Correlation between body length and fluke width in humpback whales, *Megaptera novaeangliae*

RENATA S. SOUSA-LIMA

Bioacoustics Research Program,
Cornell Laboratory of Ornithology,
159 Sapsucker Woods Road,
Ithaca, New York 14850, U.S.A.
and
Instituto Baleia Jubarte,
Rua Barão do Rio Branco, 26,
Caravelas, Bahia 45900-000, Brazil

KÁTIA REGINA GROCH

Instituto Baleia Jubarte,
Rua Barão do Rio Branco 26,
Caravelas, Bahia 45900-000, Brazil

Researchers use body size to test for correlation with ecological (Peters 1983) and behavioral traits (Fitch 1997) because body size is often correlated with mating success (Dubey *et al.* 2009) and is used as a quality index by conspecifics during intra- and intersexual selection (Davies and Halliday 1978, Poole 1989, Webster 1992, Leutenegger and Kelly 2006).

Assessment of body size in marine mammals is challenging, especially in large species that occur in turbid waters where full body photo- or videogrammetry (as used by Spitz *et al.* 2000 and Gill *et al.* 2008) is impossible. Indirect measurements of sperm whale body length have been achieved by finding a correlation between the interpulse interval of their clicks (or IPI) and the size of the sound production organ (Gordon 1991, Goold 1996). Nonetheless, Jaquet (2006) pointed out problems with these indirect measurements: uncertainty of the actual speed of sound in the spermaceti at varying depth; and limited sample size ($n = 5$) used in finding a correlation between the size of the spermaceti organ and total body length (Clarke 1978, Gordon 1991).

Direct measurement of body parts visible at the surface and that correlate well or are proportional to total body length using photogrammetric techniques are subject to less error. Known height-above-water (Gordon 1990) and stereo-photogrammetry (Dawson *et al.* 1995) are techniques that use the distance between the blowhole and the dorsal fin, but effectively incorporating these into field protocols can be difficult and complicated under most cruise conditions. The simplest of these photogrammetric techniques uses fluke width measurements to correlate with body length. Identifying a mathematical relationship between fluke width and body length has proven invaluable for the estimation of body size in sperm whales (Jaquet 2006). Our objective was to provide such a mathematical relationship for humpback whales

(*Megaptera novaeangliae*) as the first step to achieving body length estimates that can be used as covariates of ecological and behavioral traits in future research.

We compiled all the available data from the literature on fluke width (*FW*) and body length (*BL*) for humpback whales (excluding fetuses) (Tomilin 1957, Nishiwaki 1959, Glockner and Venus 1983, True 1983), even though humpback whales from the Southern Hemisphere tend to be larger than their northern counterparts (Tomilin 1957). We also obtained measurements from stranded whales on the coast of Brazil. The data from stranded animals, other than that which we obtained (Instituto Baleia Jubarte), included measurements made by other Brazilian institutions that are part of the national stranding network: Instituto ORCA, Centro Mamíferos Aquáticos (CMA/ICMBio), Instituto Mamíferos Aquáticos (IMA), and AQUASIS.

Data from stranded animals in Brazil were only considered for analysis if a linear measurement between the extremes of the flukes was available. Animals with injured flukes (bitten or with lesions) were not included in the analysis. In cases of individuals with only one fluke lobe, the measurements were taken in a straight line from the lateral extreme to the notch. To evaluate the utility of single lobe measurements we compared values obtained from the left and right lobes of intact flukes (*n* = 8). The differences in width between lobes were negligible, ranging from 0.5 to 2 cm. Therefore, single lobe measurements can be multiplied by two to yield accurate estimates of *FW.* It is important to emphasize that single lobe measurements are only useful if taken in a straight line from the outer tip of the fluke to a perpendicular projection from the notch. Unfortunately, single lobe measurements from stranded animals were not considered for the correlation with *BL* due to the difference in measurement techniques (*i.e.* using a straight line between the extreme of the lobe and the notch rather than using a projection from the notch to the extreme of the lobe).

The variance in our data was proportional to the expected value of *BL.* Therefore, we used generalized linear regression models adjusted for nonconstant variance (R version 2.9.2). We first evaluated three models to determine the best one to use when the sex of the individual is known (*n* = 45): (1) Model 1 assumes the same relationship for males and females, *i.e.*, no sex effect; (2) Model 2 assumes there are differences in the intercept of the relationships including only males or females, but the slope is the same for both sexes and; (3) Model 3 (full factorial) includes sex as a covariate assuming the intercept as well as the slope of the relationship between *FW* and *BL* are different for males and females.

