MARINE MAMMAL SCIENCE, 3(2):179–185 (April 1987)


# SIZE-CLASS SEGREGATION OF BOWHEAD WHALES DISCERNED THROUGH AERIAL STEREOPHOTOGRAMMETRY

JAMES C. CUBBAGE

JOHN CALAMBOKIDIS

Cascadia Research Collective, Waterstreet Building,
Suite 201, 218-½ West 4th Avenue, Olympia, Washington 98501

ABSTRACT

Bowhead whales (*Balaena mysticetus*) summering in the eastern Beaufort Sea in 1983 were measured through aerial stereophotogrammetry. Photos were taken from a turbine Aerocommander 690 with wingtip-mounted, calibrated 35-mm cameras. Photos were measured on an analytical plotter with scale data provided by radar altimeter and focal length of the lenses. Coefficient of variation of known-sized targets 12 m long was 1.7 percent ($n = 25$). Potential duplicate photographs of whales were removed from consideration through an algorithm based on whale swim speed and elapsed time between sightings. Significant segregation by bowhead whale length was found between four broad regions ($P < 0.001$, ANOVA, Chi square). Also an inverse correlation appeared between longitude and size of animals ($P < 0.001$), with the larger animals occurring farther east. This unequivocal size-class segregation confounds an accurate assessment of overall size-class composition of the population as well as recent attempts to determine calving rate from aerial survey data.

Key words: bowhead whale, Balaenidae, photogrammetry, aerial survey, photography, Beaufort Sea, age-class segregation.

Aerial photogrammetry, the measurement of objects from aerial photographs, has been applied extensively to cartography and resource evaluation (Wolf 1983). Recently this technique has been applied to measure the size distribution of cetaceans from the air (Scott and Winn 1980, Davis *et al.* 1983, Sumich 1984). These studies all relied on a single camera to measure the length of whales in two dimensions, thereby not correcting for the flex (vertical curvature) of whales. Stereophotogrammetry, employing simultaneous photographs from two cameras, allows the measurement of whales in three dimensions but has not previously been used for cetacean measurements. We report on the use of aerial stereophotogrammetry for measurement of cetaceans and the size segregation of bowhead whales on their summering grounds revealed by this technique.

## METHODS

Surveys were flown between 7 August and 6 September 1983 in the area east to 120°W, west to 144°W and from the coastline north to 72°N, the summering grounds for bowhead whales in the Beaufort Sea and Amundsen Gulf. Surveys were flown between 500 ft (152 m) and 1,000 ft (304 m) altitude and 218–261 km/h airspeed in a Rockwell Turbo Aerocommander equipped with wingtip-mounted 35-mm cameras, radar altimeter and a VLF (very low frequency)—OMEGA navigation system. Both cameras had 105-mm lenses and were loaded with color negative film. Data were recorded to an onboard computer (Apple II+) directly interfaced to the navigation system, radar altimeter, airspeed indicator, as well as an internal clock and calendar. Shutter closure, controlled by observers, signalled the computer to record flight parameters. Three-dimensional images of calibration targets, beach targets and whales were measured from negatives on a Matra Traster Analytical Plotter by Analytical Surveys of Colorado Springs, Colorado. Image quality was graded in four categories of resolution (good, fair, poor and unacceptable) before measurement.

To calibrate altimeter readings and nominal focal length simultaneously and to determine the scale for measurements of whales, we photographed a target composed of a set of 13 crosses on 41 occasions. The ratio of the actual distances between crosses (between 5 and 15 m) and their measurement on film was regressed on altitude/focal length to provide an equation for calculating photo scale based on altitude. A linear regression provided a good fit for this relationship ($r^2 = 0.992$, $n = 41$). Whale length was then calculated as:

$$\text{Whale size} = (-5.64 + 0.9786\ (\text{Altitude/Focal length}))\text{Image length}$$

