Age Classification of Bowhead Whales using Recursive Partitioning

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ABSTRACT

An algorithm was derived for using morphometric data to classify bowhead whales, *Balaena mysticetus*, into three age brackets: over 90 years ("very old"), 60-90 years ("old"), and under 60 ("younger"). Recursive partitioning was applied to a subset of the data set from postmortem examinations. This subset consists of whales with higher quality data scores and those with characteristics of "older" animals such as near-maximum body length and baleen length, heavy scarring, ancient weapons imbedded in them, etc. Statistical analysis suggested that for males, body length and peduncle girth provide the most useful information for this age classification. For females, anterior flipper length and body length were the key variables for classifying age. If anterior flipper length is not available for females, then body length, baleen length and peduncle girth may be used to classify age.

INTRODUCTION

The subsistence harvest of bowhead whales (*Balaena mysticetus*) in the Bering Chukchi Beaufort Seas stock (BCBS) provides important nutritional and cultural needs for several coastal Alaskan Eskimo and Russian Native communities in the Chukotka region. The Alaska Eskimo Whaling Commission (AEWC) locally manages the harvest through an agreement with the National Oceanic and Atmospheric Administration (NOAA). The hunt has been the subject of scientific scrutiny from both the US and international scientific community since the 1970s. In 1977, the IWC placed a moratorium on the hunt sighting uncertainty about the population size and increased hunting mortality. Following that, in a special meeting, a quota system for the hunt was established beginning in 1978. The quota was uninterrupted for some 25 years, however, at the 2002 IWC meeting (Shimonoseki, Japan), the quota renewal was blocked based on concerns about possible stock sub-structure within BCB bowheads (IWC, 2003, p.18-22).

At the annual meeting of the International Whaling Commission (IWC) in 2004, the US committed to conducting bowhead whale stock structure research. Elements of the stock structure program were discussed during the 2004 meeting of the IWC Scientific Committee (Item 9.1.6 of the Report of the SC).

Givens *et al.* (2004) provided some of the first genetic evidence of population structuring in the Bering Chukchi Beaufort Seas (BCBS) stock of bowhead whales. However, they also found evidence of age related genetic structuring termed "generational gene shift" (GGS) and concluded:

> *"As yet, it is impossible to determine if observed differences among groups are attributable to 1) a single stock exhibiting generational gene shift, 2) a sub-stock harvested around St. Lawrence Island, 3) two stocks having different temporal migration patterns past Barrow, 4) inadequate data with small sample sizes consisting of unrepresentative whales and potentially unreliable genetic loci, or 5) some combination of the above."*

Jorde *et al.* (2004) also found evidence of temporal genetic structuring in whales migrating past Point Barrow in autumn. However, this structuring could also be related to age classes since there is stock size/age structure in both the spring and fall migration, and the magnitude was unclear.

Interpretation of genetic data using samples from the bowhead hunt is complicated by two factors: 1) the population is out of genetic equilibrium resulting from a recent history of a large reduction (from commercial whaling) followed by a rapid expansion, and 2) the hunt is known to be non-random with respect to age (smaller animals are often preferred). To aide in interpreting empirical data, simulation are being conducted to emulate the population dynamics and the sampling. The latter requires some estimate of the age of the whales from which genetic samples originated (B. Taylor, pers. comm., 2007; Martien *et al.* 2007).

Expected patterns of genetic heterogeneity can be computed under the age model and compared to observed data. The relevant cohorts for this comparison are "very old", "old" and "younger" whales. The "very old" whales are ones that were born before 1909 which was near the end of the commercial hunt. We approximate this cohort with whales believed to be at least 90 years old at time of harvest. Old whales are defined to be between 60 and 90 years in age. All others are designated to be "younger" whales.

METHODS

We use a subset of the bowhead whale harvest database maintained by the North Slope Borough (1973-present). The variables include: whale identification code, an assessment of the data quality, sex, length, baleen length, testis length, anterior flipper length, corpora count, estimated age, aging technique, and verbal comments describing other characteristics of note.

