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ESTIMATING BODY MASS AND CONDITION OF LEOPARD SEALS BY ALLOMETRICS

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Abstract: Leopard seals (*Hydrurga leptonyx*) are formidable marine predators and require sedation before scientific examination. Mass-specific drug dosage for leopard seals has usually been determined from generic allometric equations or visual estimates. However, the leopard seal is a slender phocid and generic equations are likely to return inaccurate mass estimates, which may lead to fatal overdoses of drugs. We used published and unpublished morphometric data to construct allometric models for estimating leopard seal body mass. The model using volume (Vol), which combined measures of snout-tail length (STL) and the square of girth (G^2), provided our best estimate of mass ($r^2 = 0.97$). The model using STL alone was sample-site specific (each $r^2 \geq 0.85$), highlighting G as an important measure to obtain where possible. The confidence and prediction intervals associated with each model broadened with increased seal size and decreased sample size, suggesting the use of extra caution when estimating drug dosage for larger seals to avoid over- or under-dosing. We also developed a seal body condition index that can assist wildlife management when deciding if rehabilitation of vagrant seals is warranted. Body condition may also affect the induction, duration and recovery times of anaesthetized leopard seals.

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Key words: allometric equations, anesthesia, Antarctica, body condition, *Hydrurga leptonyx*, leopard seal, mass, morphometrics.

Leopard seals have the second largest body size of any pinniped species occurring in Antarctic circumpolar waters; only the southern elephant seal (*Mirounga leonina*) is larger. Due to logistic and practical difficulties associated with fieldwork, Antarctic pack-ice seals are among the least understood of the phocids, and the leopard seal is no exception. Leopard seals are aggressive upper trophic level predators that can severely harm humans handling them for scientific examination, and thus sedation of study animals is often mandatory. Ross (1847) described the leopard seal as a "formidable creature to engage." However, leopard seals are very vulnerable to the negative effects of anesthesia (Mitchell and Burton 1991). Mortality rates between 5 and 38% have resulted from immobilization trials using a variety of drugs on animals whose mass was either judged from previous experience (Higgins et al. 2002) or estimated from allometric equations specific to female southern elephant seals (Mitchell and Burton 1991). During the study by Higgins et al. (2002), 38 animals were sedated (of which 2 died) but due to equipment restrictions and incomplete immobilization, only 1 seal was weighed. Therefore, estimates of mass and dosage rates remained inexact.

The health of an animal can be reflected in certain key characteristics of its body condition. Based on their emaciated appearance, lethargy and open wounds on various body regions, vagrant leopard seals (i.e. seasonal visitors seen far to the north of their typical Antarctic habitat) are often assessed to have "poor" body condition (Rodriguez et al. 2003). Vagrant seals are most often seen in the lower latitudes during winter when the Antarctic sea-ice has reached its maximum extent (Hamilton 1939, Best 1971), where assessment of their condition can be misleading to the inexperienced observer because leopard seals are lean for their length, and leaner than other phocids such as the southern elephant seal (Duignan

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Table 1. Sample sizes and sources of the data for morphometric measurements of male and female leopard seals (*Hydrurga leptonyx*) encountered at locations both near and distant from the Antarctic, 1972–2003. Mass (kg), STL = snout-tail length (m), G = axillary girth (m).

		Sex		Measurement			
Study site	Capture status	Male	Female	Mass	STL	G	Source (s)
Heard Island (HI)	Live	25	10	35	35	33	This study
Macquarie Island (MI)	Live	8	9	17	16	12	This study
New Zealand (NZ)	Post-mortem	3	3	6	6	6	This study
Prydz Bay (PB)	Post-mortem	2	1	3	3		This study
Australia (AU)	Live	2	4	6	6		Gales 1984, This study
Palmer Station (PA)	Live	5	5		10	10	Hofman et al. 1977
Totals		45	32	67	76	61	

2003). Thus, leopard seal body condition maybe best described with the use of a condition index derived from body measurements. Two such indices are the Smirnov condition index (Smirnov 1924) and the Fineness Ratio (Castellini and Kooyman (1990). Precise snout-tail length (STL) and axial girth (G) measurements are required to calculate the Smirnov condition index, but the Fineness Ratio, calculated as the ratio between STL and maximum diameter (H), can be determined from a distance; both indices are not easily interpreted for management purposes.

We compiled morphometric measurements of leopard seals to develop predictive equations for mass estimation, which can be used to improve the accuracy of mass-specific dosage and reduce the possibility of drug related mortality. We used the morphometric data to substantiate a subjective body condition index that might be used by management to improve our understanding of the need to rehabilitate vagrant seals and the ways in which leopard seals of different body conditions react to anesthesia.

