A METHOD FOR ESTIMATING MASS OF LARGE PINNIPEDS

Michael P. Haley
Charles J. Deutsch
Burney J. Le Boeuf
Biology Board of Studies, University of California at Santa Cruz, Santa Cruz, California 95064

Abstract

Fifty-two male elephant seals were weighed and photographed at Ano Nuevo State Reserve, California, to establish a predictive relationship between photographically measured morphological variables (length, side area, and girth area) and body mass. Regression of mass on these variables revealed that side area, roughly equivalent to a longitudinal cross-section, was the most useful single variable for predicting mass, and that adding the other two variables to side area slightly improved the accuracy of the photogrammetric technique. Curvilinear regressions based on a power model provided the best predictive relationships. This technique may prove useful for estimating body mass of other pinnipeds.

Key words: northern elephant seal, Mirounga angustirostris, mass, mass estimation, photogrammetry.

Assessment of body mass in pinnipeds is vital in understanding aspects of their behaviour, physiology and life history (Calder 1984, Peters 1983). However, direct measurement of mass in large pinnipeds is difficult, due to the dangers and disturbance created by immobilization with drugs (see Gales 1989), and because of logistical problems associated with transporting heavy weighing equipment in the field (Anderson and Fedak 1985, Deutsch et al., 1990, Costa et al. 1986, Gales and Burton 1987a). We describe a photogrammetric method for estimating mass of male northern elephant seals, Mirounga angustirostris, that minimizes many of these problems.

1 Address correspondence to: M. P. Haley, Zoology Department, University of the West Indies, Mona, Kingston 7, Jamaica, West Indies.

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Figure 1. Representative length photograph of a male elephant seal. Dashed lines show the area traced with a pointer when digitizing the photograph, to obtain side area. Length was measured from the base of the nose to the base of the tail (arrows).

**METHODS**

This study was conducted at Ano Nuevo State Reserve, California, during the 1988 and 1989 winter breeding seasons. Males near breeding harems were weighed and photographed, and body mass was regressed against various photographic measurements. Most measurements were taken between mid-January and early March. All males in this study were identified individually by names marked on the pelage with a mixture of bleach and 30% peroxide (Le Boeuf and Peterson 1969). Eighty-five weights and corresponding photographs were obtained for 52 adult and subadult males (5–13 yr old); 29 of these males were weighed more than once, at intervals that varied from 9 to 83 d.

**Photographic measurement**—Two photographs were taken of each male for whom weights were obtained, using a 35-mm camera and a 28–90-mm zoom lens. Length pictures (Fig. 1) were taken from a distance of approximately 6 m with the camera approximately 1 m above the ground, usually with a focal length of 50 mm. Girth pictures (Fig. 2) were taken with the camera approximately 0.5 m above the ground, with a focal length of 90 mm. For length pictures, it was important that the male was lying straight on his ventrum, and preferably on packed sand with no depressions. Similarly, girth pictures were taken only if the forequarters of the male were straight. Since side area (see below) varied with respiratory cycle, photographs were standardized by taking pictures after complete inhalation. For each picture, a researcher approached the animal from behind to avoid being seen, and held a calibrated surveying pole
over the back of the animal for reference. For length pictures, the pole was held over the midline of the animal, parallel to the body axis, while for girth pictures it was held perpendicular to the body axis, directly over the axilla (Fig. 1, 2).

Length (L) was measured from the first crease at the base of the proboscis to the base of the hindflipper, where it meets the body (Fig. 1). Standard lengths (≈ 1.1 L) were not determined as the flippers usually obscured the position of the tail. The nose and flippers of the animal were excluded from both length and area estimation as their positions were variable and they were relatively trivial components of overall weight. Repeated length measurements of the same animal, either at different times of the season, or on the same day, were generally within 2% of each other.

Area determination—For both length and girth pictures, the area of the animal (roughly equivalent to longitudinal and cross-sectional areas, respectively) was measured using a digitizer (GTCO Digi-Pad 5, GTCO Corp, Rockville, MD, USA). Each photographic slide was projected onto the digitizing screen, and the outline of the body was traced with a pointer (Fig. 1, 2). The digitizer calculated the area of the figure traced by the pointer. This procedure was repeated several times to ensure consistent measurements that were within 1–2% of each other. The measured area of the photograph was converted into actual area by using the surveying pole in each photograph as a scale, and the formula:

\[ \text{Actual Area (m}^2) = \text{Digitized Area (cm}^2) \times \left( \frac{\text{Actual Length (m)}}{\text{Digitized Length (cm)}} \right)^2 \]
where digitized area and length refer to measurements made on the digitizing screen.