Our subset, with 74 females and 49 males was selected according to the following criteria. Whales were included that had the highest data quality scores (1 and 2; scale 1-5), for which we have estimated ages and data on at lest two morphometric measurements. Because of the very small number of "very old" whales, and because a goal is to classify whales into the three age cohorts of Martien *et al.* (2007), we also included whales that did not have assigned ages, but that are believed to be particularly old based on verbal comments in the data set. Suitable comments included "stone point in blubber" since it is acknowledged that hunting with stone harpoon points ceased in ~1880 with the advent of Yankee weapons for hunting. Thus a whale with a stone point in its blubber must have been very old – and certainly alive before 1919. Revisions to our data set were made when the recent updates of age estimates (Zeh, pers. comm., 2006) differed from the values in the full bowhead whale harvest database.

Recursive partitioning (Clark *et al.* (1992)) is a statistical method for classifying multivariate data points into categories based on qualitative and/or quantitative variables. That is, the input or covariate data may be qualitative or quantitative. The output or dependent variable is categorical. Recursive partitioning methods are well suited to the present analysis also because of their adaptability to missing data. Another critical advantage is that, unlike other methods such as logistic regression, the resulting partition can include more than just two categories, such as the three age categories of present interest.

The recursive partitioning algorithm creates a classification tree by a series of binary spits of the data based on covariate values. At each branching of the tree the data are partitioned into two subgroups based on a binary split at a selected value of a selected covariate. The covariate and the splitting value used are optimal in the sense that they minimize the misclassifications into the categories of the output variable. Any individual with missing information for some

covariate(s) is not used in setting the split value for covariate(s) it is missing, but is included in setting the split values when the relevant covariate data are available. That is, if the peduncle girth measurement for a whale is available, but baleen length is missing, then that whale would be included in setting a split value based on peduncle girth, but cannot be used in setting a split value based on baleen length. Thus, using recursive partitioning, we can include individuals for which we have only partial information. Recursive partitioning was implemented using the *rpart* algorithm in the R statistical package.

For the present analysis, males and females are analyzed separately. Growth curves differ noticeably for the two sexes of bowhead whales. Because a goal is to partition these whales into age categories based on morphometric measurements, separate models are appropriate. The separately constructed models perform very well.

Corpora counts are likely good predictors of age (for females) (George et al., 2004). Graphical data exploration indicates that the females are categorized less successfully than are the males using the variables at hand, except for corpora counts. However, in our data set, the age values of many of the females, and of all of the older females, are estimates based on corpora counts. Therefore it would be circular and not valid to use corpora counts for age classifying these whales. For estimating the ages of the female whales, as opposed to age classifying, we recommend using models that specifically target use of corpora counts.

RESULTS

Males

Based on recursive partitioning of the 49 male whales in our data set, the initial division is based on body length. The 40 whales with body length less than 14.55 m are classified as “younger”. All thirty-nine of the whales with estimated ages less than 60 years were successfully partitioned off in this step. Among the longer whales (length at least 14.55 m) a second split at peduncle girth < 190.5 cm. Five of the 6 “very old” (aged over 90 years) whales were identified at this stage. All 3 of the “old” (aged 60-90 years) whales were correctly identified as well. Thus, this set of splits correctly classifies all but one of the 49 male whales in the data set. The one whale that was not classified correctly is whale 95B16, which fell into the “very old” category. It measured 14.1 m in length and a peduncle girth of 169 cm. Thus it was noticeably the smallest “very old” whale. The others measured between 15.2 and 17.7 m in length, with peduncle girths between 190 and 230 cm. Whale 95B16 was aged via aspartic acid racemization to be 92 years. It is at the low end of the “very old” age category. We later checked the field notes for whale 95B16, which said “morphometric data suspect” because the examiners were inexperienced – thus in further analysis, this whale should possibly be excluded from the dataset. The resulting classification tree is displayed in Figure 1. This classification yields correct classifications for 47 of the 49 whales, as summarized in Table 1.

Empirical probabilities also are given in the table. They are P(actual category i | estimated category j). For example, the six whales classified as "very old" are represented in the column for estimated age category “very old”. Five of them actually are "very old" and one actually is "old" (60-90 years). Thus, in the “very old” estimated age category column of Table 1, five of six, or 0.83 of the whales actually are “very old” (over 90 years). One of six, or 0.17 actually is “old”, and none of the six, or 0.00 actually is “younger”.