STUDY AREA

We collected data on 66 leopard seals captured or found dead between 1972 and 2003 at Heard Island (HI) and Macquarie Island (MI), in New Zealand (NZ) waters and Prydz Bay (PB), and on the east coast of Australia (AU; Table 1). To this data set, we added published morphometric data on seals captured and studied by Hofman et al. (1977) and Gales (1984). Thus, the data set used to develop the allometric models represented 77 leopard seals of both sexes (Table 1) encountered at locations in Fig. 1.

For the purposes of some analyses, we subdivided the study area in which these seals were captured into 3 geographic realms, the first progressing northward from the Antarctic coast, through the pack-ice belt, to 60°S (the Antarctic Realm), the second encompassing the sub-Antarctic between 60°S

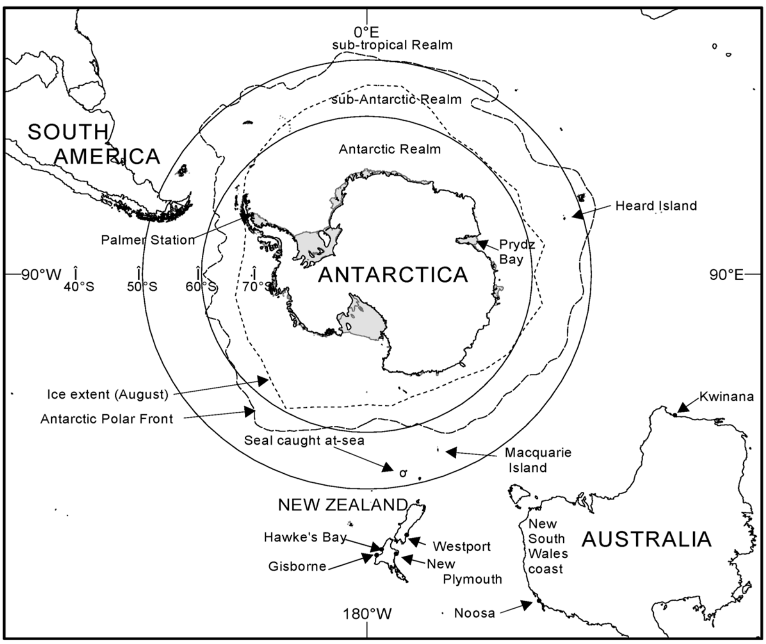

Fig. 1. Study site locations within the range of the leopard seal (*Hydrurga leptonyx*), 1972–2003. The study area has been subdivided into three geographic realms: the Antarctic between the coast of Antarctica and 60°S, the sub-Antarctic between 60°S and 50°S, and the sub-Tropical realm at latitudes lower than 50°S. Grey shaded areas are permanent ice shelves. Average annual position of the Antarctic Polar Front is based on Orsi et al. (1995), and August sea-ice extent data originates from Jacka (1999).

and 50°S (the sub-Antarctic Realm), and the third extending to the sub-tropical shores of Australia north of 50°S (the sub-Tropical Realm; Fig. 1). These realms exhibited a range of habitats and prey types increasingly unfamiliar to leopard seals, whose habitat typically centers on the Antarctic pack-ice belt south of the Antarctic Polar Frontal zone (Fig. 1), where penguins and Euphausids form much of their diet.

METHODS

Capture and Immobilization

We caught and handled leopard seals at Heard and Macquarie Islands and in Prydz Bay with the approval of the Antarctic Animal Ethic Committee. The Tasmanian Parks and Wildlife Service issued permits for research at Macquarie Island. Leopard seals caught in the state of New South Wales (NSW), Australia were examined by veterinary staff from Taronga Zoo (Zoological Parks Board of NSW) in association with NSW National Parks and Wildlife Service. All leopard seals in New Zealand were examined under a permit issued by the Department of Conservation, New Zealand.

Leopard seal capture and restraint methods varied among the studies represented here. At Heard Island (HI), seals were chemically immobilized with a remote intramuscular injection (Fig. 2A) of cyclohexamine anesthetics and xylazine between September and November 1987 (Mitchell and Burton 1991). At Palmer Station (PA), the seals were administered phencyclidine hydrochloride and diazepam by remote injection with a syringe attached to a ski pole between December 1972 and February 1973 (Hofman et al. 1977). The seal captured at Kwinana, Western Australia was immobilized with an intramuscular injection of a ketamine, diazepam and atropine in August 1983 (Gales 1984). Post-mortem measurements were collected from seals in Prydz Bay (PB) after a combination of midazolam/pethidine or tiletamine/zolazepam was administered intramuscularly by dart (Higgins et al. 2002) during the austral summers 1999–2000 and 2000–2001.

