size (Table 1c; Figure 4).

Figure 5 shows the same information as Figure 3, except that the results are reported in the form of the mean length of animals per year during 1848-1905. The sometimes wide confidence intervals (for the means) result from high variability among animals in oil yield within each year, and small sample sizes for some years (years for which the sample size is less than 2 are not reported in Figure 5).

The length-frequencies in Figs 2 and 5 suggest that the average size of whales during the early phase of commercial whaling was somewhat larger than the average size of whales in the B-C-B population today based on photogrammetry (Koski *et al*, 2006) (Figure 6). This could be due to selectivity for large animals, the impact of the historical harvest, and simply imprecision/error in Equation 1. However, historic accounts suggest that whalemen were not selective, except that they avoided calves because of their low oil and baleen yields. The largest animals seem to have been taken in the northwestern Bering Sea and Chukchi Sea along the Chukotka coast (Bockstoce *et al.*, In Press).

Bockstoce and Burns (1993) report a massive bowhead taken early in the commercial fishery which produced 375 barrels (44,724 liters[2]) of oil. If these data are accurate, our conversions suggest this was an animal of "blue whale" proportions. That is, the estimated body mass is roughly 164 metric tons. Bockstoce and Burns (1993) also report a 25 m whale taken by the whaleship *Majestic* on 26 July 1850. The length of this second whale lends some credibility to the body mass we estimated for the "375-barrel" whale. No whales nearly this size have been measured in over 7,000 photogrammetric

[2] This could propel a vehicle at 10 km/litre over 400,000 km (assuming an energy density of vegetable oil).

images (e.g., Koski *et al*., 2006) (Figure 6). However, Eskimo hunters tell us they have harvested whales to 22 m in length at Barrow (prior to 1970).

Partial validation and comparison with current data

Mau (2004) measured blubber lipid levels for bowhead whales in several size/sex classes, including: yearlings, sub-adults, mature females (pregnant and non-pregnant), and mature males. The blubber lipid levels ranged from 61.5% to 89.0%. Immature whales were at the high end of the range and large adult males at the low end. We suspect that large females that have recently weaned a calf would have relatively low lipid levels. Post lactational females (and possibly old adult males) may be what Yankee whalers referred to as "dry skins" that produced little oil (Bockstoce, 1986). Lockyer *et al.* (1984) measured a maximum lipid percentage of 77.4% wet weight in the (posterior dorsal) blubber of fin whales. One might expect that rendering fin whale blubber would produce an "oil mass" of, at most, 77% of its blubber mass. The average change in mass (blubber-to-oil) following rendering in our data was 79.5%. This suggests that our oil yield estimates compare reasonably well with "theoretical" oil yield estimates.

Scammon (1874) provides body length and oil yield data for two bowhead whales. These data are listed in Table 2. The data in Table 2 are not inconsistent with the distributions in Figure 7, although the observed lengths are near the upper 95% limits. The results in Table 2 and Figure 7 offer some independent corroboration that the relationship we have derived is reasonable – at least for most of the range of data of oil yields.

This analysis suggests that whales that yielded 200 barrels of oil in the Yankee fishery were roughly on the order of 17 m in body length (95% intervals ~14 - 19 m; Figure 7). Whales of this size are among the larger animals harvested by Eskimos or measured photogrammetrically in the last three decades (Koski *et al*., 2006; Suydam and George, 2004). For comparison, the average length of whales harvested by Alaskan Eskimos from 1974-2006 is 11.25 m (*SD*=3.0). Eskimos hunters generally try to harvest small whales since they are more palatable and are easier to process. Many of the whales that had the largest oil yields were taken early in the fishery (Figs 1 and 7). These large whales may have been adult females since the longest harvested bowheads we have measured have been females. This is consistent with the tendency for females in Family *Balaenidae* to grow larger than males (Koski *et al*., 1993). It should be noted, however, that the largest whale on which the length-weight relationship was based was only 15.7m and its weight was not measured but extrapolated (see footnote 1).

Conclusions and further work

The results of this preliminary study suggest that it may be possible to estimate length-frequency distributions for the harvest of B-C-B bowheads during the 19th Century, and that the animals taken were larger, on average, than those in the current population. The latter might also be explained by selectivity for larger animals, however historic records indicate it was rare for the whalemen to be selective in the whales they chased. The present analysis is based on few data so the predictions are fairly uncertain. While the predictions of the model are not inconsistent with the few data we have on length and oil yield, this remains a fairly weak test owing to the few validation data and the high uncertainty of the predictions. Additional data or refinements along the lines of Tables 1a – 1c and should enable a more through examination of this issue.