Females

For the 74 female whales in our data subset, the initial binary split was based on anterior flipper length. Three groups are separated – those with anterior flipper length less than 287.5 cm, those between 287.5 and 299 cm, and those greater than 299 cm. Further divisions within these groups classify individuals based on body length. Within the 287.5 to 299 cm flipper length group,

individuals at least 16.25 m in length are classified as “old” (60 to 90 years). The shorter individuals are classified as “younger” (under 60 years). Within the under 287.5 cm flipper length group, individuals at least 18.15 m in length are classified as “old” (60 to 90 years). Again, the shorter individuals are classified as “younger” (under 60 years). The resulting groups are displayed in Figure 2.

This set of splits results in perfect classification for our set of 74 female whales, except for 2 whales. One “very old” and one “old” whale, with body lengths recorded at 15.6 m and 16.4 m respectively each were classified as “younger”. Both had missing data for anterior flipper length. The empirical classification counts from classifications based on anterior flipper length and body length are given in Table 2.

The two whales misclassified by this recursive partitioning tree both had missing anterior flipper length and anterior flipper length was the first variable used in a binary split in this tree. Therefore a second binary tree was made for the case when anterior flipper length is not available. The resulting tree uses body length at the first split, then baleen length, and peduncle girth.

Omitting anterior flipper length as a candidate explanatory variable, the recursive partitioning tree for age classification of the 74 females whales is as follows. The resulting partition tree is displayed in Figure 3.

When anterior flipper length is missing for a female whale, this back-up algorithm, constructed without the anterior flipper length variable, can be used. Females initially are partitioned according to body length. Those less than 16.25 m long, are classified as “younger”. The whales with body length at least 16.25 m in length are partitioned into three groups according to baleen length. If baleen is less than 321 cm then the whale is classified as “younger”; if baleen is in (321 - 354) cm then the whale is classified as “old”; if baleen is at least 354 cm then another portioning is made. Within this group of large whales (>16.25 m body length) and long baleen (>354 cm), two subgroups are formed based on body length. The split is at 17.5 m. Those longer than 17.5 m are classified “very old”. Those shorter than 17.5m are subdivided by peduncle girth. If peduncle girth is less than 197 cm, then the whale is classified “younger”. If its peduncle girth is at least 197 cm, then the whale is classified “very old.” The resulting classification yields correct classifications for 71 of the 74 whales, as summarized in Table 3.

Description of Figures

Males

Graphical displays of the data are useful for confirming the validity of the partitioning results. Figure 4 shows body length versus peduncle girth for the 49 male bowhead whales. The points are coded by age category. It is readily apparent from this plot that body length and peduncle girth would be good predictors for age category. The dotted lines added to the plot indicate the subgroupings from the recursive partitioning algorithm. Whales whose points are to the left of the vertical dotted line are classified as “younger”. The crosses indicate the whales that actually are “younger”. From Figure 4 we see that all of the “younger” whales were correctly classified by the recursive partitioning algorithm. Whales whose points are to the right of the vertical dotted line and below the horizontal dotted are classified as “old”. The circles indicate the whales that actually are “old”. Again, we see that all of the “old” whales in the plot were correctly classified. The algorithm classifies all whales in the upper section of the plot as “very old”. The whales classified in the data set as “very old” correspond to the triangular plot points. The triangular point outside this region corresponds to the misclassified “very old”.

Females

Similarly for the 74 female whales in the data set, Figure 5A shows anterior flipper length versus body length, corresponding to the main recursive partitioning algorithm derive, Figure 6A shows body length versus baleen length for these whales. These are the primary variables used in the

back-up portioning algorithm for the case when anterior flipper length is not available. Figures 5B and 6B focus on the upper ranges of the displayed variables to show more clearly the partitions.

DISCUSSION

The recursive portioning algorithms perform very well in identifying age classification for these bowhead whales. For males, 47 of the 49 of the whales were classified correctly. For females, 71 of 74 were correctly classified by the primary algorithm. This is a 96% rate of correct classification within each sex group.

However, we urge caution because these analyses were based on very limited sample sizes, especially at the upper age range. The results therefore have limited reliability.

There are substantially more data for the younger age classes; hence, richer models could be developed for those animals. Such models potentially could yield numerical estimates of ages rather than relying on age categories as we have in this analysis. The use of age categories in this analysis was appropriate here since we were primarily concerned with the detection of "very old" whales.

