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Rapid noninvasive field estimation of body length of female elephant seals (*Mirounga leonina*)

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Body size is an important correlate of physiology, life history, and ecology of animal species (Bonner 2006, Schmidt-Nielsen 1984). Body size estimation is an important component of research on social behavior (Pelletier *et al.* 2006), parental investment (Wheatley *et al.* 2006), foraging ecology (Hassrick *et al.* 2013) and conservation (Berger 2012). There is an increasing tendency to use noninvasive methods to study wildlife, to reduce the impact on the subjects' welfare (Pauli *et al.* 2010). Most noninvasive body size measurement methods are based on photogrammetry (Berger 2012). An important drawback of those methods is that they are based on pictures and, therefore, cannot produce size estimates in the field. The measurement of pictures usually requires manual processing and, even when automated processing is possible, extensive manual clean up and validation is required. The processing of pictures can be very time consuming, and requires specialized software in the case of 3D photogrammetry (de Bruyn *et al.* 2009).

We used photogrammetry to study various aspects of southern elephant seal (*Mirounga leonina*) male biology, including reproductive effort (Galimberti *et al.* 2007), vocal communication (Sanvito *et al.* 2007*a*), and secondary sexual traits (Sanvito *et al.* 2007*b*). Application of photogrammetry to female elephant seals was problematic, because photogrammetry required a scale to be placed in the picture, and females were more difficult to be approached than males, due to their smaller size, greater sensitivity to disturbance, and gregariousness. We explored other photogrammetric options without success. In particular, we tried the parallel lasers method (Durban and Parsons 2006), but we were not able to obtain reliable measures because parallel lasers work well on flat targets, where the measurement is taken on the same plane where the lasers point, while in the case of elephant seals it was difficult to target the lasers on the middle axis of the subjects. Moreover, parallel lasers needed to be pointed exactly perpendicular to the measurement plane, and this was not an easy task in field work conditions.

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Here, we present a method to measure wild seals noninvasively that is implemented with inexpensive instruments, requires no postprocessing, and produces size estimates that can be used immediately. We calculated the error of the method by measuring objects of known size, we applied the method to female elephant seals and calculated repeatability of field measurements, and we estimated empirical equations that permit conversion among the different measurements that can be obtained. We discuss the advantages of this new method in comparison with photogrammetric approaches.

Our measurement method was based on the application of simple trigonometry to measured distances and angles. We measured distances using a laser range-finder with integrated digital viewfinder (Leica Disto A8, https://lasers.leica-geosystems.com/eu/disto), and angles using an 8 in. digital protractor (Wixey WR-410, http://wixey.com/digitalprotractor/). The laser range-finder was mounted on the mobile blade of the protractor, and the range-finder plus protractor assembly was mounted on a tripod fitted with a pistol grip (Manfrotto 144, http://www.manfrotto.it). We measured (1) the distance to the tip of the nose of seals, (2) the distance to the tip of the tail or the rear flipper base, and (3) the angle between the two distance segments. From these distances and angle we calculated the length of the seal (Fig. 1a). In strong sunlight it was sometimes difficult to directly see the laser dot and, therefore, we used the viewfinder.

Validation trials and field work were carried out at Sea Lion Island, Falkland Islands, during the 2015 breeding season (September–November). To assess the