A conical canvas head bag and a pole net were used to capture and physically immobilize leopard seals caught at MI between July 1997 and December 2000. Four seals caught in AU on the New South Wales coast between 1972 and 2003 were immobilized with a hoop net, and 1 seal was sedated with 40 mg of diazepam administered orally in

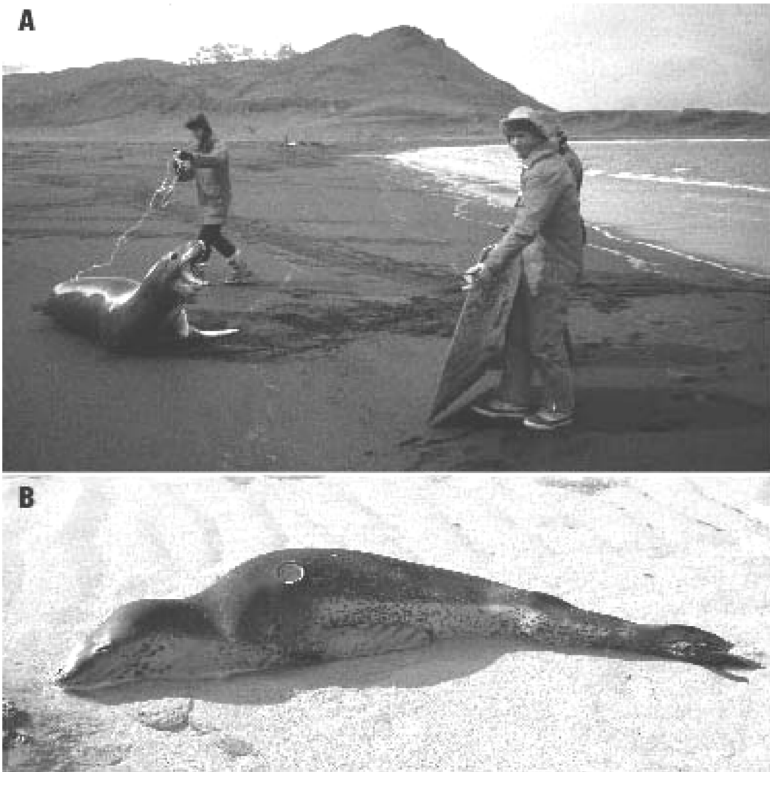

Fig. 2. (A). A male leopard seal (*Hydrurga leptonyx*) assessed in medium body condition receives an intramuscular injection of sedative administered remotely into the dorsal muscle of the pelvic region by means of a 90 mm 18G spinal needle attached to 4 m of intravenous drip tubing loaded with sedative and saline solution, Heard Island 10 Dec 1987. This seal had a snout-tail length of 280 cm, a girth of 230 cm, and weighed 362 kg. Boards carried by the 2 assistants were used as protection and to prevent the seal from entering the water after the drugs were administered. (B). A young vagrant female leopard seal hauled out on a beach at Lord Howe Island (31°33′S, 159°4′E) some 4,000 km from the Antarctic coast. This seal was classified in poor body condition according to its snout-tail length to height ratio of approximately 5.5:1. The seal's pelvis and neck regions show distinct signs of wasting. A cookie-cutter shark (*Isistius brasiliensis*) has inflicted its unique bite mark above the seal's fore flipper.

fish. A large circular net with a draw string was used to restrain a leopard seal captured near Noosa (AU), in August 1996. Post-mortem measurements were collected from seals recovered in NZ waters (Fig. 1) between January 1997 and November 2002; 5 seals had hauled out and died on the coast of the north and south islands and one seal died after becoming bycatch in a commercial fishery south of NZ (Fig. 1).

Indices of Condition

At HI, the body condition of 26 seals was visually assessed (on 24 of these seals, girth measurements were also made). Each seal was given a condition rating where 1 = very poor, 2 = poor, 3 = moderate, 4 = good, and 5 = very good. Smirnov's (1924) condition index (G*100/STL; hereafter known as the Smirnov Index) and a Fineness Ratio (Castellini and Kooyman 1990) of STL to seal height (H), which is directly proportional to G using the formula $H = 2(G/2\pi)$, were calculated for each seal to compare relative condition between the seals (Anderson et al. 1993), and also to verify the 5 visual condition assessment categories.

Morphological Measurements

Snout-tail length (STL) was measured as the seals lay in ventral recumbency (Scheffer 1967). Axillary girth (G) was measured as the seals' circumference at position C3 (Gales and Burton 1987) located immediately behind the fore flippers of the seal. STL and G were measured to the nearest centimeter with a flexible tape measure. Mass (M) was measured (±1 kg) with an electronic balance suspended from 1) a hydraulic crane (HI) or 2) a chain-block attached to a tripod (MI and PB) while the seal lay in the pole net. M of the seal caught at Noosa, Australia, was measured to the nearest 0.5 kg with a digital crane scale while the seal, still wrapped in the capture net, was suspended in a stretcher. Seal volume (Vol) was determined from STL and G using the formula $Vol = STL*G^2$ (Castellini and Kooyman 1990).