Data on the upper age range are sparse. Several of the oldest whales do not have numerical estimates for age, but based on qualitative findings (e.g., heavily scarred) were deemed to be very old.

The morphological growth patterns are of some interest. For females, we found an allometric relationship that suggests the pectoral limbs (flippers) for very old females are disproportionately larger than younger whales of similar body length. For males, body length and peduncle girth provide the most useful information for age classification. The latter suggests that the caudal region of old males is more robust than younger males of similar length. The evolutionary significance of these growth patterns (for both males and females) is unknown.

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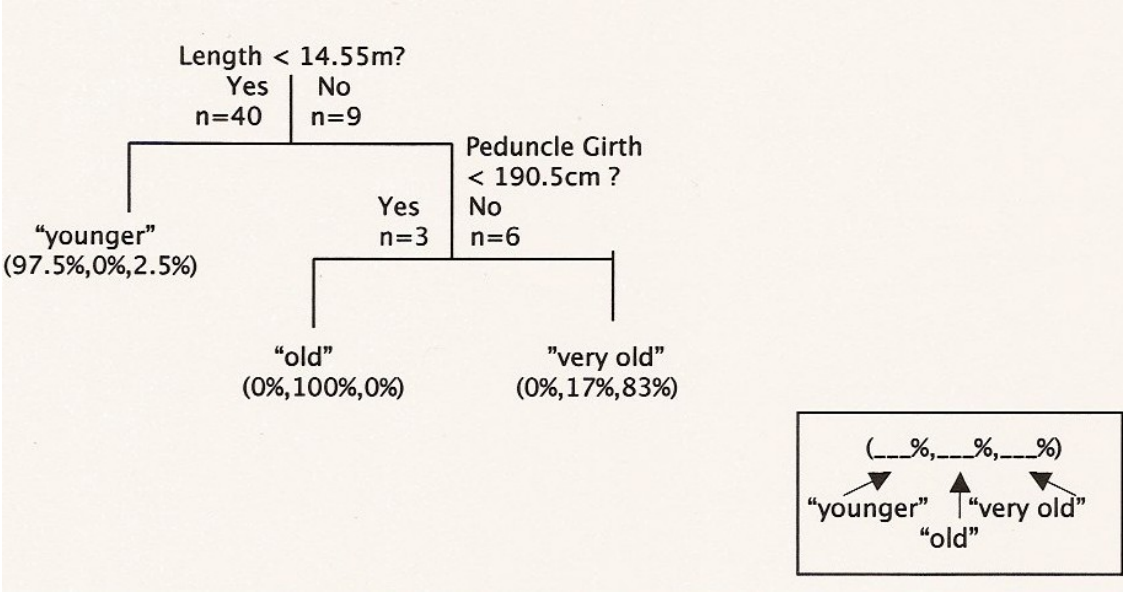

Figure 1. Partition for age classification of male bowhead whales using body length and peduncle girth.

