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

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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).

\[ BL = 0.77226 + 2.89694 \times FW \] (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
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:

\[
BL_{est} = 0.77226 + 2.89694 \times FW_{obs}
\]  

(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:

\[
BL_{est} - 2.011741 \times \sqrt{(0.08814903 \times BL_{est})} \leq BL_{pred} \leq BL_{est} + 2.011741 \times \sqrt{(0.08814903 \times BL_{est})}
\]  

(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.

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LITERATURE CITED


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