Analytical Methods

Data were tested for normality with the Shapiro-Wilk *W*-test. Tests were performed for each variable for each site after data collected from seals at Noosa, Kwinana and the New South Wales coast (Fig. 1) were pooled into an "Australia" (AU) group ($n = 6$). Owing to small sample sizes and missing data from some study sites, we could not determine normality for all variables collected at all sites. Log transformations of the M, STL, and Vol were made to restore data normality. The nonparametric Kolmogorov-Smirnov test was used to test for sex differences in morphometric measurements. We used one-way analysis of variance (ANOVA) and a post-hoc unequal sample size HSD test to determine whether seals assigned to different subjective body condition groups also had significantly different mean scores on the Smirnov Index and Fineness Ratio.

Models predicting M from STL and Vol. were derived using linear regression analysis. A forward-stepwise model building approach was used to determine whether the addition of independent variables (sample location, sex, and season) would improve the model. This stepwise approach starts with a model with the most significant predictor, stopping when the addition of variables does not statistically increase the model's r^2. All analyses were performed using STATISTICA (StatSoft, Oklahoma, USA). Probability values (P) ≤ 0.05 were considered statistically significant.

RESULTS

Mass data were not normally distributed (Shapiro-Wilk tests for HI, MI, and the full data-set; all *W*s < 0.94, all *P*s < 0.002). STL data at HI lacked normality ($W = 0.93$, $P = 0.042$). Vol at HI and in the full data-set also lacked normality (both *W*s < 0.93, all *P*s < 0.002). Therefore, all M, STL, and G data were log transformed. The sex-ratio was not significantly different from unity (1.4 M : 1.0 F), and there were no significant sex differences for M, STL and G (all Kolmogorov-Smirnov test statistic *P*s > 0.10).

Indices of Condition

Upon first inspection, the ANOVAs identified significant differences in the mean Smirnov Index and the Fineness Ratios among the 5 different body condition groups determined by visual inspection of the HI seals (Smirnov Index: $F_{4, 19} = 6.32$, $P = 0.002$; Fineness Ratio: $F_{4, 19} = 7.16$, $P = 0.001$), but the post-hoc HSD test found not all the means were significantly different at $P \leq 0.05$. Therefore, we used the HSD test results and our own judgement to distill the 5 HI groups into 3 new visual condition groupings as follows; 1) poor (= very poor + poor), 2) medium (= moderate + good) and 3) good (= very good). The re-run ANOVAs were significant (Smirnov Index: $F_{2, 21} = 9.74$, $P = 0.001$; Fineness Ratio: $F_{2, 21} = 10.33$, $P < 0.001$). The post-hoc HSD tests showed significant ($P \leq 0.05$) differences between the Smirnov Index and the Fineness Ratios means for seals in poor

Table 2. Smirnov Index and Fineness Ratio (mean ± 95% CI) for leopard seals (*Hydrurga leptonyx*) captured at Heard Island, Sep–Nov 1987 and visually assessed as being in 3 different body condition categories. Post-hoc unequal sample size HSD test found seals in poor condition have a significantly different mean Smirnov Index and Fineness Ratio than seals in medium and good condition ($P < 0.05$); means were not significantly different between medium and good condition ($P > 0.05$). LCL = lower CI, UCL = upper CI.

	Smirnov Index (G*100/STL) ($F_{2, 21} = 9.74$, $P = 0.001$)				Fineness Ratio (STL:H) ($F_{2, 21} = 10.33$, $P < 0.001$)			
Body CI	$\bar{x}$	LCL	UCL	n	$\bar{x}$	LCL	UCL	n
Poor	52.39	51.05	57.27	5	5.91	5.54	6.08	5
Medium	59.73	57.89	61.26	17	5.27	5.13	5.43	17
Good	64.47	65.90	70.82	2	4.88	4.37	5.23	2

condition compared to those in medium and good condition (Table 2); the body condition indices for seals classed in medium and good condition were not significantly different ($P > 0.05$).

The body condition of seals captured in the subtropics at NZ ($n = 5$) was 1.06 index groups below that of seals captured in the sub-Antarctic (HI/MI, $n = 50$) and 0.5 index groups below that of seals captured at PA in the Antarctic ($n = 10$; $F_{2, 62} = 7.32$, $P < 0.002$; Fig. 3). The seals pictured in Fig. 2 show this difference; the seal from HI (Fig. 2A) has a thick neck and well rounded body, and was judged in medium condition. In comparison, the vagrant seal (Fig. 2B) pictured hauled out on a beach at Lord Howe Island (31°33′S, 159°4′E), approximately 4,000 km from the Antarctic coast, has a wasted body appearance, a thin neck and protruding pelvic region typical of a seal judged to be in poor body condition.