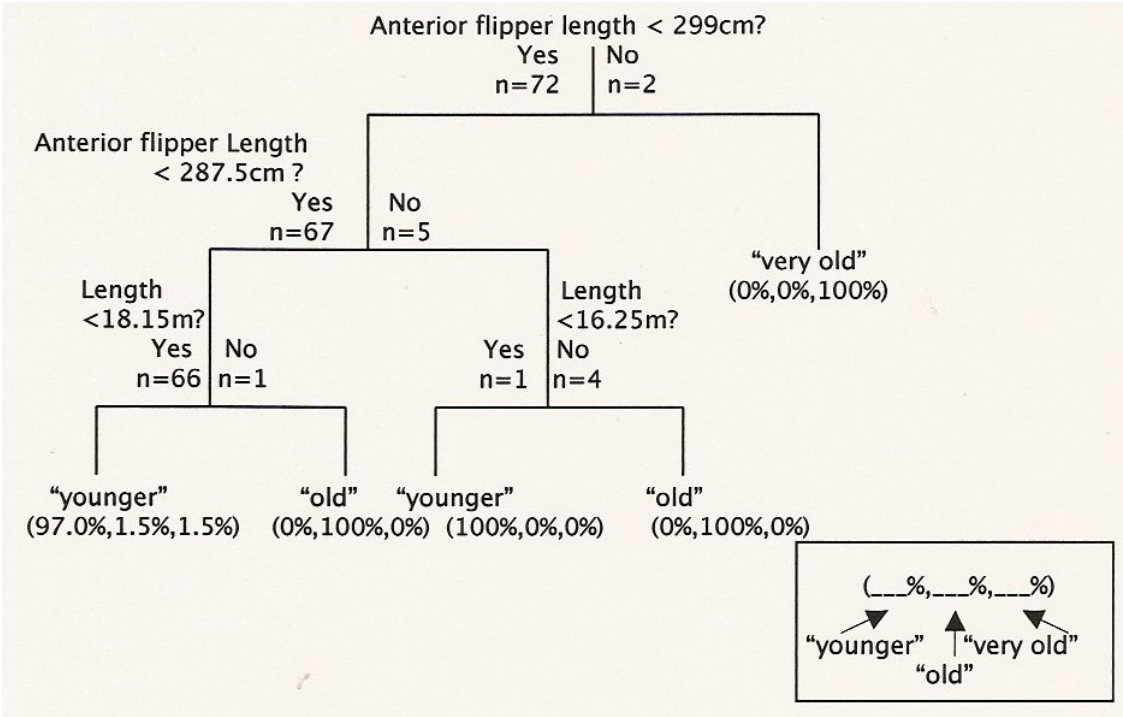

Figure 2. Partition for age classification of female bowhead whales using anterior flipper length and body length.