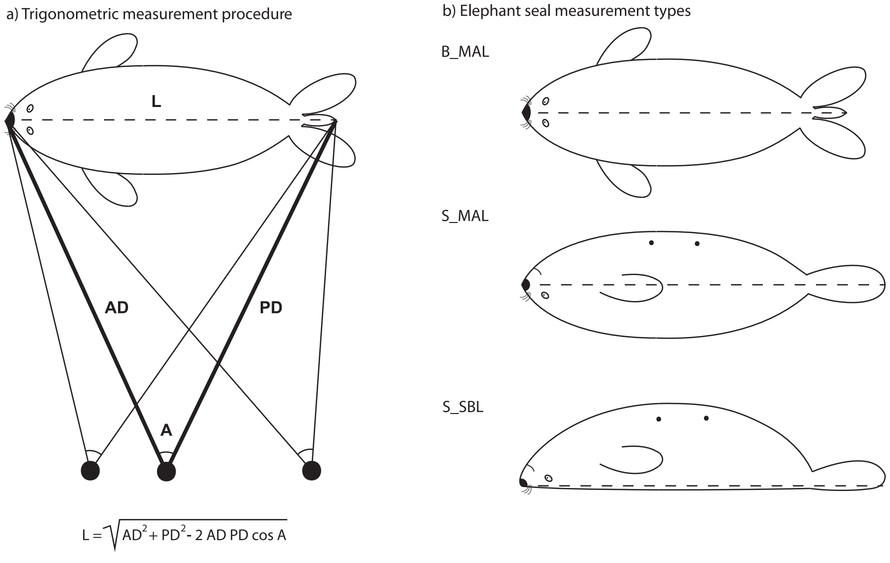

Figure 1. (a) Schematic view of the measurement procedure. AD: anterior distance, PD: posterior distance, A: angle between the distances. The position of the operator can be either centered with respect to the animal or shifted from the center. (b) The three types of seal measurements, as if they are seen from the air. (Top) B_MAL: middle axis length with seal on the belly; (middle) S_MAL: middle axis length with seal on the side; (bottom) S_SBL: straight back length with seal on the side. The dashed lines represent the lines along which the actual measurements were taken.

error of the measurement and the effect of operator's experience and weather conditions, we ran validation trials asking five operators, three experienced (minimum 2 mo of field measurements of seals) and two inexperienced (few hours of training before the trial), to measure two known size objects approximately as long as a small and large female elephant seal (2.00 and 2.83 m), from three different distances (5, 7, and 9 m), with three replicated measures for each object, one with the operator centrally placed with respect to the object, one with the operator shifted to the right of it, and one shifted to the left. Each operator carried out the validation trial in two light conditions, moderate (cloud coverage $\geq 80\%$) and strong ($\leq 20\%$), and in two wind conditions, light (wind speed ≤ 10 knots) and strong (>15 knots), for a total of four combinations, 72 measurements per operator, and 360 total measurements for the five operators. We timed the duration of each measurement, to assess if lack of experience increased the time required to take measurements. We classified the difficulty of measurement due to environmental factors in three classes, easy = moderate light and low wind, medium = moderate light and strong wind or strong light and moderate wind, and difficult = strong light and strong wind.

Field work was carried out by the three experienced operators. All elephant seals of the population are marked by tags in the rear flippers at birth and by hair dye as soon as they haul out during each breeding season (Galimberti and Boitani 1999). We obtained a total of 1,104 measures of three different types (Fig. 1b), each one with end at tail (T) or rear flippers (F) variants: (1) middle axis length with seal on the belly (B_MAL_T and B_MAL_F; Fig. 1b top); this is equivalent to the photogrammetric length that we previously estimated in males of the same population (Galimberti *et al.* 2007); (2) middle axis length with seal on the side (S_MAL_T and S_MAL_F; Fig. 1b middle); in this measurement the female body was symmetrically distributed around the middle axis; and (3) straight back length with seal on the side (S_SBL_T and S_SBL_F; Fig. 1b bottom); this measure is equivalent to standard body length (American Society of Mammalogists 1967). Each subject was measured three times while it was in the same position, with the operator changing his own distance and/or position between measurements. These repeated measures with the animal in the same position helped to identify wrong measurements directly in the field, and were averaged to produce a single independent measurement. We considered measurements of the same seal as independent only if the seal changed its body position. In most cases independent measurements of each seal were taken on different days. The number of measurements and individuals are tabulated in Table 1. Field work was carried out in accordance with established guidelines (Gales *et al.* 2009, Sikes *et al.* 2011).

To assess the reliability of the measuring system in the validation trials we calculated the absolute and percentage errors of the measurements of known size objects. We had a fully balanced measurement set, and we analyzed the effects of factors considered in validation trials on measurement error and duration using fixed factor repeated measure models, considering single factors and two-way interactions. To obtain P values we used Monte Carlo randomization of the F value of the model (10,000 permutations), that is more robust than asymptotic estimation (Manly 2007).