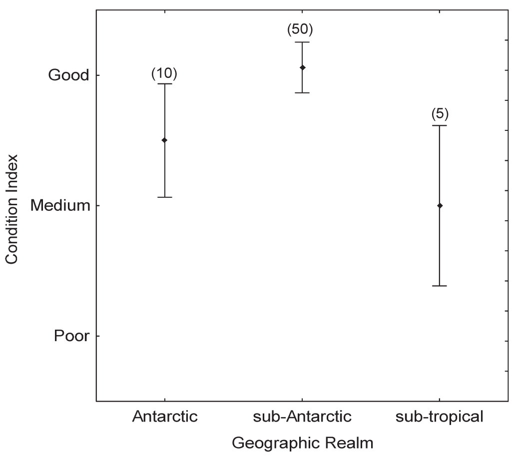

Fig. 3. Geographic differences in body condition (±95% CI) of leopard seals (*Hydrurga leptonyx*). The condition index was derived from visual assessment of leopard seals at Heard Island (Sep–Nov 1987), and applied to seals caught in the Antarctic at Palmer Station (Dec 1972–Feb 1973), at sub-Antarctic Macquarie Island (Jul 1977–Dec 2000) and sub-tropical New Zealand (Jan 1997–Nov 2002). Sample locations within the Antarctic realm are at latitudes > 60°S; the sub-Antarctic realm is between 60–50°S; and the sub-Tropical realm is north of 50°S. Numbers above the CI's represent sample sizes. Significant differences exist where the CI's do not overlap ($P < 0.002$).

Regression Equations

The relationship between log(M) and log(Vol) was linear (Fig. 4) and had an $r^2 = 0.966$ (Table 3). Forward stepwise addition of independent variables (sample location, sex and season) did not significantly improve the model coefficient. The relationship between log(M) and log(STL) was also linear ($r^2 = 0.832$); however there was a high degree of data-point scatter that we attributed to differences among locations (Fig. 5A). Therefore, we made the following decisions to improve the model: (1) remove an outlier observation (log(M) = 2.35 and log(STL) = 2.49) from the NZ data; (2) remove the PB data because the sample size was very small ($n = 3$); and (3) pool the HI and MI data to form a HI/MI group because the slopes and intercepts of these 2 data sets were not significantly different (post-hoc Tukey test $P > 0.05$). Final location groupings for STL were HI/MI ($n = 51$), AU ($n = 7$) and NZ ($n = 5$; Fig. 5B). Although the slope and intercept for the AU data looked different to those for the HI/MI and NZ groups, the interaction term [sample location*log(STL)] was not significant ($F_{2,57} = 1.033$, $P < 0.363$). A main effects model (no

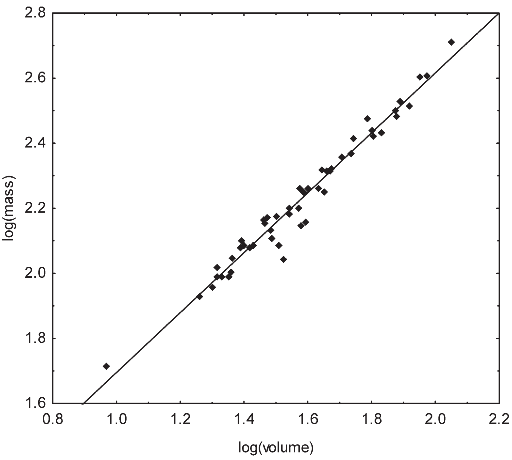

Fig. 4. Regression of log(mass) against log(volume) for leopard seals (*Hydrurga leptonyx*) captured at Heard and Macquarie Islands and New Zealand, 1987–2002. The solid line plotted through the data is the line of best fit.

Table 3. Generic and site-specific predictive equations for estimating leopard seal (*Hydrurga leptonyx*) body mass (kg) from morphometric measurements. STL = snout-tail length (m), Vol = volume derived from STL*G^2. G = girth (m). HI/MI = Heard and Macquarie Islands, AU = Australia, NZ = New Zealand.