ACKNOWLEDGEMENTS

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Table 1. Data used to estimate the values for the parameters of Equation 1.

(a) Total weight – blubber weight			(b) Blubber weight – oil yield	
Whale ID	Total weight (kg)	Blubber weight (kg)	Blubber weight (gm)	Oil yield (gallons)
90B8	27345.1	11801.9	1045.9	0.1828
87B3	14750.0	6551.4	905.0	0.1585
88B4	12170.2	6149.5	238.5	0.0370
88B8	4819.8	1883.0	237.9	0.0357
90B1	13439.2	5855.9		

(c) Weight-length data		
Whale ID	**Length (m)**	**Actual Wt. (Kg)**
88B8	7.50	4820
90B1	8.38	13439
88B4	9.04	12170
87B3	11.00	14750
90B8	12.87	27345
87b6	15.7	55088

Table 2. Basic data for two bowhead whales taken during the period of commercial whaling. Oil was measured in barrels (bbl; 31.5 US gallons).

Whale_ID	**Captain**	**Sex**	**Oil Yield (bbl).**	**Body Length (m)**	**Comment**
Whale A	Poole	Female	80	14.3 m, (47 ft)	Poole thought this whale should have yielded 150 bbls
Whale B	Smith	Male	60	13.7 m (45 ft).	Yielded 476.2 kg (1050 lbs) baleen

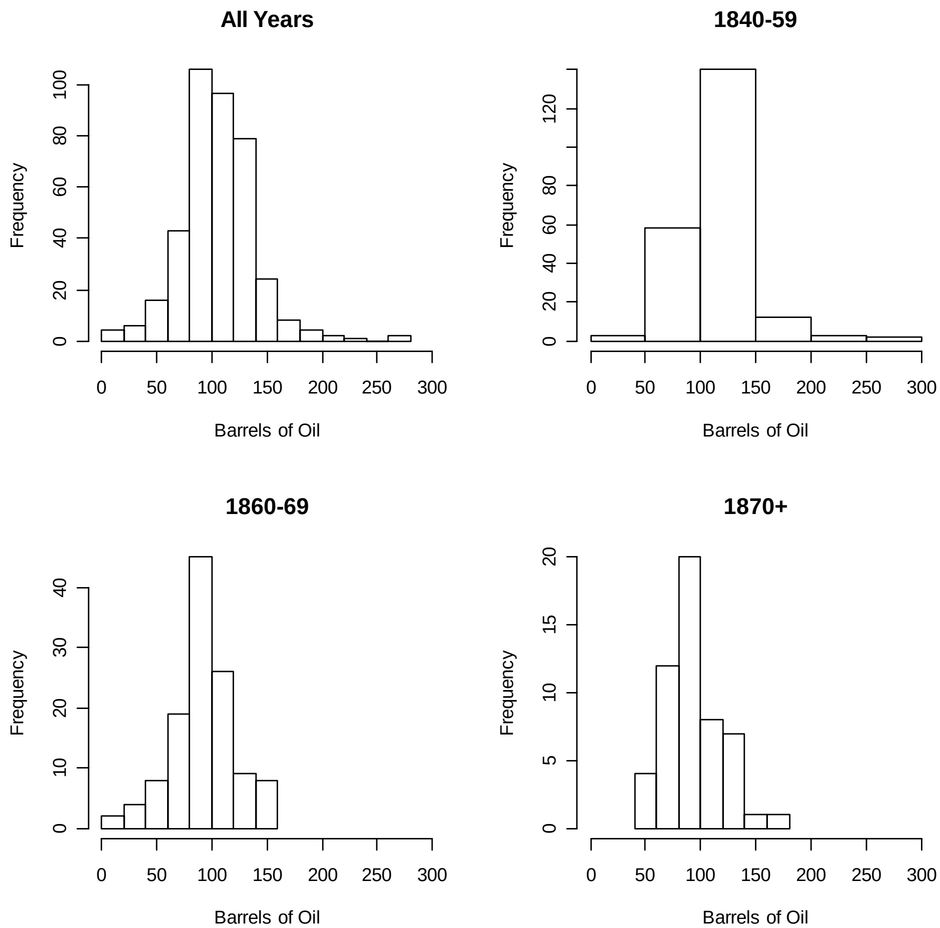

Figure 1
Barrels of oil per whale for three time-periods during the period of commercial whaling of bowheads and for all years combined.