To assess the reliability of elephant seal size estimates obtained in the field we used the repeated independent measurements of the different individuals. We calculated repeatability (equals intraclass correlation; Lessells and Boag 1987) from variance components of a random factor model, in which the random factor was the identity of the seal. We calculated standard error and confidence interval of

Table 1. Repeatability of the different types of measurement. *n*: number of measures; *n* ind.: number of individuals; R = repeatability; SE(R): standard error of repeatability; LCL: lower 95% confidence limit; UCL: upper 95% confidence limit; *P*: probability of the randomization test on H0: R = 0 (10,000 replicates).

Measurement	*n*	*n* ind.	R	SE(R)	LCL	UCL	*P*
S_MAL_F	110	55	0.9643	0.0077	0.9492	0.9795	0.0001
S_MAL_T	16	8	0.9574	0.0196	0.9191	0.9958	0.0001
S_SBL_F	24	12	0.8567	0.0433	0.7719	0.9415	0.0001
B_MAL_F	30	15	0.8951	0.0277	0.8407	0.9495	0.0001

repeatability using bootstrap (bias corrected accelerated method, 1,000 replicates). We used bootstrap because it proved to be more robust than asymptotic estimation in a wide range of situations (Manly 2007). To obtain empirical equations to convert between measurement types we used least squares linear regression. All analyses were run in Stata (version 14 MP for Windows, http://www.stata.com).

In the validation trial (two objects, $n = 360$ measurements), mean absolute error was 0.86 cm (SD = 0.72 cm) and mean percentage error was 0.36% (SD = 0.32). Percentage error was lower for experienced operators (mean = 0.29%) than for inexperienced operators (mean = 0.46%; Randomization test: $F = 23.84$, $P = 0.0001$). Distance from the object slightly increased the percentage error (5 m: mean = 0.32%, 7 m: mean = 0.33%, 9 m: mean = 0.42%; Randomization test: $F = 3.46$, $P = 0.0287$). Contrary to expectations, percentage error was higher in moderate light (mean = 0.43%) than in strong light (mean = 0.28%; Randomization test: $F = 21.86$, $P = 0.0001$), while wind had no effect ($F = 0.86$, $P = 0.3353$). There was no interaction between experience and light (Randomization test: $F = 0.55$, $P = 0.5174$) or wind ($F = 0.005$, $P = 0.8174$). Duration of measurement was longer for inexperienced operators (mean = 3.01 min) than for experienced ones (mean = 2.34; Randomization test: $F = 15.50$, $P = 0.0018$). There was no effect of distance from the object on the duration of measurement (Randomization test: $F = 1.18$, $P = 0.3274$), or light level ($F = 0.16$, $P = 0.7076$), but measurements required more time in strong (mean = 2.84 min) than in light wind (2.36; $F = 7.76$, $P = 0.0067$). Experience showed no interaction with wind (Randomization test: $F = 2.03$, $P = 0.1541$), but had an important interaction with light level ($F = 7.84$, $P = 0.0059$). Although experienced operators were always faster, the difference between experienced and inexperienced operators was bigger in low (2.19 *vs.* 3.36 min) than in strong light (2.48 *vs* 2.70). Restricting analysis to experienced operators, that are the ones that collected the seals length data in the field, we observed a modest increase of measurement duration with difficulty of the measurement (easy: mean = 2.08 min, medium = 2.33, difficult = 2.64; Randomization test: $F = 2.94$, $P = 0.0722$), while no clear trend of duration with difficulty was observed for inexperienced operators. The viewfinder was used in 57.2% of measurements taken in strong light ($n = 180$), and in 11.1% of measurements taken in low light ($n = 180$), and the difference was significant (Fisher exact test: $P = 0.0001$).