We found no support for any of the more complex models including a sex effect using our data set. Therefore, we re-ran Model 1 including individuals with unknown sex (*n* = 49). The relationship between the values of *FW* and *BL* of all sampled humpback whales is presented in Figure 1. The generalized linear regression model adjusted for nonconstant variance shows that there is a significant correlation between *FW* and *BL* ($P < 0.0001$).

$$BL = 0.77226 + 2.89694 \times FW \qquad (1)$$

The positive coefficient of *FW* in Equation 1 also indicates that bigger animals tend to have proportionally wider flukes. Wider flukes allow greater acceleration reaction
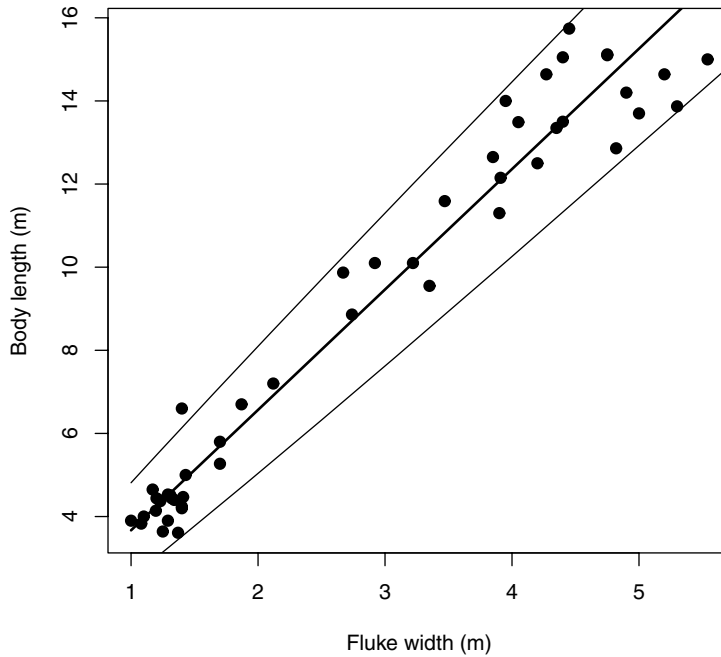
Figure 1. Correlation between fluke width and body length of humpback whales.

forces suitable for quick maneuvers (Webb 1984). Compared to other whale species, humpbacks have the widest flukes relative to their body size, which contributes to the quick maneuverability required in their acrobatic movements (Woodward *et al.* 2006).

Intraspecific variation in *FW* could also be related to individual advantages in maneuverability. Larger humpbacks with wider flukes may be more efficient at maneuvering while feeding and during intraspecific interactions within competitive groups in calving areas. Selection would favor larger females to escape male harassment and also favor larger males during competition for principal escort position alongside females. In fact, Spitz *et al.* (2002) showed that male humpback whales which are observed as principal escorts tend to be the largest or second-largest individuals in a competitive group.

The typical fluking behavior of humpback whales has allowed multiple researchers around the globe to estimate population sizes based on capture-recapture techniques using the unique markings on the ventral part of the flukes (Katona *et al.* 1979). Given the significant linear relationship between *FW* and *BL* presented here, field researchers could also take advantage of the fluking behavior of humpback whales to estimate individual body length by adopting fluke measurement protocols during sightings (see Jaquet 2006 for the description of the fluke measurement technique) and calculating the mean body length (BL_{est}) based on the measured width of the

fluke (FW_{obs}) as follows:

$$BL_{est} = 0.77226 + 2.89694 \times FW_{obs} \qquad (2)$$

The estimated proportionality coefficient of the variance (0.08814903) should be used in calculating 95% prediction intervals for the total body length one wishes to estimate (BL_{pred}), as follows:

$$BL_{est} - 2.011741 \times \sqrt{(0.08814903 \times BL_{est})} \leq BL_{pred} \leq BL_{est}$$
$$+ 2.011741 \times \sqrt{(0.08814903 \times BL_{est})} \qquad (3)$$

where 2.011741 is the value of the 95% t-student distribution with df $= 47$.

Sexual selection theory predicts strong selection for traits that increase reproductive success in males and females. Bigger male humpback whales are more often observed as principal escorts of females (Spitz $et\ al.$ 2002), and males prefer to associate with larger females which give birth to larger calves (Pack $et\ al.$ 2009). Evidence of mate preference for bigger individuals in humpback whales suggests a positive correlation between body size and reproductive success. Sexual selection for bigger individuals may be related to fighting ability (mate defense against other males and predators) or survivorship (increased feeding efficiency), and rely on variation in displays that reliably broadcast individual body size. Such predictions based on intra-specific size variation can be tested with data from calibrated fluke photographs and length estimations based on Equations 2 and 3.