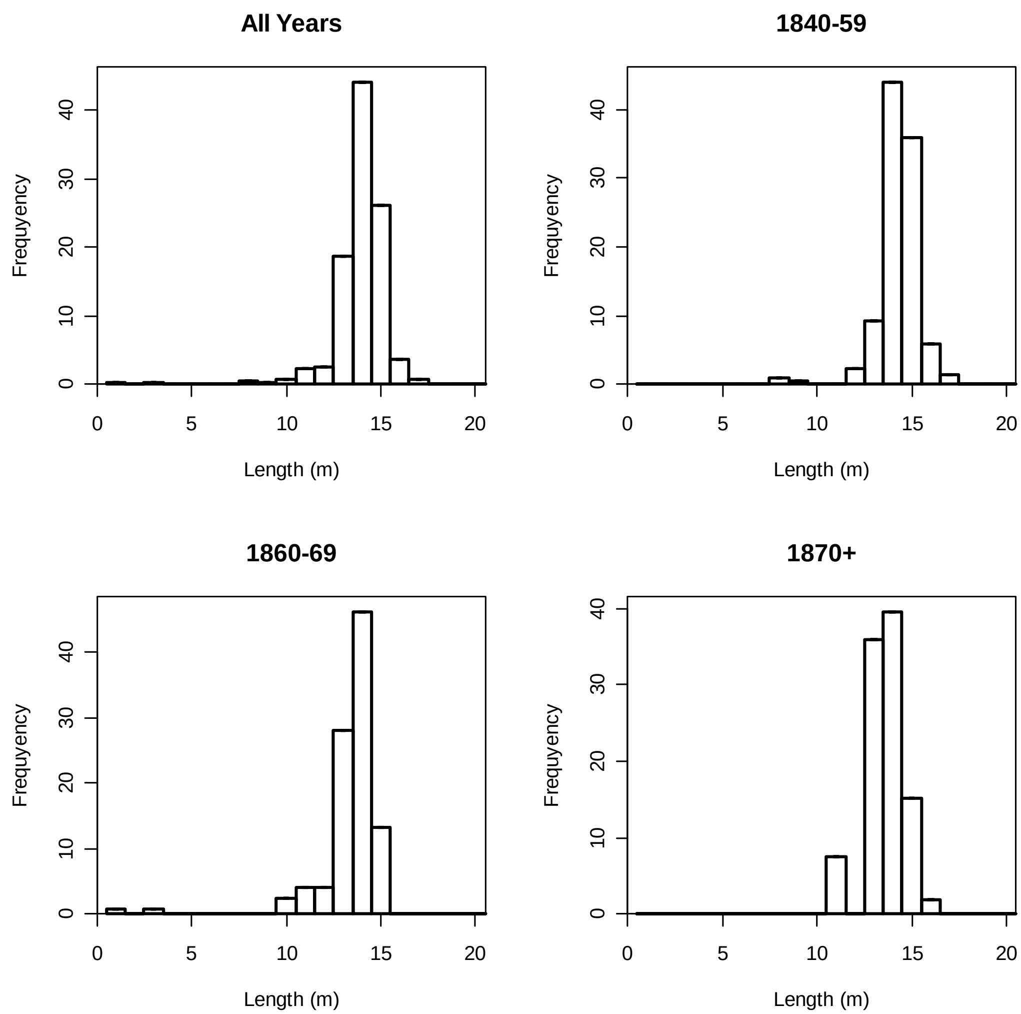

Figure 2
Point estimates of the length-frequency of whales taken in the commercial fishery.

