Morphometric measurements and body condition of healthy and starveling Steller sea lion pups (*Eumetopias jubatus*)

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Abstract

The thickness and weight of skin, blubber, and body core were measured from 12 dead Steller sea lion pups (*Eumetopias jubatus*). These necropsied pups represented a wide range of body sizes and conditions (small to large, and fat to no-fat), and were chosen to compare the relative body conditions of healthy and starved pups. Seven of the pups lacked blubber and were significantly lighter for a given length compared to the five that had fat at their time of death. Volume exceeded mass by a factor of 1.3% with density averaging 0.987 g cm^{-3}. Skin and blubber were not uniformly thick over the body surface. Skin was thinnest on the head and around the flippers (3 mm), and became thicker towards the rump (5 mm). Skin thickness did not differ between dorsal and ventral sides, unlike blubber, which was thickest on the ventral side, increasing from the snout (1.5 mm) to mid-trunk (7 mm) and decreasing posteriorly (5 mm at the tail). Along the back, blubber increased from 1 mm at the snout to about 4.5 mm at mid-trunk. The five pups that died of trauma had about 13% skin and 10% blubber (expressed as a proportion of total body mass). Starvelings lost an estimated 43% of their body mass before dying (10% blubber, and 33% body core). Morphometric measurements applied to three proposed indices of body condition suggest that girth is not a good predictor of body condition for Steller sea lion pups. Only the ratio of observed to predicted body mass derived from standardized mass-length relationships could distinguish starvelings from pups with body fat.

Key words: Steller sea lion, *Eumetopias jubatus*, pups, blubber, skin, volume, density, body condition, starvation.

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Introduction

There is considerable interest in applying simple methods to assess the general health of individual marine mammals. In the case of pinnipeds, there are generally two approaches. The first measures the thickness of the blubber layer or the amount of body fat, and is premised on the idea that a fat animal is healthy (e.g., Gales & Burton, 1987; Ryg *et al.*, 1990a; Castellini *et al.,* 1993, Renouf *et al.*, 1993; Gales *et al.*, 1994; Arnould, 1995; Jonker & Trites, unpublished data). The second approach uses a standardized growth curve to determine how heavy an individual should be, based on its measured length and girth. Animals that are underweight for a given length are assumed to be in poorer physical condition compared to those that are average or overweight (e.g., Pitcher, 1986; Markussen *et al.*, 1989; Trites, 1992; Trites & Bigg, 1992; Renouf *et al.*, 1993). Neither approach has received wide acceptance.

One species of pinniped that currently is receiving considerable research attention is the Steller sea lion (*Eumetopias jubatus*). It was declared an endangered species in parts of its Alaskan range, where it has undergone a dramatic decline since the late 1970s (Merrick *et al.*, 1987; NMFS, 1992; Trites & Larkin, 1996; Loughlin, 1998). One of the leading theories to explain the population decline is that Steller sea lions are not getting enough to eat and are nutritionally stressed. Support for this theory comes from morphometric measurements of adult Steller sea lions shot in the 1970s and 1980s that indicated adults were smaller during the period of sharp population decline (Castellini & Calkins, 1993; Calkins *et al*., 1998).

The primary goal of our study was to examine one age class of Steller sea lions—pups—to understand the mass-length relationship, the distribution of blubber, and the relationship between blubber thickness and overall health. We measured the lengths, girths, weights, volumes, and skin and

blubber thicknesses of 12 dead Steller sea lion pups. These pups died either of starvation or trauma. They represented a wide range of body sizes and conditions (small to large, and fat to no-fat), and provided a useful data set for evaluating some proposed morphometric-based indices of body condition.

Materials and Methods

Sea lions

Twelve dead Steller sea lion pups were recovered from rookeries at Forrester Island in southeastern Alaska in June and July 1994. We sought a range of sizes and states (heavy to light and fat to no-fat). Some pups apparently were healthy at their time of death, while others had starved. All pups were assumed to be between the ages of 3 and 14 days based on the synchronous timing of birth and the size and condition of the bodies. Standard length (precision ± 0.5 cm), weight (± 0.01 kg), and axillary girth (± 0.5 cm) were taken according to accepted procedures (American Society of Mammalogists, Committee on Marine Mammals, 1967). Volume (± 0.5 l) was determined by placing the pups in a graduated bucket, and measuring the displacement of water.