LITERATURE CITED

Clarke, M. R. 1978. Structure and proportions of the spermaceti organ in the sperm whale. Journal of the Marine Biological Association of the United Kingdom 58:1–7.
Davies, N. B., and T. R. Halliday. 1978. Deep croaks and fighting assessment in toads, $Bufo$ $bufo$. Nature 274:683–685.
Dawson, S. M., C. J. Chessum, P. J. Hunt and E. Slooten. 1995. An inexpensive stereophotographic technique to measure sperm whales from small boats. Report of the International Whaling Commission 45:431–436.
Dubey, S., G. P. Brown, T. Madsen and R. Shine. 2009. Sexual selection favours large body size in males of a tropical snake ($Stegonotus\ cucullatus$, Colubridae). Animal Behaviour 77:177–182.

Goold, J. C. 1996. Signal processing techniques for acoustic measurement of sperm whale body lengths. The Journal of the Acoustical Society of America 100:3431–3441.

Fitch, W. T. 1997. Vocal tract length and formant frequency dispersion correlate with body size in rhesus macaques. The Journal of the Acoustical Society of America 102:1213–1222.

Gill, P. C., C. M. Kemper, M. Talbot and S. A. Lyons. 2008. Large group of pygmy right whales seen in a shelf upwelling region off Victoria, Australia. Marine Mammal Science 24:962–968.

Glockner, D. A., and P. C. Venus. 1983. Identification, growth rate, and behavior of humpback whale (*Megaptera novaeangliae*) cows and calves in the waters off Maui, Hawaii, 1977–79. Pages 223–258 *in* R. Payne, ed. Communication and behavior of whales. Westview Press, Boulder, CO.

Gordon, J. C. 1990. A simple photographic technique for measuring the length of whales from boats at sea. Report of the International Whaling Commission 40:581–588.

Gordon, J. C. 1991. Evaluation of a method for determining the length of sperm whales (*Physeter catodon*) from their vocalizations. Journal of Zoology 224:301–314.

Jaquet, N. 2006. A simple photogrammetric technique to measure sperm whales at sea. Marine Mammal Science 22:862–879.

Katona, S. K., B. Baxter, O. Brazier, S. Kraus, J. Perkins and H. Whitehead. 1979. Identification of humpback whales by fluke photographs. Pages 33–44 *in* H. E. Winn and B. Olla, eds. The behavior of marine mammals. Volume 3. Plenum Press, New York, NY.

Leutenegger, W., and J. T. Kelly. 2006. Relationship of sexual dimorphism in canine size and body size to local, behavioral, and ecological correlates in anthropoid primates. Primates 18:117–136.

Nishiwaki, M. 1959. Humpback whales in Ryukyuan waters. The Scientific Reports of the Whales Research Institute 14:49–87.

Pack, A. A., L. M. Herman, S. S. Spitz, S. Hakala and M. H. Deakos. 2009. Male humpback whales in Hawaiian breeding grounds preferentially associate with larger females. Animal Behaviour 77:653–662.

Peters, R. H. 1983. Ecological implications of body size. Cambridge University Press, Cambridge, U.K.

Poole, J. H. 1989. Mate guarding, reproductive success and female choice in African elephants. Animal Behaviour 37:842–849.

Spitz, S. S., L. M. Herman and A. A. Pack. 2000. Measuring sizes of humpback whales (*Megaptera novaeangliae*) by underwater videogrammetry. Marine Mammal Science 16:664–676.

Spitz, S. S., L. M. Herman, A. A. Pack and M. H. Deakos. 2002. The relation of body size of male humpback whales to their social roles on the Hawaiian winter grounds. Canadian Journal of Zoology 80:1938–1947.

Tomilin, A. G. 1957. Zveri SSSR I prilezhashchikh stran. *Zveri vostochnoi Evropy I severnoi Azii*. Volume IX. Kitoobraznye. Izdatel'stvo Akademi Nauk SSSR, Moscow. 756 pp. {Translated in 1967 as Mammals of the U.S.S.R. and adjacent countries. Mammals of eastern Europe and adjacent countries. Volume IX. Cetacea by the Israel Program for Scientific Translations, Jerusalem, 717 pp.}.

True, F. W. 1983. The whalebone whales of the western North Atlantic compared with those occurring in European waters with some observations on the species of the North Pacific. Smithsonian Institution Press, Washington, DC.

Webb, P. W. 1984. Form and function in fish swimming. Scientific American 251:72–82.

Webster, M. S. 1992. Sexual dimorphism, mating system and body size in New World blackbirds (Icterinae). Evolution 46:1621–1641.

Woodward, B. L., J. P. Winn and F. E. Fish. 2006. Morphological Specializations of baleen whales associated with hydrodynamic performance and ecological niche. Journal of Morphology 267:1284–1294.