Variables	*n*	Location	Model	r^2
Vol.	51		Log(mass) = 0.774 + 0.921 * log(Vol)	0.966
STL	51	HI/MI	Log(mass) = –5.330 + 3.126 * log(STL)	0.857
STL	7	AU	Log(mass) = –5.325 + 3.126 * log(STL)	0.886
STL	5	NZ	Log(mass) = –5.222 + 3.126 * log(STL)	0.862

interaction term) for sample location was significant ($F_{2,59}$ = 31.213, P < 0.001). From a parameterized model, using HI/MI as the baseline group, we found that the slope for AU was significantly different from that for HI/MI (t = 4.698, P < 0.001) but NZ was not different from HI/MI (t = 0.185, P = 0.85). We decided not to pool the HI/MI and NZ data because there were only a few observations in the NZ group, and pooling the groups would likely broaden the 95% confidence intervals (CI) and the 95% prediction intervals (PI) for the HI/MI model. The derived regression equations for estimating M from STL at each of the three sample locations had r^2 values > 0.857 (Table 3).

Log transformed variables were back-transformed to display the relationships between estimated M and Vol (all locations pooled), and for STL at the 3 location groupings (HI/MI, AU, NZ; Figs. 6A–D). Back calculations also clarified the estimates of precision (95% CI and the 95% PI) surrounding each regression line, which broadened as seal size increased. Based on these models, a seal with an intermediate Vol of 40 (STL*G^2*10^{-5}) can have an estimated M between 150–210 kg, while a larger seal with a Vol of 80 (STL*G^2*10^{-5}) can have an estimated M of between 280 and 400 kg, a potential error of 120 kg. Using STL, a 2.2 m seal seen at HI/MI can have an estimated M value between 120 and 230 kg, while a larger seal of 2.8 m STL can weigh between 240 and 480 kg, a difference of 240 kg. Estimates of M from STL for seals seen in NZ and AU have greater margins of error, particularly for larger seals.

DISCUSSION

The leopard seals encountered during this study (n = 77) were not sexually dimorphic, and, as has been previously reported by Walker et al. (1998) and Rodriguez et al. (2003), the seals' body condition diminished when they were seen at subtropical latitudes. We developed a subjective visual index, validated against 2 empirical indices (the Smirnov condition index and the Fineness Ratio), to determine the body condition for these vagrant seals; the visual index can delineate poor condition seals from others. For leopard seals, the relationship between log mass (M) and log snout-tail length (STL) was linear; as was the relationship between log(M) and the log of the seals' volume (VOL = STL*axillary girth^2).

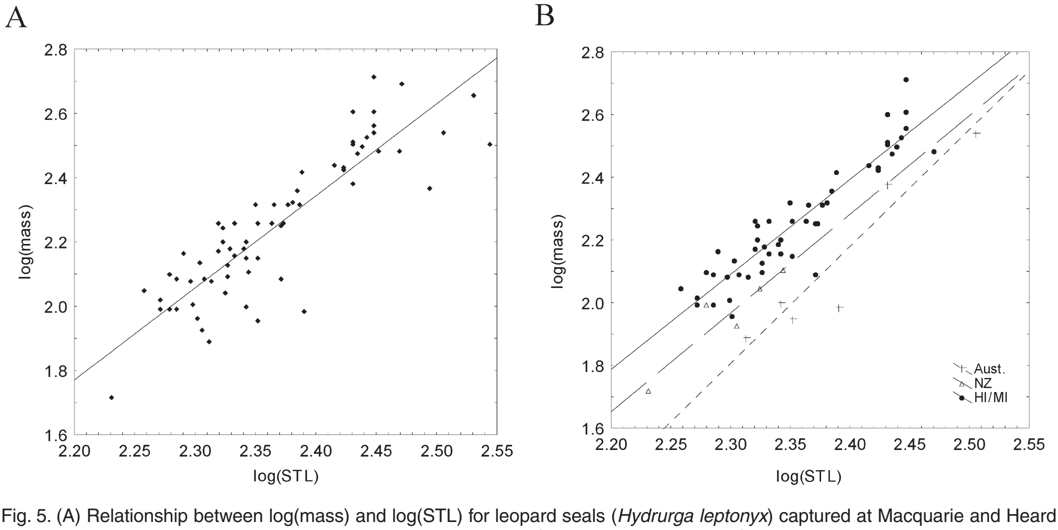

Fig. 5. (A) Relationship between log(mass) and log(STL) for leopard seals (*Hydrurga leptonyx*) captured at Macquarie and Heard Islands, and in Prydz Bay, New Zealand and Australia, 1987–2003 (n = 66, data were pooled). The solid line plotted through the data is the line of best fit. (B) Site specific differences in the relationship between log(mass) and log(STL) for leopard seal STL data collected in Australia (AU; n = 6), New Zealand (NZ; n = 5) and at Heard and Macquarie Islands combined (HI/MI; n = 51). Slopes of the three regressions were not significantly different according to the interaction term [sample location*log(STL)] (P = 0.363). STL = snout-tail length. Black dots and solid line = HI/MI, Open triangle and broken line = NZ, Black cross and dotted line = AU.