Direct weight measurement—The weighing apparatus was a platform scale (Senstek, Inc., Saskatoon, Saskatchewan, Canada) consisting of an aluminium platform (4.9 × 1.2 m) that was held about 13 cm off the ground by 2 weigh bars containing load cells, which were connected to a 23-m long cable that terminated in a battery operated (6 V) liquid crystal display instrument. Both the manufacturer’s specifications and our own experience (obtaining reliable weights for a male twice in the same day) indicated that the weights obtained were accurate to within 5–9 kg.

Males were moved onto the scale by either waving tarpaulins and playing male aggressive vocalizations with a playback system, or by luring them with a model female and playback of female protest calls. To obtain an accurate reading, each male was kept on the scale for at least 5–10 sec by standing in front of him or by raising a remotely operated snow fence. Two males were anaesthetized as part of another project and subsequently weighed and photographed. Details of the above techniques are presented in Deutsch et al. (1990).

Data analysis—Using SAS (Statistical Analysis System), body mass was regressed on length, side area, and girth area (singly and in various combinations; Table 1). We utilized power models for the regressions because most body measurements scale allometrically to body mass (Peters 1983). Confidence intervals of 95% were calculated; as these varied among mass estimates, sample values are presented for three groups of males—small (600 kg), medium (1,300 kg) and large males (2,000 kg). Confidence intervals are slightly asymmetrical for power models (Peters 1983); for clarity, symmetrical approximations are presented.

RESULTS

Regression of body mass on single variables revealed that body mass was highly correlated with side area (Fig. 3); the $r^2$ value of the side area model exceeded that of models based on length or girth area (Table 1). This was expected since length does not take into account differences between fat and slim individuals, and girth area does not show differences between short and long individuals; side area, on the other hand, is influenced by both length and girth. Regression models which included side area and one or both of the other photogrammetric variables accounted for a slightly greater proportion of the variance in mass ($r^2 = 0.93–0.95$) than side area alone ($r^2 = 0.92$; Table 1).

Body mass was proportional to length$^3$ and to area$^{1.5}$ (Table 1), as expected based upon simple geometrical relationships between volume and linear dimensions. However, mass was proportional to girth area$^{1.017}$ rather than to $G^{1.5}$ (Table 1). This may be because variability in blubber thickness is greater in the axillary region than at other points in the body, and consequently a change in girth area may scale almost linearly to body mass.

The 95% confidence intervals were a nearly constant percentage of mass
Table 1. Regression equations, coefficients of determination ($r^2$), and 95% confidence intervals for different morphological measurements used as predictors of male elephant seal mass (kg). L = Length (m), G = Girth Area (m²), A = Side Area (m²). All regression equations significant at $P < 0.0001$. 95% confidence intervals for individually predicted weights are given for three categories of males (see text); small (600 kg), medium (1,300 kg), and large (2,000 kg). Note that confidence intervals are symmetrical approximations of slightly asymmetrical values. "% predicted mass" is the 95% confidence interval expressed as percentage of predicted mass.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Equation</th>
<th>$r^2$</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>% Predicted mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>71</td>
<td>1,782.002(G^{1.017})</td>
<td>0.765</td>
<td>150</td>
<td>312</td>
<td>510</td>
<td>±25%</td>
</tr>
<tr>
<td>L</td>
<td>85</td>
<td>31.287(L^{3.023})</td>
<td>0.778</td>
<td>148</td>
<td>308</td>
<td>495</td>
<td>±24%</td>
</tr>
<tr>
<td>A</td>
<td>84</td>
<td>507.738(A^{1.544})</td>
<td>0.923</td>
<td>86</td>
<td>180</td>
<td>290</td>
<td>±14%</td>
</tr>
<tr>
<td>L, G</td>
<td>71</td>
<td>162.094(G^{0.548})(L^{1.845})</td>
<td>0.897</td>
<td>100</td>
<td>208</td>
<td>336</td>
<td>±16%</td>
</tr>
<tr>
<td>L, A</td>
<td>84</td>
<td>301.337(L^{1.319})(G^{0.339})</td>
<td>0.928</td>
<td>84</td>
<td>177</td>
<td>284</td>
<td>±14%</td>
</tr>
<tr>
<td>A, G</td>
<td>70</td>
<td>688.211(A^{1.209})(G^{0.288})</td>
<td>0.940</td>
<td>76</td>
<td>158</td>
<td>250</td>
<td>±12%</td>
</tr>
<tr>
<td>A, G, L</td>
<td>70</td>
<td>553.77(A^{0.928})(L^{0.678})(G^{0.279})</td>
<td>0.948</td>
<td>72</td>
<td>149</td>
<td>240</td>
<td>±12%</td>
</tr>
</tbody>
</table>