Average female elephant seal length varied between 2.33 and 2.38 cm for nose to flipper measurements and from 2.50 to 2.58 cm for nose to tail measurements. To-flipper measurements were easier to obtain than to-tail measurements (to-flipper measurements = 81.0%) because the tip of the tail was often covered by the

Table 2. Equations to convert among measurements of different type. Indep.: independent variable in the OLS regression; Dep.: dependent variable; n: number of measurements, R = coefficient of linear determination, a: intercept, b: regression coefficient; SE(b): standard error of the regression coefficient; LCL = lower 95% confidence limit; UCL = upper 95% confidence limit.

Indep.	Dep.	n	R	a	b	SE(b)	LCL	UCL
(a) Flipper to tail conversion								
S_MAL_F	S_MAL_T	43	0.9164	0.0728	1.0559	0.0474	0.9630	1.1488
S_MAL_T	S_MAL_F			0.1302	0.8679	0.0409	0.7852	0.9506
S_SBL_F	S_SBL_T	24	0.9144	0.0805	1.0527	0.0669	0.9215	1.1838
S_SBL_T	S_SBL_F			0.1316	0.8686	0.0495	0.7715	0.9657
B_MAL_F	B_MAL_T	9	0.9364	0.3012	0.9510	0.1235	0.7089	1.193
B_MAL_T	B_MAL_F			−0.1423	0.9847	0.1119	0.7653	1.2041
(b) Conversion among flipper measurements								
S_MAL_F	S_SBL_F	34	0.9044	0.342	0.8487	0.0564	0.7383	0.9592
S_SBL_F	S_MAL_F	34	0.9044	−0.1396	1.0656	0.0682	0.9319	1.1993
S_MAL_F	B_MAL_F	39	0.8729	0.4884	0.7967	0.0536	0.6916	0.9017
B_MAL_F	S_MAL_F	39	0.8729	−0.2384	1.0957	0.0679	0.9626	1.2289
S_SBL_F	B_MAL_F	20	0.8641	0.0502	0.9885	0.106	0.7808	1.1963
B_MAL_F	S_SBL_F	20	0.8641	0.2755	0.8741	0.0965	0.685	1.0632

flippers. Among to-flipper measurements, S_MAL_F was the easiest to obtain (57.7%; S_SBL_F = 16.8%; B_MAL_F = 25.5%), because it was easier to find females laying on their side and straight aligned on their middle axis. Repeatability of measurements was high ($R > 0.85$) for all measurements for which we had independent repeated measurements of the same individual (Table 1). We were not able to calculate repeatability of S_SBL_T and B_MAL_T due to lack of replicates. S_MAL_F had the highest repeatability of all measurements, although there was overlap of confidence intervals with repeatability of other measurements. Conversion equations among flipper and tail variants of each type of measurement are presented in Table 2a. Conversion equations among different types of flipper measurements are presented in Table 2b. Strength of relationships was variable, but all equations had a coefficient of determination greater than 0.86 (Fig. 2).

Our trigonometric method showed a small error in validation trials with known size objects, was fast and easy to implement in the field, and produced size estimates with good repeatability. The most repeatable measure, the straight middle axis length with seal on the side, was also the easiest measure to obtain in the field, probably due to the tendency of females to place themselves straight on middle axis when laying on a side of the body. Therefore, we suggest this measure as the best one in elephant seals and pinnipeds at large. We expected measurements to be more accurate for experienced operators, closer objects, moderate light, and light wind, but in the validation trials the only factor having a consistent effect was experience. Trained operators had lower percentage error and shorter measurement duration than inexperienced ones, but in all cases measurement errors were so small that the method was robust to variation in operator experience and weather conditions.

The main advantages of our trigonometric method over photogrammetric approaches are the following: (1) the method can be implemented using readily available tools, and the whole assembly is cheaper than the average camera used in photogrammetric work; (2) the method is fast, requires only one operator, and