The skin and subcutaneous fat (blubber) layer of the dead pups were sliced every 10-cm along the dorsal and ventral side of the body with a scalpel to measure the actual sculp (skin and blubber) thickness with a ruler (± 0.5 mm). Each location was measured three times (by measuring all points over the animal's body once, then measuring all points a second time, before starting the series over for a third and final time). The median of the three measurements is more robust than the mean and was retained as the best estimate for each spot. Thickness of the blubber layer was calculated by subtracting the median skin thickness from the median sculp thickness (for those pups that had blubber). The sculp, excluding flippers, was dissected from the body core with a scalpel. Blubber was removed and weighed from five pups.

Indices of body condition

Two general condition indices (C_i) have been used to calculate a relative measure of body condition for Steller sea lions from morphometric measurements:

$$C_1 = \frac{G}{L} \cdot 100\% \tag{1}$$

and

$$C_2 = \frac{M}{\hat{M}} \tag{2}$$

where, G is girth, L is standard length, M is mass, and $\hat{M}$ is expected mass (Brandon *et al.*, 1996; Trites & Rosen, unpublished data). Expected mass can be estimated from two empirical relationships. The first relates mass to body volume (Castellini & Calkins, 1993),

$$\hat{M} = 4.96 \times 10^{-5} \cdot L \cdot G_2 \tag{3}$$

while the second relates mass to body length (Trites & Rosen, unpublished data),

$$\hat{M} = -63.88 + 0.8966 \cdot L. \tag{4}$$

The body-volume-index regression (Eq. 3) was derived using data from all age groups of Steller sea lions (Castellini & Calkins, 1993), while the stoutness-index regression (Eq. 4) is specific to Steller sea lion pups (Trites & Rosen, unpublished data). Substituting Eqs. 3 and 4 into Eq. 2 yields the following two indices of body condition:

$$C_2 = \frac{M}{4.96 \times 10^{-5} \cdot L \cdot G^2} \tag{5}$$

and

$$C_2 = \frac{M}{-63.88 + 0.8966 \cdot L}. \tag{6}$$

Three sets of condition indices were calculated for the 12 necropsied pups (i.e., Eqs. 1, 5 and 6). Standard two sample *t*-tests were applied to the condition indices to determine whether the small sample of pups with fat could be distinguished from those without fat. All analyses were completed with S+ (Becker *et al.*, 1988) using standard statistical techniques (Zar, 1996).

Results

Morphological measurements from the twelve dead pups are contained in Table 1. Dissection of the 12 pups revealed that 7 did not have any discernable blubber (no-fat—starveling pups). Average weights, girths and lengths of pups with blubber (fat pups) were not significantly different from those of starvelings (fat: $\bar{x} = 22.3$ kg, 60.8 cm girth, and 99.0 cm length; no-fat: $\bar{x} = 17.6$ kg, 54.9 cm, and 98.6 cm respectively; $P = 0.16, 0.19$ and 0.92 respectively). Plotting the relationship between mass and length (Fig. 1) showed that many of the pups lacking blubber were significantly longer for a given weight compared to those that had blubber. The relationship between volume and mass was essentially one-to-one for pups with and without blubber (Fig. 1, top panel). Volume exceeded mass by a factor of 1.3%, suggesting that pups were slightly

Table 1. Morphometric measurements from 12 dead Steller sea lion pups. Pups are ordered from lightest to heaviest with date indicating when they were recovered from the rookery in 1994. Body mass includes skin and blubber.

Pup No.	Date	Sex	Mass (kg)			Volume (1)	Length (cm)		Axillary Girth
			Body	Skin	Blubber		Standard	Curvilinear	
1	25 June	F	12.60	2.75	0.00	13	89.0	94.5	48.0
2	28 June	F	14.20	1.90	1.20	14	95.0	103.5	51.0
3	1 July	F	14.78	—	0.00	14	94.0	100.5	54.0
4	14 July	M	16.00	3.70	0.00	16	99.0	106.0	56.0
5	6 June	F	16.00	2.50	1.30	16	88.0	99.0	50.5
6	28 June	M	17.10	3.60	0.00	17	102.0	107.5	50.5
7	26 June	F	19.30	4.00	0.00	19	104.0	112.0	54.0
8	25 June	M	20.00	4.10	0.00	21	96.0	106.0	61.0
9	24 June	M	22.68	3.22	2.00	23	97.0	106.0	63.5
10	30 June	M	22.90	5.08	0.00	23	106.0	113.0	61.0
11	30 June	M	27.60	3.72	2.90	27	105.0	113.5	67.0
12	30 June	M	30.80	3.95	3.95	33	110.0	118.0	72.0

positively buoyant with an average density of 0.987 g cm^{-3}.