Several tests of the precision of the system were made during the study. A different target, designed to simulate the length and shape of a whale (15 m length, 4.5 m fluke width, 1.67 m height above the ground), was photographed when possible, at the start and end of every survey and was measured to verify the accuracy of the calibration (Table 1). The mean of the x, y (horizontal) and z (vertical) measurements was very close to the true length (within 0.5, 0.7 and 6 percent respectively). The vertical measurements on the z axis appear to be less precise, probably because of the low base to height ratio (1:14) of the photography or difficulty in viewing the target. As the vertical component added an average of 3.2 percent to the length of the animals, the greater variance in the z component does not greatly affect overall measurements. The measurements of individual whales, identified through scar patterns, photographed more than once indicated good precision with the average difference of a given measurement from the mean measurement of that whale being 1.15 percent (CV = 0.59 percent, $n = 8$).

Repeated measurements of the same whale, which undoubtedly occurred when several photographs were made of whales in the same area, could cause spurious statistical results through loss of independence of samples. Possible duplicate measurements were eliminated on the basis of their position and assumed maximum swimming speed. The maximum speed that a whale could be expected to travel during the summer was judged to be 5.5 km/h (3 kt)

*Table 1.* Results of measurements of the whale-shaped beach target.

| Target | $n$ | True length (T) (m) | Mean meas. length (M) (m) | Diff. (T − M) | % (of T) | SD (m) | 95% CI of mean (m) | Coefficient of variation ((SD/M)·100) |
|---|---|---|---|---|---|---|---|---|
| "Length" | 25 | 14.99 | 15.06 | −0.07 | 0.47 | 0.25 | ±0.10 | 1.7% |
| "Fluke" | 25 | 4.51 | 4.48 | 0.03 | 0.67 | 0.079 | ±0.033 | 1.8% |
| "Vertical" | 8[a] | 1.67 | 1.77 | −0.10 | 6.0 | 0.17 | ±0.12 | 9.6% |

[a] Vertical target was added late in the field season.

based on the data from Davis *et al.* (1983) and Krogman *et al.* (1984). In any group of whales seen on one day, the distance between all possible pairs of whales was calculated, as were the elapsed times. To correct for possible VLF-Omega location measurement error (found during one hour of repeat photographs of a stationary target tested within 275 km of all measured whales), 0.37 km was subtracted from all pairs of distances. This subtraction will bias the sample towards excluding some animals as duplicates that were not and thus will result in a sample conservatively filtered for possible duplicates. All whales within 5.5 km/hr of one another were considered possible duplicates and only the first measurement used. All whales re-identified by scars that occurred in more than one photo were removed by this algorithm. Although these criteria may have excluded some whales that were not photographed twice, problems with testing non-independent samples were avoided. To test for differences in length distribution by location, the study area was divided into four locations. Boundaries of location areas were drawn around clumps of sightings

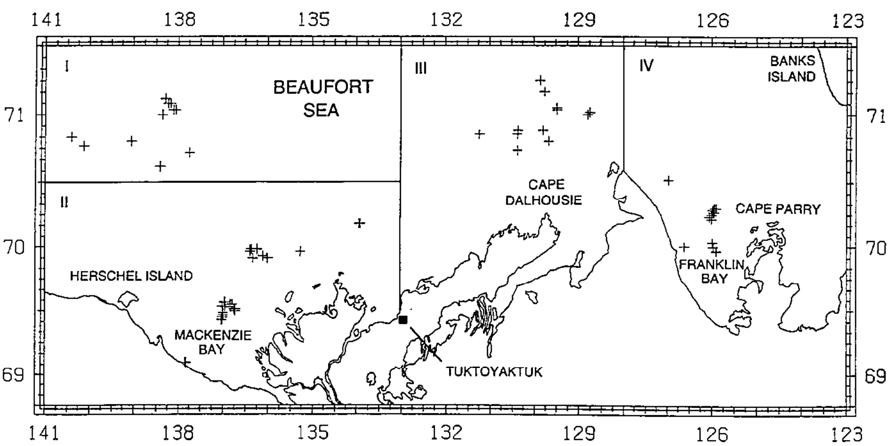


*Figure 1.* Map of study area showing the four regions used for examining location differences and the locations of measured whales. All potential duplicate whales photographed on the same day (based on location and estimated maximum swimming speed) have been removed from consideration ($n$ = 71).