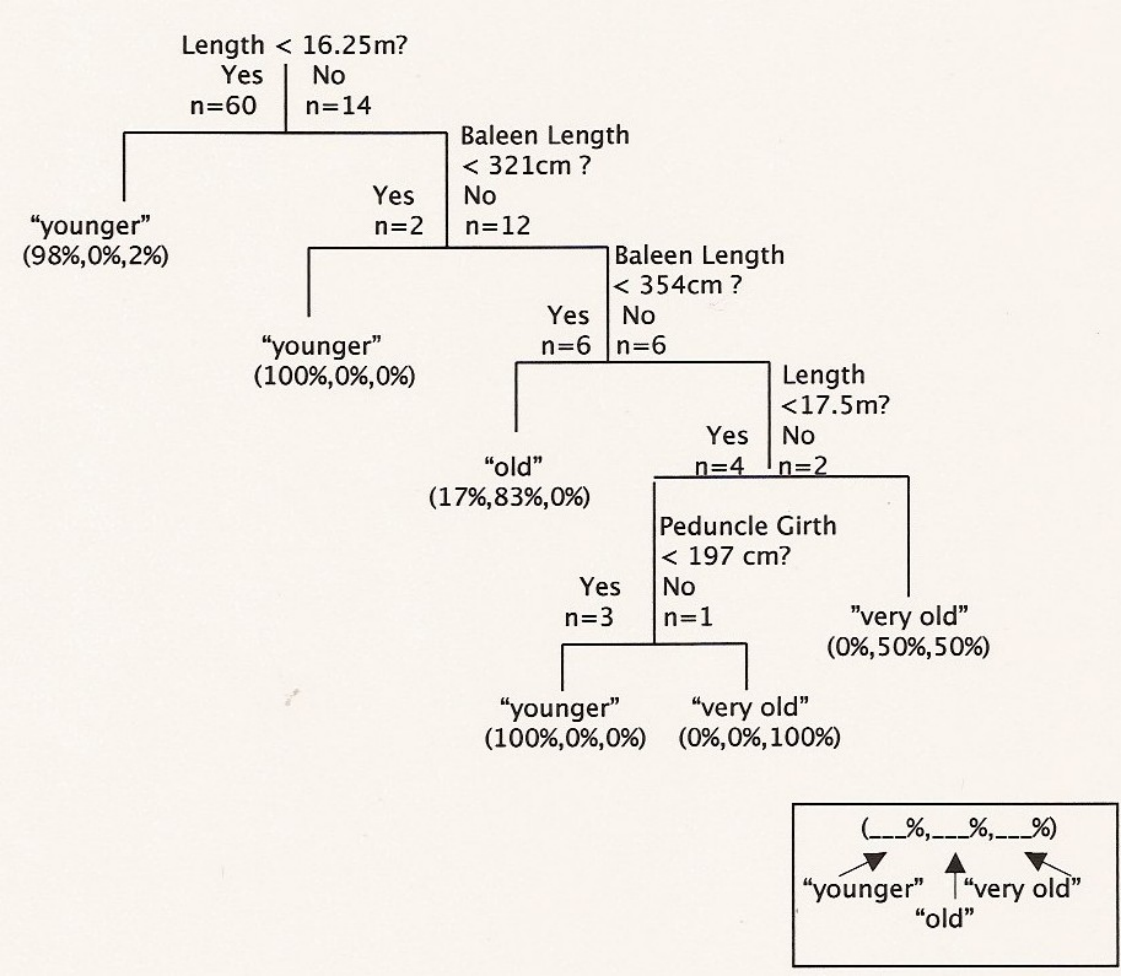

Figure 3. Partition for age classification of female bowhead whales using body length, baleen length, and peduncle girth.

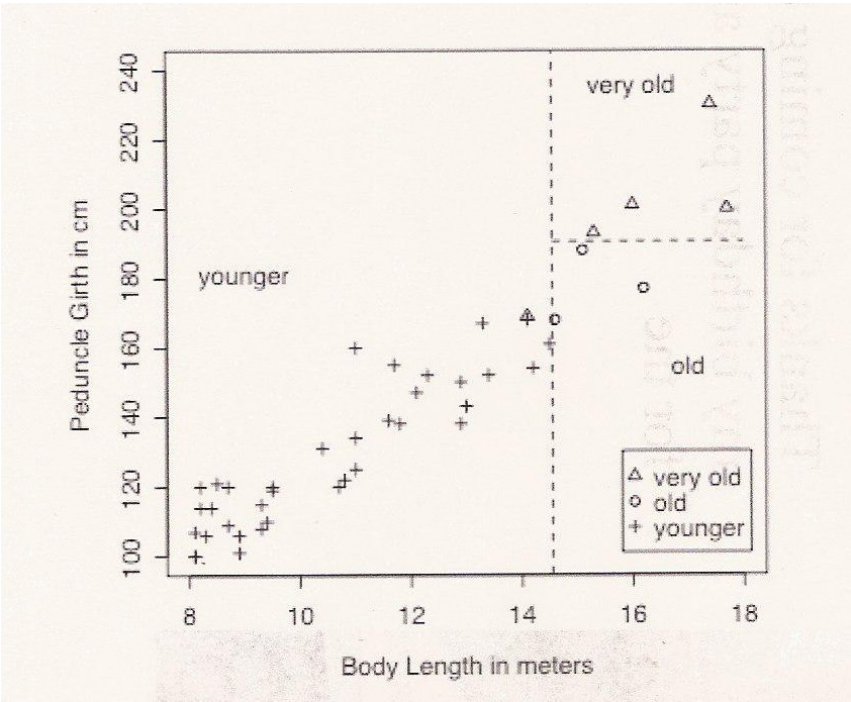

Figure 4: Body length versus peduncle girth for 49 male bowhead whales.