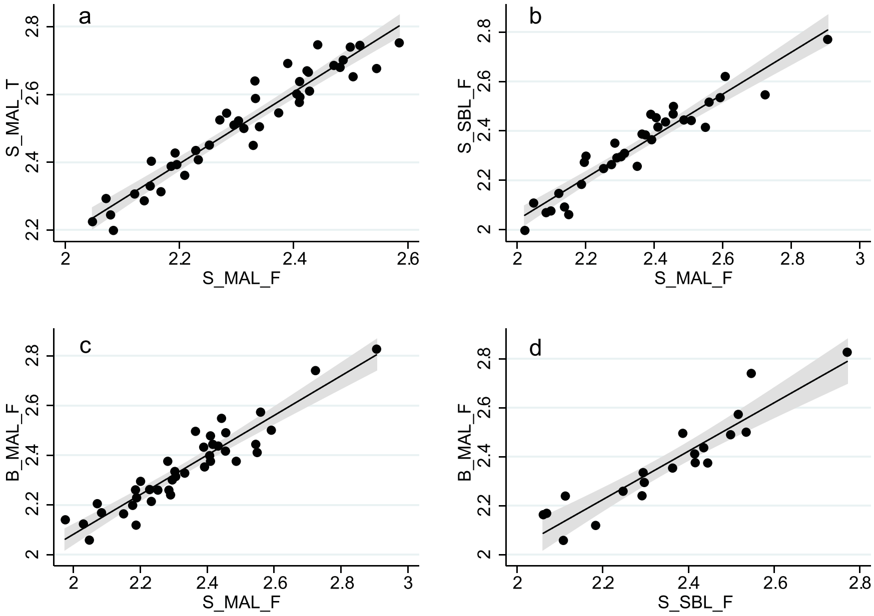

Figure 2. Scatterplot and regression line of a sample of conversions between different types of measurement. (a) tail middle axis length with seal on the side *vs*. flipper middle axis length with seal on the side; (b) flipper straight back length with seal on the side *vs*. flipper middle axis length with seal on the side; (c) flipper middle axis length with seal on the belly *vs*. flipper middle axis length with seal on the side; (d) flipper middle axis length with seal on the belly *vs*. flipper straight back length with seal on the side. Heavy line: least square linear regression line; shaded area: 95% confidence band of the regression.

permits the accumulation of body size data without placing a heavy work load on operators; (3) the method does not require any kind of postprocessing, and directly produces size estimates in the field; (4) the method can be applied from the distance, and does not require a scale to be placed close to the subject; and (5) the method works well even if the operator is not well placed, *i.e.*, not exactly facing the center of the animal and perpendicular to the middle axis of the seal, while these two aspects are crucial for parallel laser applications, and very important for photogrammetry. A fast, easy and reliable way to collect size measurements can be a notable advantage for long-term monitoring studies, that are proving fundamental in both theoretical and applied biology (Clutton-Brock and Sheldon 2010) and in which a simple, standardized, data collection protocol should be implemented to buffer variability due to changes of operators over time. In our own experience (*e.g.*, Sanvito *et al*. 2007*b*), standard photogrammetric approaches, although potentially very effective, require a great deal of postprocessing of the photos taken in the field, a burden that can be heavy, in particular when 3D techniques are applied. Moreover, they often require specialized software, and long training of operators to achieve a good intra- and interoperator reliability. Our method can be effectively applied by inexperienced operators, and permits to obtain size estimates directly in the field. This capability to provide field size estimates on demand, can greatly help in the rest of the field work, for example when estimation of body size is required to determine doses for chemical sedation of subjects. Being operated from the distance, our method can be applied to social pinniped species that are gregarious, avoiding biases due to easier access to peripheral females (*e.g.*, Fabiani *et al.* 2004). Being able to measure from the distance, without approaching the subjects and disrupting their behavior, can be of paramount importance in behavioral ecology studies that try to link structural phenotype to behavioral performance. An additional advantage of our methods is that estimates are produced in the field and, therefore, obvious errors can be corrected.

Although we showed that the accuracy of the method was not much affected by light and wind conditions, the time required to obtain a valid measure was. The impact of environmental conditions was affected by operator experience, which interacted with light conditions more than with wind. In very bright conditions it was not easy to see the red dot of the laser on the seal, it was often necessary to use the viewfinder to see it, and the measurement took longer but, all together, the best aspect of our method is that it can achieve good accuracy even when weather conditions and operator experience are suboptimal.

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