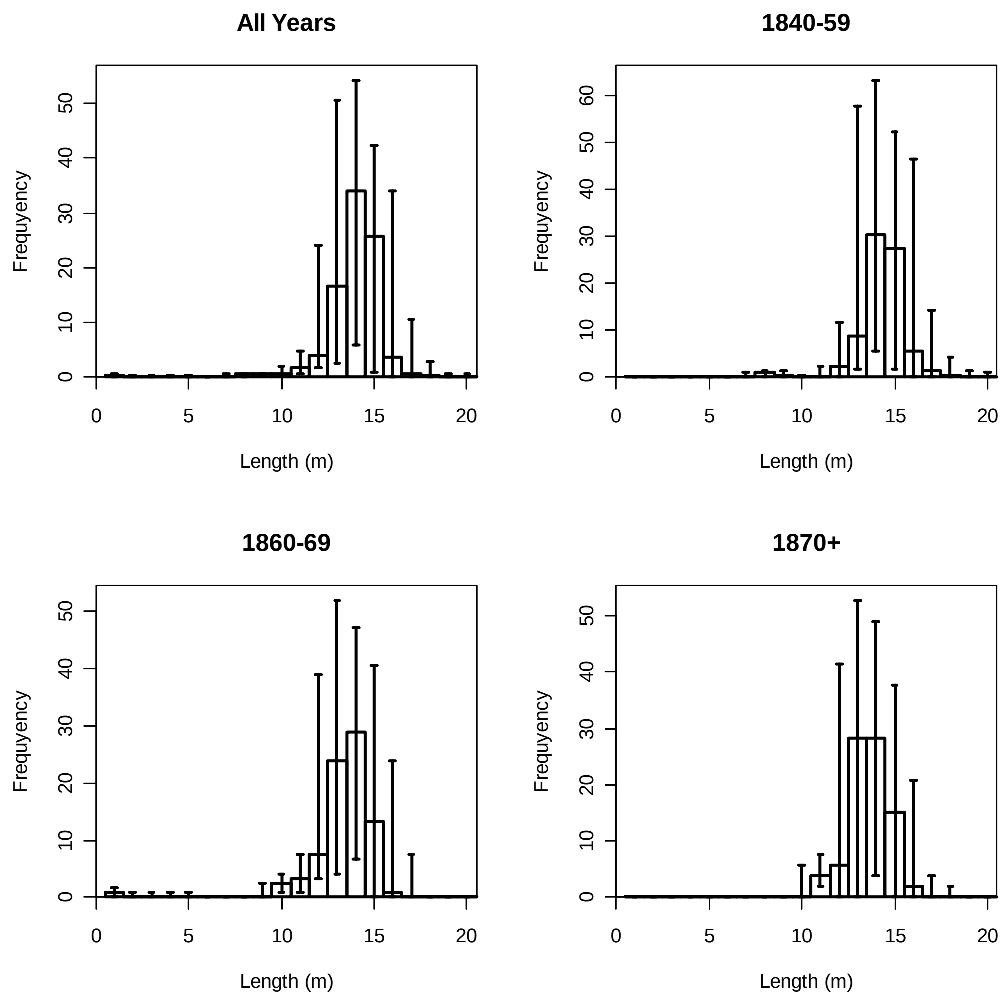

Figure 3
Point estimates of the length-frequency of whales taken in the commercial fishery with associated 90% intervals.

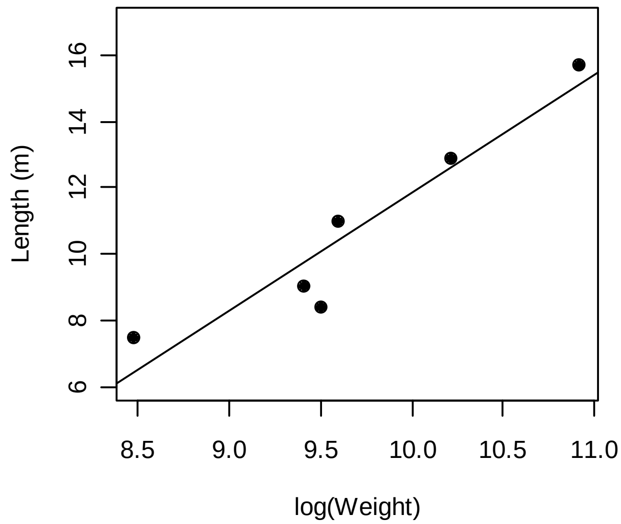

Figure 4
Length versus log(Weight) for six bowhead whales (see Table 1c). R^2 is 0.8621 (p=0.0047)

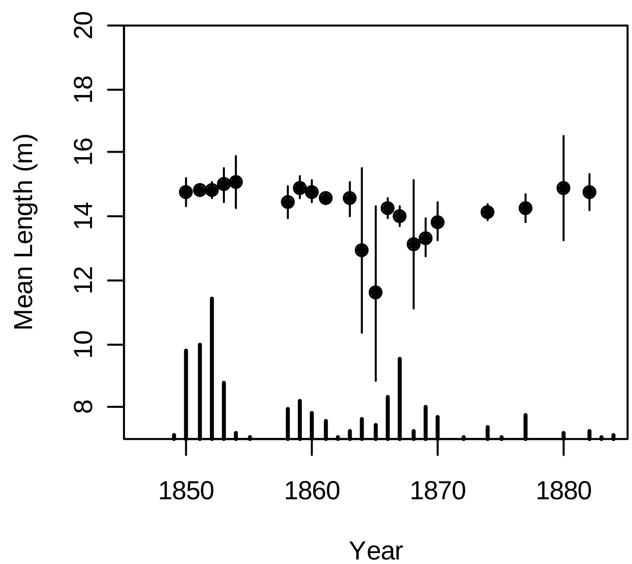

Figure 5
Mean lengths (with 95% confidence intervals) for bowheads harvested from 1849-1885. Results are only shown if data on oil yields are available for at least two whales. The rug indicates the number of animals for which oil yield data are available for the specific year.