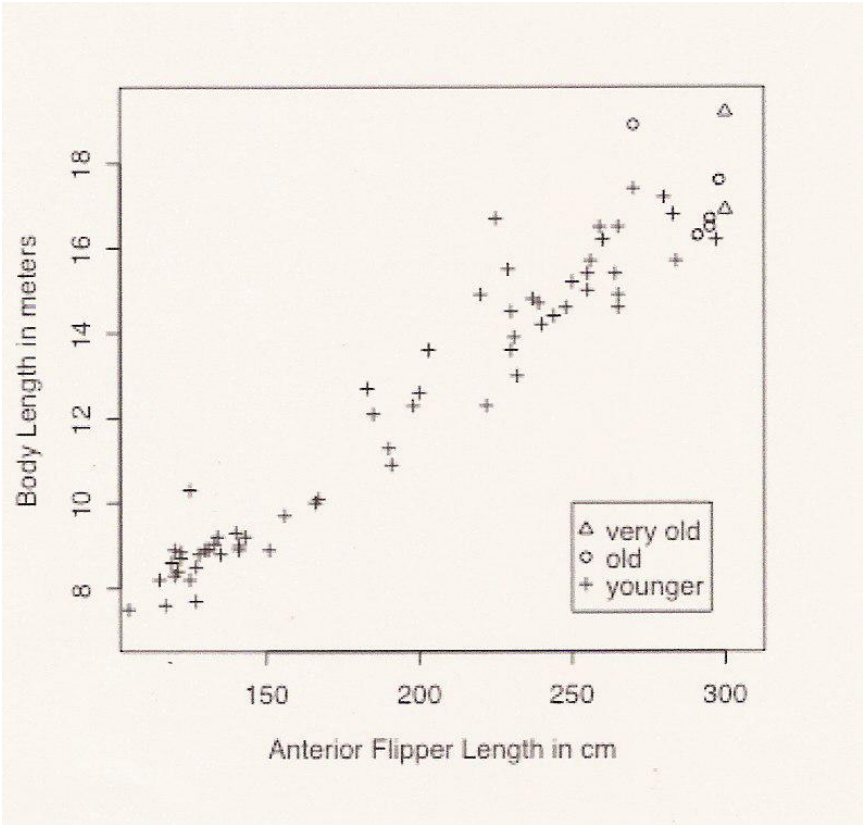

Figure 5A: Anterior flipper length versus body length for 74 female bowhead whales.

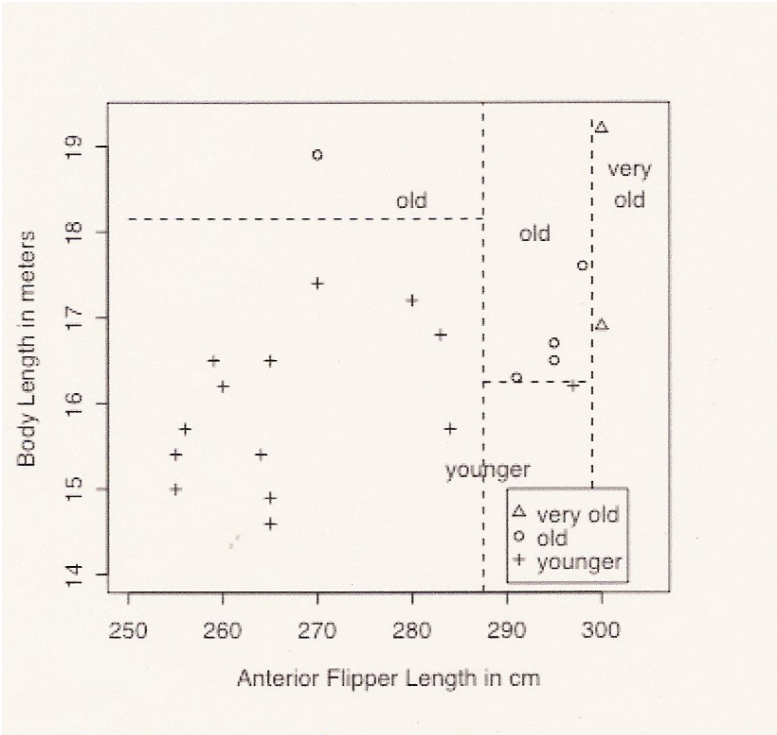

Figure 5B: Anterior flipper length >250 cm versus body length>14m for female bowhead whales.