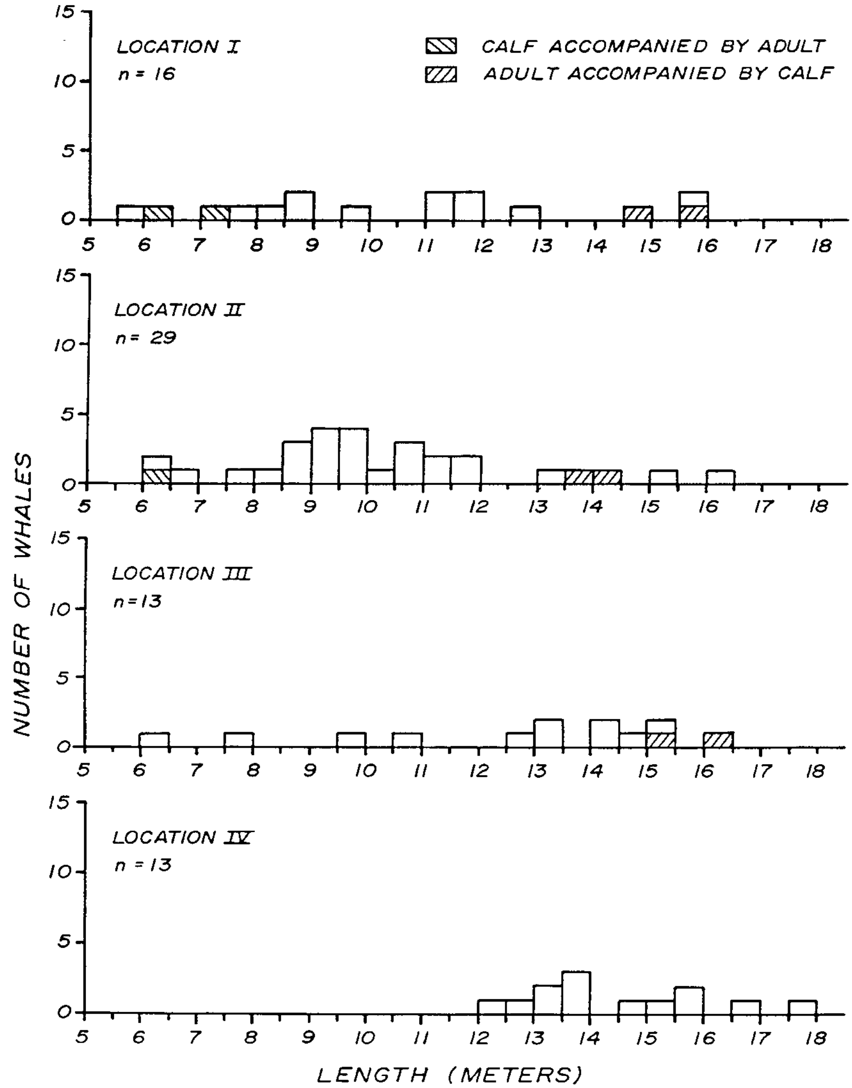


*Figure 2.* Size classes of bowhead whales in 0.5 m increments by location. All potential duplicate whales photographed on the same day (based on location and estimated maximum swimming speed) have been removed. The size of whales is not considered in this algorithm and, thus, in the case of cows with calves, either the cow or calf will be excluded from consideration. Therefore, cows and calves depicted in these histograms were not paired with each other. All measurements include three dimensions.

without regard to size of whales; thus the potential for statistical problems with *a posteriori* analysis is small.