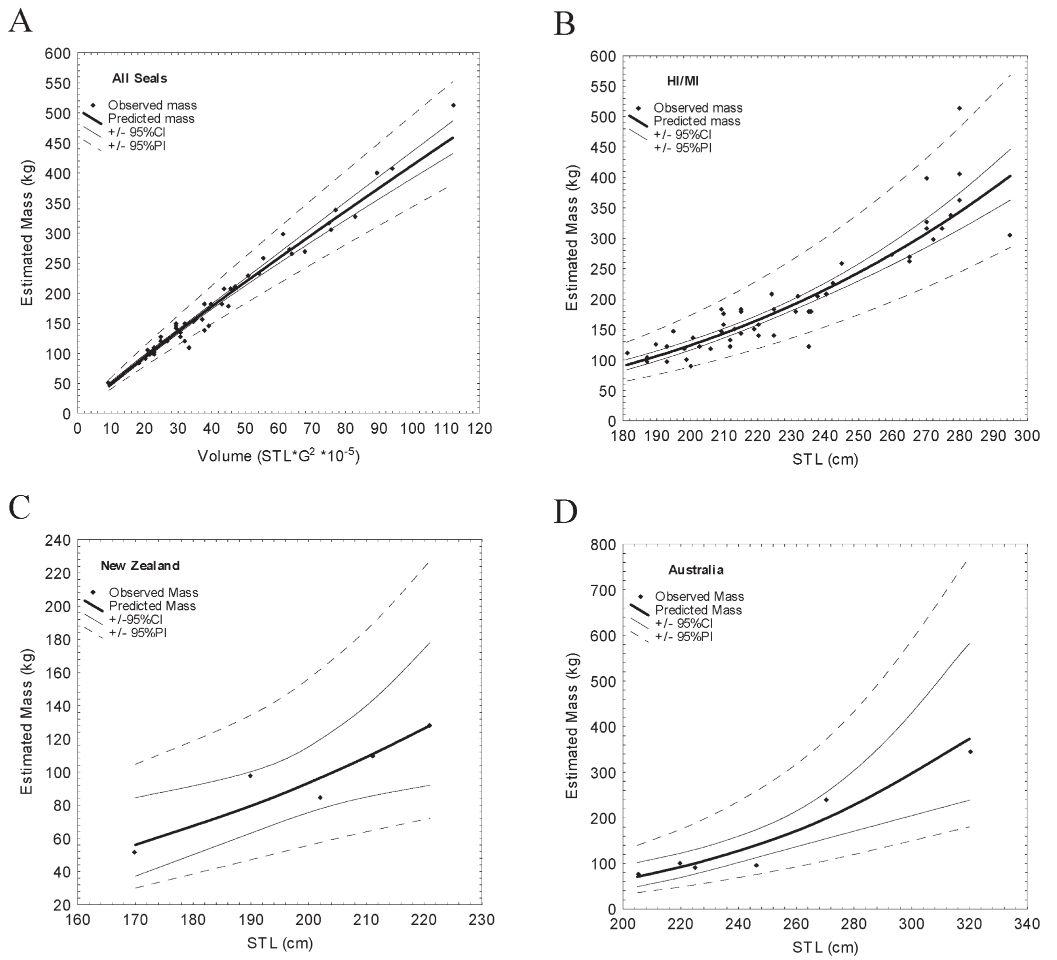

Fig. 6. Relationships between back transformations of (A) log(mass) to log(vol.) and (B, C, D) log(mass) to log(STL) for leopard seals (*Hydrurga leptonyx*) captured at Macquarie and Heard Islands (HI/MI; $n = 51$), New Zealand ($n = 5$), and Australia ($n = 6$) from 1987 to 2003. The thick solid line represents the line of best fit, the thin solid lines are the 95% confidence intervals, and the dotted lines are the 95% prediction intervals. STL = snout-tail length. The 95% CI is the confidence interval for the *average* prediction of seal mass, and the 95% PI is the confidence interval for the prediction of an *individual* seal's mass. Note differences in axis scale.

Although the data set we presented in this paper is the largest yet compiled for the leopard seal, we found our allometric equations had particularly high levels of uncertainty, especially for larger seals. A seal's STL is 1 of the simplest measurements to collect in the field; it can be made while seals are sleeping or estimated from marks made in the substrate close to the animal's snout and tail. Our relationship to determine log(M) from log(STL) for all the data pooled had a high r^2 (0.832); however, site-specific differences contributed to the high variability surrounding the regression line. When each sampling location was considered separately, there were significant differences between the intercepts for the AU equation and the HI/MI and NZ equations. Location-specific equations had higher r^2 values (between 0.857 and 0.886) than did the equations based on the combined STL data set. Variations in seal body condition or seal age are the most likely explanations for the observed differences in the intercepts, making sampling location and body condition important factors to consider when using log(STL) to estimate log(M) of leopard seals.