Skin thickness increased from 3 mm at the snout to 4 mm at the neck, and averaged about 5 mm over the rest of the body (Fig. 2). There was no significant difference between dorsal and ventral skin thickness (paired t-test: $t_{10} = -1.27$, $P=0.23$). In comparison, blubber (of the five pups that had blubber) was thickest on the ventral side (paired t-test: $t_{10} = -7.64$, $P<0.001$), increasing from the snout (1.5 mm) to mid-trunk (7 mm), and decreasing thereafter (5 mm at tail). Along the back, blubber increased from 1 mm at the snout to about 4.5 mm at mid-trunk (Fig. 2).

The weight of the sculps (containing only skin, *or* skin and blubber) averaged 22.6% of total body mass ($\sigma=1.6\%$, $n=11$, Fig. 3). There was little variability in proportional sculp weight between pups with and without blubber. For the 5 pups with blubber, skin averaged 12.9% of body mass, with blubber contributing 9.7% of total body mass.

The three sets of condition indices calculated for these 12 pups showed considerable variability. Only Eq. 6, which predicted mass from length (the stoutness-index), was able to distinguish between pups with and without fat (Eq. 6: $\overline{C}_{\text{fat}}=0.90$, $\overline{C}_{\text{no-fat}}=0.72$, $t_{10}=2.51$, $P=0.031$). Neither Eq. 1 (the girth-index) nor Eq. 5 (the volumetric-index) were able to distinguish the two groups of pups (Eq. 1: $\overline{C}_{\text{fat}}=61.2$, $\overline{C}_{\text{no-fat}}=55.8$, $t_{10}=1.88$, $P=0.089$; Eq. 5: $\overline{C}_{\text{fat}}=1.21$, $\overline{C}_{\text{no-fat}}=1.18$, $t_{10}=0.37$, $P=0.723$).

Discussion

Starvation and body condition
All pinnipeds have an inner core of muscle and viscera that is mainly protein, and a subcutaneous
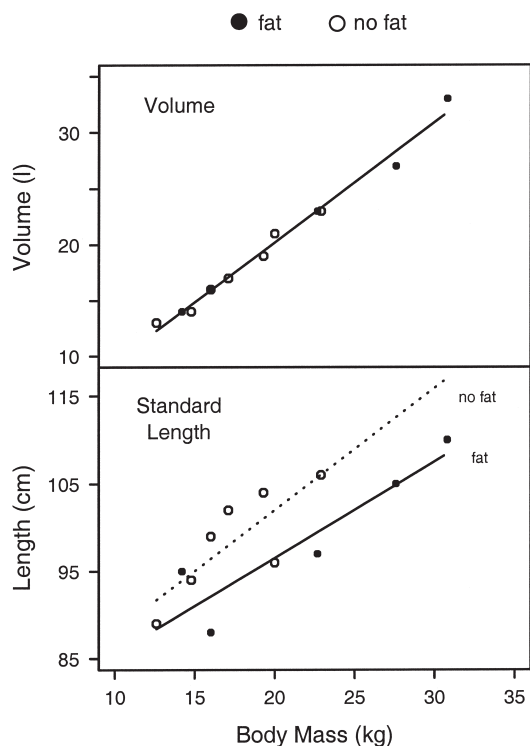