## Results

Of more than 200 whale images on film, 153 were of sufficient quality for measurement. Of these, 71 remained after all potential duplicates based on

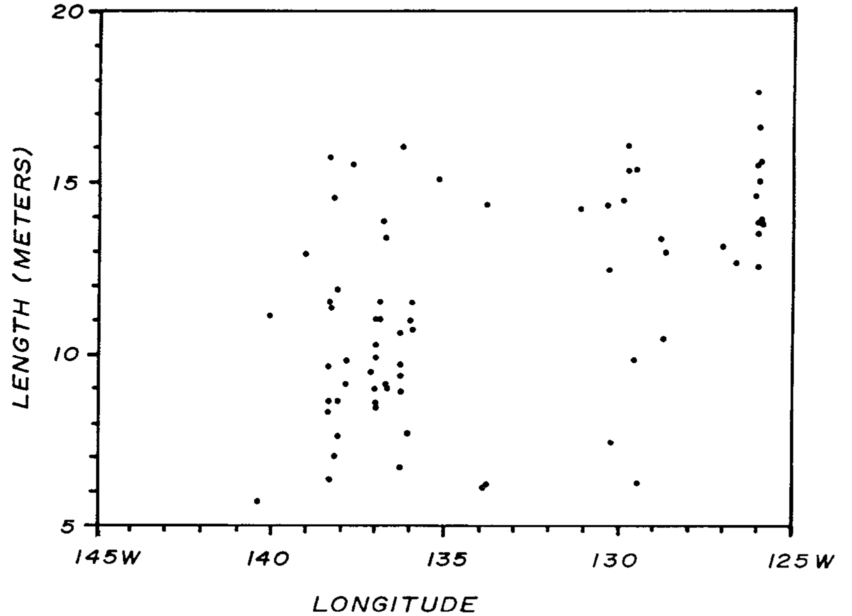


*Figure 3.* Correlation of whale length and longitude in the study area. All potential duplicate whales photographed on the same day (based on locations and estimated maximum swimming speed) have been removed ($r = -0.52$, $P < 0.001$, $n = 71$).

location and swim speed were removed (see algorithm description above). Figure 1 shows the locations of the 71 bowhead whales. Whale lengths ranged from 5.71 to 17.6 m and averaged 11.5 m (Fig. 3). Chi square test for differences in the number of whales greater or less than 12 m indicated significant differences by location ($P < 0.001$). ANOVA showed significant differences between locations ($P < 0.001$). Whales were smallest at locations I and II, averaging approximately 10.5 m; and largest at location IV, Franklin Bay, averaging just under 14.5 m. Locations I, II and III all contained whales ranging from 5 to 15 m long although whales from location III tended to be larger than whales from locations I and II (*see* Fig. 2). Location IV is unique in that it harbors almost solely large whales.

Overall patterns of segregation were seen. The animals in Franklin Bay (location IV) could have included resting mature females as well as mature males, the animals in MacKenzie Bay (location II) were mostly immature (<12 m)(73 percent) and cows with calves (22 percent), and those off Cape Dalhousie (location III) included mature, immature and neonate bowheads.

Whale lengths by location generally increased in size from west to east. We found a highly significant inverse correlation ($P < 0.001$) between whale length and longitude (Fig. 3). Although sample sizes were small, we could not find any significant differences in whale length by day within each location.

The three-dimensional measurements appeared more precise than two-dimensional measurements. The variation from the mean of two-dimensional measurements of duplicate whales (1.71 percent, SD = 0.93 percent, $n = 8$)

was significantly greater than the same value for three-dimensional measurements (1.15 percent, SD = 0.59 percent, $n = 8$) as determined from a Paired T-test ($P < 0.05$). Variations, between photos, in whale flex and orientation with respect to the surface, is better accommodated by measurements in three rather than two dimensions.

## Discussion

Right whales (*Eubalaena australis*) of South Africa and along the Argentine coast have been reported to segregate by age class with cows and calves in one area, immature animals in a second and resting animals in a third (Payne 1983). Davis *et al.* (1983) suggested that bowheads may segregate by age class. Considerable evidence exists that segregation occurs during bowhead migration (Nerini *et al.* 1984).