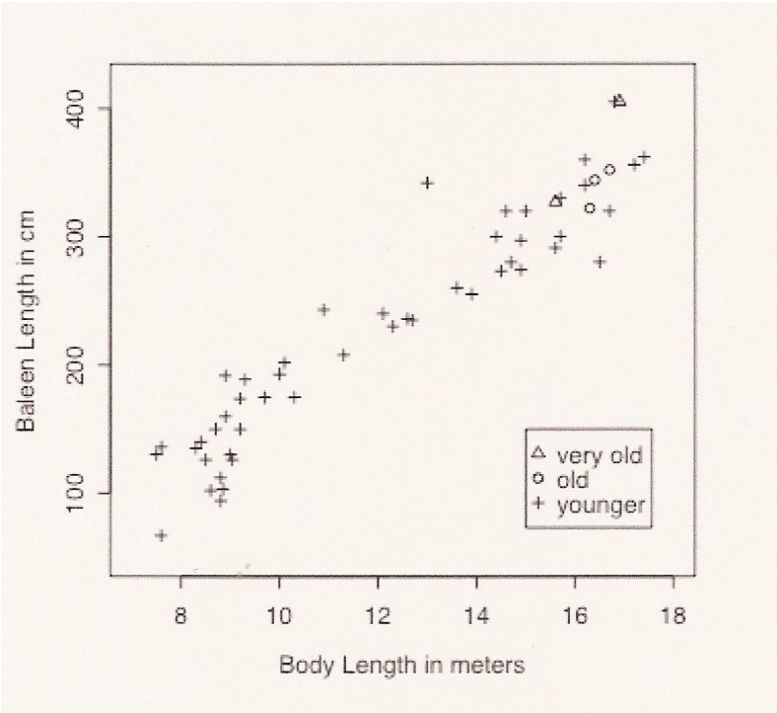

Figure 6A: Body length versus baleen length for 74 female bowhead whales.

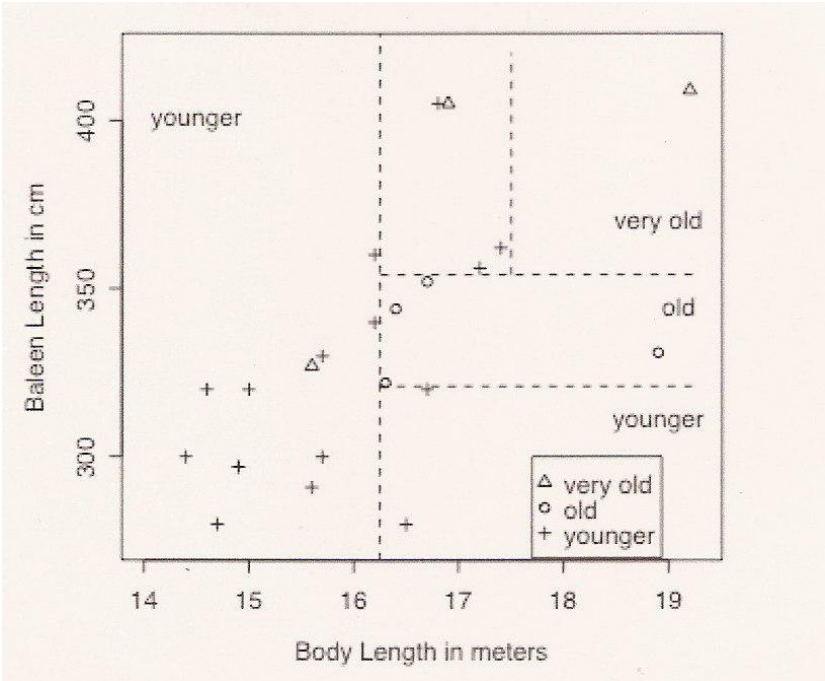

Figure 6B: Body length >14m versus baleen length >275 cm for female bowhead whales.

Table 1: Empirical Classification Counts for male bowhead whales. Classification is based on body length and peduncle girth.

		Estimated age category			
		Under 60 years "younger"	60-90 years "old"	Over 90 years "very old"	Total
Actual age category	Over 90 years "very old"	1 (0.025)	0 (0.00)	5 (0.83)	6
	60-90 years "old"	0 (0.00)	3 (1.00)	1 (0.17)	4
	Under 60 years "younger"	39 (.975)	0 (0.00)	0 (0.00)	39
	Total	40	3	6	49

Table 2: Empirical Classification Counts for female bowhead whales. Classification is based on anterior flipper length & body length.

		Estimated age category			
		Under 60 years "younger"	60-90 years "old"	Over 90 years "very old"	Total
Actual age category	Over 90 years "very old"	1 (0.015)	0 (0.00)	2 (1.00)	3
	60-90 years "old"	1 (0.015)	5 (1.00)	0 (0.00)	6
	Under 60 years "younger"	65 (.970)	0 (0.00)	0 (0.00)	65
	Total	67	5	2	74

Table 3: Empirical Classification Counts for female bowhead whales. Classification is based on body length, baleen length, and peduncle girth.

		Estimated age category			
		Under 60 years "younger"	60-90 years "old"	Over 90 years "very old"	Total
Actual age category	Over 90 years "very old"	1 (0.015)	0 (0.00)	2 (0.667)	3
	60-90 years "old"	0 (0.00)	5 (0.833)	1 (0.333)	6
	Under 60 years "younger"	64 (.985)	1 (0.167)	0 (0.000)	65
	Total	65	6	3	74