±95% Confidence intervals (kg)
Figure 3. Regression of measured body mass on side area, using a power model (solid line), with 95% confidence limits (dashed lines).

(Table 1), and consequently the absolute values increased with increasing male size (Table 1 and Fig. 3). This pattern is due to the properties of power models (Peters 1983, Neter et al. 1989). Confidence intervals were greatest for single variable regressions, and were usually reduced as the number of variables increased (Table 1). For the best model the 95% confidence interval was ±12% estimated mass (Table 1).

DISCUSSION

For male elephant seals, side area was the most useful single variable for mass estimation. Although adding length and girth area only marginally improved $r^2$ values, the weights could be predicted with less error as the 95% confidence intervals were decreased by up to 50 kg (Table 1). Based on these results, we recommend the measurement of side area (either with or without additional variables) and the utilization of power models for photographic estimation of mass in pinnipeds.

Previous studies on both terrestrial (e.g., Berger and Peacock 1988) and marine mammals have also correlated morphological measurements with mass. A combination of length and girth provided a good predictor of body mass in ringed seals (Phoca hispida) (Usher and Church 1969), and in fin (Balaenoptera physalus) and sei (B. borealis) whales (Lockyer and Waters 1986). Castellini and Kooyman (1990) correlated length and girth$^2$ to body mass in Weddell seals (Leptonychotes weddellii). In our study, a combination of length and girth area (proportional to girth$^2$) was a good predictor of mass for male elephant
seals, although it was not as good as side area, with or without additional variables (Table 1). Ryg et al. (1988) also showed that total surface area can be used to predict body mass in ringed seals. Some studies have used length to estimate weight (e.g., Bryden 1969). However, as we show above (Table 1), length alone is not very accurate at predicting body mass; this is particularly true for phocids that lose weight continually over the breeding season while remaining at the same length (Anderson and Fedak 1987, Costa et al. 1986, Deutsch et al., 1990).

One potential source of error in estimating body mass from morphological measurements is variation in body composition. Based on data from male southern elephant seals and female northern elephant seals (Bryden 1972, Costa et al. 1986, Gales and Burton 1987b), we expect the maximum range in percentage fat in male M. angustirostris to be 15% to 45%. From the relative densities of fat and non-fat constituents (Gales and Burton 1987b, Lukaski 1987, G. Worthy, personal communication), and examining two hypothetical males of equal volume with 15% and 45% fat, we estimate the error introduced by variation in body composition in this study to be ±3%. This value is substantially less than the total variation present in the data (Table 1), and therefore changes in body composition are probably a minor source of error in our photogrammetric technique.

We suggest that other researchers may find this photogrammetric technique useful in estimating pinniped mass in the field, although slight adjustments to the methodology may be necessary to accommodate differences in the behavior of other species. This technique cannot be used as a complete substitute for direct weighing, since it is initially necessary to calibrate photographs with measured mass in order to obtain the relationship between photogrammetric measurements and mass. Given the difficulties in weighing large pinnipeds in the field, however, this method has several advantages when used in conjunction with a weighing program; only two people are needed to take photographs, mass estimations of animals in awkward localities are made possible, the equipment is relatively cheap, the risks of anaesthetizing animals are avoided, and a much larger sample can be obtained than by direct weighing alone.

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