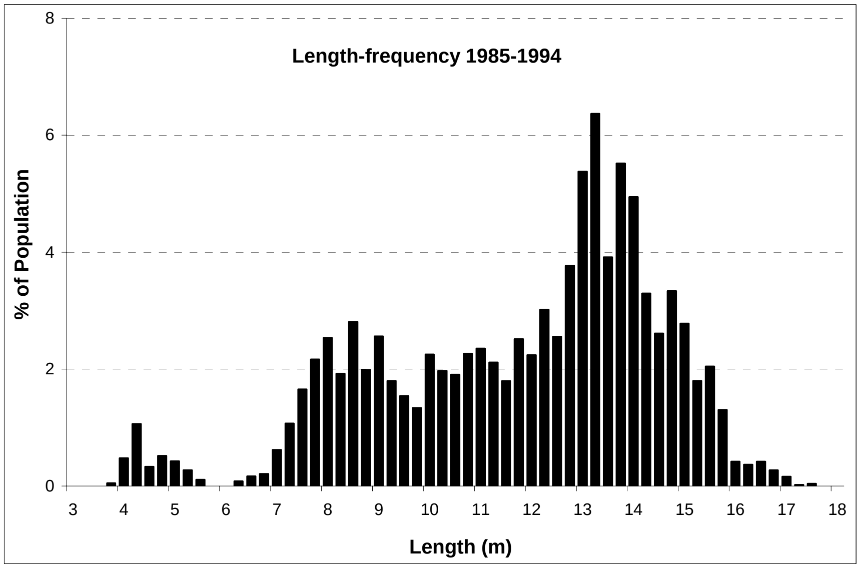

Figure 6
Length frequency data from recent photogrammetric studies of B-C-B Seas bowhead whales in the Beaufort Sea in spring and summer (from Koski *et al.*, 2006). The mean length for all whales is about 11 m, with few whales over 17 m.

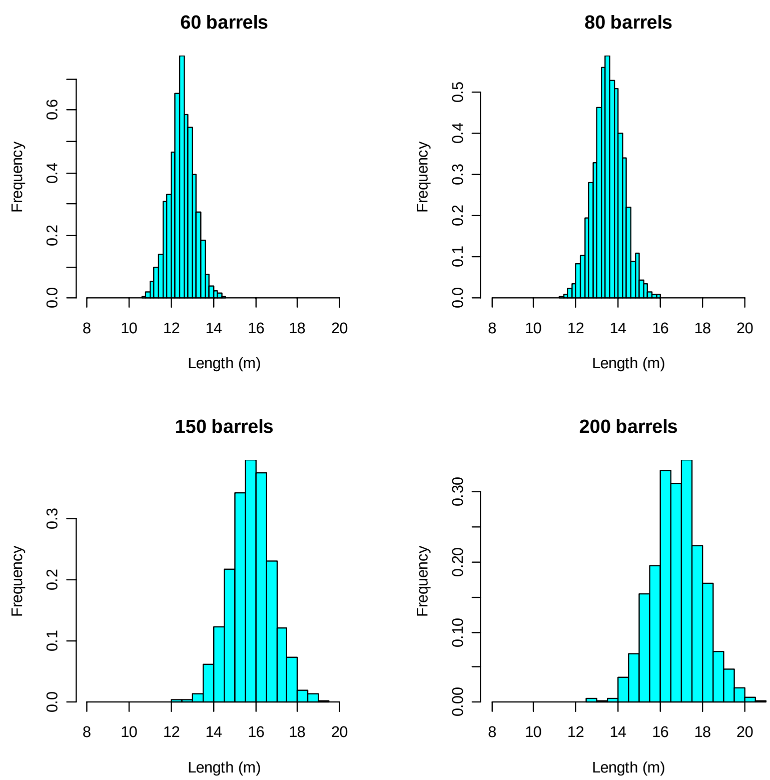

Figure 7
Estimated lengths (bootstrap distributions) for whales that yielded 60, 80, 150 and 200 barrels of oil.