The mean three-dimensional lengths of bowheads photographed in our study are similar to the 11.7 m mean two-dimensional lengths of whales found in 1982 (Davis *et al.* 1983). Given the geographic variations we found in 1983, the somewhat arbitrary sampling from different locations, and the use of three- rather than two-dimensional measurements, we consider the similarity of the mean measurements of whales coincidental. Minimum and maximum lengths of whales were smaller in 1982 (4.1 to 16.6 m) compared to our data (5.57 to 17.6 m). Differences in measurement technique (two *vs.* three dimensions) would be expected to result in longer measurements in our sample.

Segregation by size-class, and presumably age-class, will confound attempts to characterize the population age-class structure through photogrammetry. Given this segregation, the only way to get an accurate assessment of the proportion of calves or other size classes is to sample all areas and to calculate the overall population of size classes by combining the sampled areas weighted by the number of individuals in each area. The discovery of unequivocal age-class segregation by location reveals the most formidable bias in current estimates of calf production based on surveys of only a portion of the bowhead whale summering grounds.

Three-dimensional measurements appear to be more precise than comparable two-dimensional measurements. Differences in repeat measurements of individual whales were smaller when measured in three dimensions rather than in two (paired T-test, $n = 8$, $P < 0.05$). However, the added cost of preparing an aircraft to take stereo photographs (wingtip camera mounts, camera wiring, modification of aircraft), as well as the costs of measurements in three dimensions (analytical plotter with operator can run $60 per photograph), makes this small advantage in precision often too expensive for most research efforts.

## Acknowledgments

Gary Carter and David Rugh collected data in the field. Pilots were John Dufour, Dave Davalos and Jim McGuire. Aircraft was provided by Aerosystems of Erie, Colorado. Photos were measured by John Peard and by Analytical Surveys, Colorado Springs, Colorado. Polar Continental Shelf Project provided support in Tuktoyaktuk, Northwest Territories. Gretchen Steiger edited and reviewed the manuscript. This research was initiated and funded by National Marine Mammal Laboratory, National Marine Fisheries Service, Seattle, Washington, under the direction of Howard Braham and Mary Nerini. We thank all these people and organizations.

## Literature Cited

Davis, R. A., W. R. Koski and G. W. Miller. 1983. Preliminary assessment of the length-frequency distribution and gross annual reproductive rate of the western Arctic bowhead whale as determined with low-level aerial photography, with comments on life history. Contract report by LGL Ltd., Toronto, Ontario, to National Marine Mammal Laboratory, NMFS, NOAA, Seattle, WA. 91 pp.

Krogman, B., D. Ko, J. Zeh, R. Grotefendt and R. Sonntag. 1984. Experimental design considerations for the use of acoustic data to correct for whales missed by the ice-based census. Report of the International Whaling Commission 34:445–456.

Nerini, M. K., H. W. Braham, W. M. Marquette and D. J. Rugh. 1984. Life history of the bowhead whale (*Balaena mysticetus*). Journal of Zoology, London 204:443–468.

Payne, R. 1983. The structure of breeding populations of southern right whales (*Eubalaena australis*). *In* Abstracts of the Fifth Biennial Conference on the Biology of Marine Mammals. Boston, MA.

Scott, G. P., and H. E. Winn. 1980. Comparative evaluation of aerial and shipboard sampling techniques for estimating the abundance of humpback whales (*Megaptera novaeangliae*). Contract report to U.S. Marine Mammal Commission.

Sumich, J. L. 1984. Gray whales along the Oregon coast in summer, 1977–1980. Murrelet 65:33–40.

Wolf, P. R. 1983. Elements of photogrammetry. McGraw-Hill Book Company. New York, NY. 628 pp.

Received: April 15, 1986
Accepted: July 28, 1986