The addition of G^2 to the STL model provided a third dimension volume index, (log(Vol), which improved our models' predictive capabilities by 13 percentage points ($r^2 = 0.966$). Including seal sex, sampling location and season into the forward stepwise model did not significantly improve the models' ability to predict log(M) using log(Vol). The same volume measure has been used in the estimation of otariid and phocid mass (Castellini and Kooyman 1990; Castellini and Calkins 1993; Bell et al. 1997). However, measurement of a seal's circumference or axillary girth (G) is often difficult to obtain in the field prior to anesthesia, especially from larger seals that could inflict major injuries to researchers. In that case STL may be the only morphometric measurement available from which to estimate mass.

Back transformations of log morphometric measurements and the regression models error estimates were performed (Figs. 6A–D). The 95% confidence intervals (CIs) and the 95% prediction intervals (PIs) are shown around each line of best fit to indicate of how well the predictive models compare. Even with regression coefficients between 0.857 and 0.966, the CIs and PIs for each regression diverge toward the larger end of the scale (Fig. 6A–D). Difficulties in gathering data from larger seals contributed to the observed divergences, and these inaccuracies can only be reduced with increased sample size.

Using our equations, the estimated mass of a 200 cm STL seal can range from 90 to 170 kg. This 80 kg difference equates to 104 mg of tiletamine/zolazepam, if administered at 1.3 mg/kg (Higgins et al. 2002). Clearly, caution should be exercised when administering mass-specific dosages to leopard seals when such large error margins surround the M estimates. A seal weighing 130 kg could be either under- or over-dosed by 52 mg of drug, both circumstances creating their own problems. The under-dosed seal will still have the capacity to cause injury to the researchers while an over-dosed seal may die.

The leopard seal is a slim, streamlined phocid and therefore it is difficult for an inexperienced observer to gauge a seal's body condition. Estimating seal body condition with the Smirnov Index requires STL and G measurements are taken from the seals, a difficult prospect with live leopard seals. For live leopard seals, the Fineness Ratio may present a better alternative since this index is simply a ratio of the seals' STL divided by H which can be measured from a distance, reducing disturbance to the seal and risk of injury to the observer. Seal body condition could be determined from a photograph when taken perpendicular to the seal and as close to the ground (horizontal) as possible (eg. Fig. 3B). The Fineness Ratio can then be translated into one of our subjective (visual) condition indices (Table 2) so that the seal's body condition can be understood in simplified terms.

Rehabilitation of stranded and/or sick marine mammals is practiced in most countries today; however, before intervention is considered, the individual is usually assessed against certain physical criteria such as its body condition and general health. Uncertainties regarding body condition were central to arguments surrounding the capture of a leopard seal that died shortly after (Fulton 1998). We believe our body condition index will be useful in removing doubts about leopard seal body condition in the future.

We also suspected the duration and recovery time from anesthesia for poor condition leopard seals may be extended because body condition affects an individual's ability to redistribute and metabolize drugs, as Field et al. (2002) observed for southern elephant seals in poor condition; thin seals receiving a similar mass-specific dosage will experience lengthier anesthetic bouts than seals in better condition. While we have no data to test our suspicion, we provide separate mass estimation models using the STL of poor condition vagrant seals found in AU and NZ waters to reduce the possibility that seals in poor condition will experience anesthetic-related problems.

The extents for the CIs and PIs suggest our models have relatively poor predictive abilities for larger seals; however these limits provide precautionary boundaries that may facilitate safer handling of this species. We cannot stress enough the need to improve these models and their predictive power with newly collected data as they become available. We suggest our equations be tested on each occasion in the field to verify the mass estimates derived from our models, and this can be achieved by weighing immobilized seals as a priority. Any leopard seal sufficiently anaesthetized should be weighed to determine the exact mass and the drug dosage administered, in retrospect. This procedure will improve researchers' understanding of the duration of anesthesia and recovery for leopard seals of different sizes, and also suggest what factors might have contributed to a seal's death, should it occur.

MANAGEMENT IMPLICATIONS

Understanding the response of leopard seals to local and regional environmental perturbations will require a hands-on field approach that includes immobilization of free-living seals. Causes of leopard seal dispersion from the Antarctic ecosystem into the sub-Antarctic and sub-tropics are likely linked to temporal changes in the circumpolar Antarctic sea-ice extent, and to the amplitude and periodicity of the Antarctic Circumpolar Wave (White and Peterson 1996); temporal changes in these variables could precipitate a change in the number and the body condition of the seals that move as vagrants to the north of Antarctica.

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