Figure 1. Morphometric relationships for 12 dead Steller sea lion pups showing mass and volume, and mass and standard length. Mass–length regressions were significant for pups with and without blubber (fat pups: solid line Length=74.53+1.10 Mass, $F_{1,3}=15.15$, $P=0.03$; nonfat pups: dashed line Length=74.19+1.39 Mass, $F_{1,5}=9.27$, $P=0.03$). Regressing volume against mass indicated the intercept was not significant. Re-running the regression with no intercept showed Volume=1.013 Mass; ($F_{1,11}=8668.00$, $P<0.001$). Data are from Table 1.
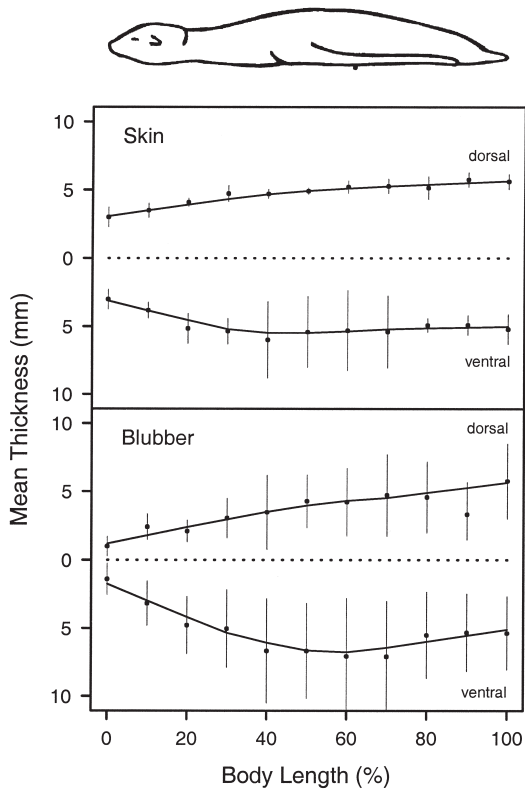
Figure 2. Mean skin and blubber thickness along the dorsal and ventral sides of 5 pups with body fat (at 10% curvilinear-length increments). The vertical bars show standard errors. The data were smoothed with a locally weighted regression (lowess, f=2/3).

blubber layer that is mainly fat (Bryden, 1964; Worthy & Lavigne, 1983, 1987). Phocids have more subcutaneous fat compared to otariids, whereas otariids have more intraperitoneal fat than phocids. Both fat and protein stores are sources of energy for animals deprived of food and can be mobilized during periods of fasting.

Steller sea lion pups are born with a dense fluffy coat and almost no subcutaneous blubber. They acquire blubber from the high fat concentration of their mother's milk, which averages 21.6% during the first month postpartum (range: 11.9–34.9%, Adams 2000). Fat content of blubber in Antarctic fur seal pups ranges from 48–72% (Arnould *et al.*, 1996) and is about 90% in phocid species (Øritsland *et al.*, 1985; Condit & Ortiz, 1987). Fat content also is known to vary between individuals and can vary from one spot to another within an individual (Reilly & Fedak, 1990).

In addition to mobilizing fat reserves, pinnipeds can also draw energy from protein stored in the core tissues and viscera. The amounts of fat and
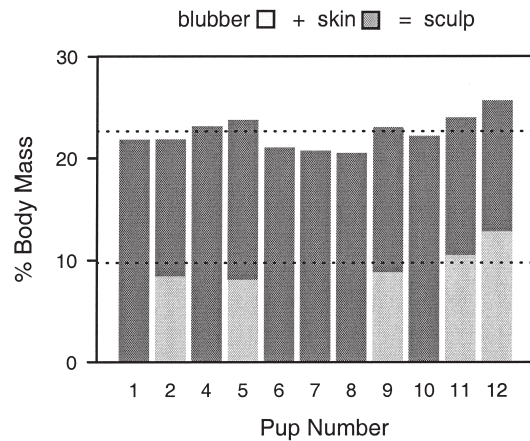

Figure 3. Percent of body mass that can be attributed to the weight of the sculp. Sculps accounted for an average of 22.6% of body mass (upper dashed line). Body fat and skin made up an average of 9.7% and 12.9%, respectively on the 5 pups with fat. Pup numbers are ordered from lightest to heaviest as in Table 1.

protein that pinnipeds mobilize during periods of reduced nutrition differ among species (Nordoy & Blix, 1985; Øritsland *et al.*, 1985; Worthy & Lavigne, 1987; Ryg *et al.*, 1990b; Rea & Costa, 1992). In many species, particularly phocids, blubber is both an energy source and a significant insulator against heat loss (Bryden, 1968; Stewart & Lavigne, 1980; Worthy & Lavigne, 1987; Markussen *et al.*, 1991). A critical balance probably exists between mobilizing (expending) too much, or too little blubber relative to the amount of energy that a pinniped can draw from the body core.

Results from the few pups we examined suggest healthy (i.e., non-starving) pups (aged 3–14 d) have about 10% blubber and 13% skin (as a proportion of total body mass—Fig. 3). Those with no blubber lost much of their core mass as they mobilized the last of their energy reserves to stay alive. Assuming skin thickness is independent of body condition, pups would have had to lose one-third (33.4%) of their core body mass to maintain the constant relative weight of the sculp at 23% of body mass (Fig. 4). Thus we estimate that starvelings lost 43% of their body mass before dying (10% which was blubber, and 33% which was body core). This amount is consistent with the lower than predicted weights of starvelings for given lengths (Fig. 1).

Skin was thinner on the head and around the flippers than anywhere else on the body, and became thicker towards the rump (Fig. 2). The only difference between the ventral and dorsal sides of the body was the high variability in skin thickness
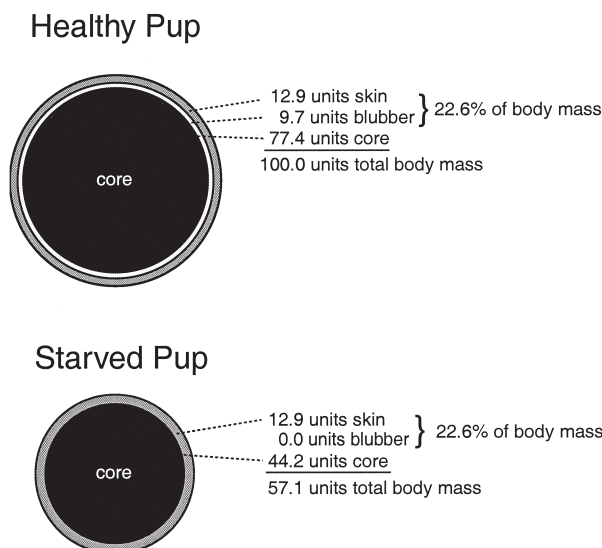
Healthy Pup

12.9 units skin
9.7 units blubber } 22.6% of body mass
77.4 units core
100.0 units total body mass

core

Starved Pup

12.9 units skin
0.0 units blubber } 22.6% of body mass
44.2 units core
57.1 units total body mass

core

Figure 4. Theoretical cross-sections of an average healthy Steller sea lion pup (with blubber) and a starveling (with no body fat). Sculps equal 22.6% of body mass. The mass of the average pup (expressed in relative units) is distributed between skin (12.9%), blubber (9.7%) and body core (77.4%). The starved pup also has 12.9 units of skin (equal to 22.6% of body mass), and consequently 43% less body core than the average pup.

recorded on the portion of the body that makes contact with the ground (at 40–70% of body length).

Average dorsal blubber thickness of 4.5 mm (Fig. 2) was comparable to the 3.0 mm measured from 9 pups by Castellini *et al.* (1993) using ultrasound. We found blubber was significantly thicker on the underside of the pup, and presume it provides better insulation for the pup resting and moving on the rocky shore. Given that only one of the five pups with blubber was a female (Table 1), it is unlikely that the thicker blubber layer on the ventral surface is related to mammary tissue distribution. Variability in the distribution of blubber was also higher over the ventral surface. A substantial amount of this variation in subcutaneous fat was undoubtedly due to the high postpartum increase in fat and the differences in the ages of the pups measured.

Indices of body condition
Based on data from the 12 dead pups, we suggest that the best morphometric-based index for assessing the relative body condition of Steller sea lion pups is the simplest of the three models examined (i.e., the one based on the length-mass ratio— Eq. 6—the stuntness-index). The body volume method (Eq. 5) failed because the relationship relating mass to body volume (Eq. 3) predicted the

'actual' weight of the pup rather than its 'expected' weight. The length-mass relationship (Eq. 4) estimated 'expected' weight and yielded a reasonable index of body condition that distinguished underweight pups from healthy pups (Eq. 6).

Although combining girth and length are useful for estimating body weight (Eq. 3), the ratio of girth to length (Eq. 1) did not distinguish pups with fat from pups with no fat. The blubber layer of Steller sea lion pups is in the order of 3.0-4.5 mm (Fig. 3, Castellini *et al.*, 1993) and is extremely thin compared to phocids. The girth-length ratio may be more appropriate for indices of condition for phocids rather than for otariids. Detailed examination of the 12 dead Steller pups showed those that had starved lost proportionally more body mass than girth.

Condition indices are a useful means of comparing the mean body condition of Steller sea lion pups over time (e.g., from one year to the next) or among sites (e.g., to compare the general health of a declining population with an increasing population). However, it is important that proposed indices be tested to understand how to interpret them. Our examination of necropsied pups suggested that the ratio of observed to predicted body mass derived from standardized mass-length relationships is a reliable and useful index of body condition for Steller sea lion pups.

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