

STELLER SEA LION BODY CONDITION INDICES

K. W. PITCHER

D. G. CALKINS¹

Alaska Department of Fish and Game,
Division of Wildlife Conservation,
333 Raspberry Road, Anchorage, Alaska 99518, U.S.A.
E-mail: ken-pitcher@fishgame.state.ak.us

G. W. PENDLETON

Alaska Department of Fish and Game,
Division of Wildlife Conservation,
P. O. Box 240020, Douglas, Alaska 99824, U.S.A.

ABSTRACT

We evaluated various measurements of mass, morphology, and blubber thickness as indices of fatness for Steller sea lions by correlation with the percentage of total body mass comprised by the sculp (%SCULP). We concluded LMD-index was the best index evaluated because it had a relatively high r^2 (0.58), had a linear relationship with %SCULP, and the intercept term was not different from 0. We suggest the development of a LMD-index for otariids would likely reduce the unexplained variation in the index. We developed a multiple regression model ($r^2 = 0.745$, $P < 0.001$) for predicting %SCULP with LMD-index and functions of sex, age, and season as predictor variables. Steller sea lions <5 yr of age had higher %SCULP values than those ≥ 5 yr. %SCULP declined with age for sea lions <5 yr. Both younger and older males were fatter during the winter/spring period than during summer/fall. Females of both age classes had similar %SCULP values throughout the year. Steller sea lions are relatively lean pinnipeds; estimates of blubber and total body lipids ranged from 5% to 17% of total body mass.

Key words: Steller sea lion, *Eumetopias jubatus*, condition indices, body condition, blubber, body composition.

The term “condition” is used to describe an animal’s health or well-being (Caughley 1977) and is generally considered a measure of an individual’s energy reserves (Read 1990). Condition is linked to an animal’s probability of living or dying, and of reproducing, and therefore is linked to the dynamics of populations (Caughley 1977, Hanks 1981).

¹ Present address: Alaska Sea Life Center, P. O. Box 1329, Seward, Alaska 99664, U.S.A.

Lipids play important roles in the life history strategy of mammals: storing energy, insulating the body core, and providing heat and metabolic water (Young 1976). The hypodermis of pinnipeds contains lipid deposits, commonly referred to as blubber, which function primarily as energy reserves and insulation (Rosen and Renouf 1997). Measures of fatness are used as indicators of condition in marine mammals, both on individual and population levels (Fowler and Siniff 1992, Beck *et al.* 1993). While the blubber layer in Steller sea lions (*Eumetopias jubatus*) and other otariids is generally not as well developed as in phocids (Costa 1991), it is still the major lipid depot and is assumed to be energetically important. Fatness was shown to be positively correlated with pregnancy status for Steller sea lions (Pitcher *et al.* 1998).

Steller sea lion numbers, in the western portion of their range in Alaska, have declined by about 80% over the past 20–30 yr (NMFS 1995, Trites and Larkin 1996) and this “western stock” is now classified as “endangered” under the U.S. Endangered Species Act. Undernutrition, resulting in reduced survivorship (Merrick 1995, NMFS 1995, Calkins *et al.* 1998) and perhaps reduced fecundity (Pitcher *et al.* 1998), is the leading hypothesis for explaining the decline; therefore there is substantial interest in body condition of Steller sea lions.

In this paper we examine potential indices of condition which can be obtained non-invasively from live-captured sea lions. We assume sculp mass (mass of skin and blubber layer), expressed as a percentage of total body mass (%SCULP), is a good indicator of body condition because it is a direct measurement of fat reserves and is scaled to body size (Stewart and Lavigne 1984, Beck *et al.* 1993). Sculp blubber content has been shown to be closely correlated ($r^2 = 0.997$) with total body lipids in harp seals (*Phoca groenlandica*) (Gales and Renouf 1994). Currently, because the western Alaskan population is depleted, it is not possible to collect Steller sea lions and obtain sculp masses. Therefore, we evaluate other potential indices of condition, obtainable from immobilized animals, to determine which is the best alternative to %SCULP. We evaluate the effects of sex and age of the animal, season, and lactation status on condition and develop an estimator of %SCULP based on these factors and the preferred non-invasive index. Estimates of body composition are made based on relative sculp masses.

METHODS

Between 1975 and 1989, 523 Steller sea lions were collected by shooting on rookeries, haul outs, and at sea from Southeast Alaska to the Bering Sea. In most cases the animals were placed aboard a vessel where they were weighed (MASS) (kg) and measured for standard length (SL) (mm), axillary girth (AG) (mm), and blubber and skin thickness (BL) (mm) over the xiphoid process of the sternum. Standard length was measured with the dorsal surface up rather than with the ventral surface up as described by the American Society of Mammalogists (1967). For a subset (107) of these animals, the sculp was removed and weighed and then expressed as a percentage of total body mass

Table 1. Predictors used to develop a multiple regression model to predict %SCULP for Steller sea lions. Terms retained in the final model are bold.

Term	<i>P</i>	Term	<i>P</i>
Season	0.839	Season*age_yo	<0.001
Sex	0.737	Sex*age_yo	0.177
Season*sex	<0.001	Season*sex*age_yo	<0.001
Lactation	0.721	LMD-index	<0.001
Season*lactation	0.788	LMD-index*season	0.349
Age_yo ¹	0.430	LMD-index*sex	0.478
Age_yo*age	0.004	LMD-index*lactation	0.398
Age ²	0.437	LMD-index*age_yo	0.138
Age_yo*age ²	0.152		

¹Age_yo is an indicator variable for young (<5 yrs) or older (≥5 yrs) animals.

(%SCULP). Sex was recorded for each collected sea lion. The mammary glands of all females were examined to determine if they were lactating. Ages were estimated from counts of cementum annuli from second upper premolar teeth using a reference collection of teeth from known-aged sea lions (Calkins and Pitcher 1982). Season of collection was categorized into two periods: 1 June–30 November (summer/fall) when pupping, breeding, blastocyst implantation, and molting occur, and 1 December–31 May (winter/spring), the period of implanted gestation.

Correlation coefficients of %SCULP with seven other indices were calculated to evaluate alternatives to %SCULP. These variables included two single measures, MASS and BL, and four composite variables BL/SL, BL/MASS, AG/SL, and MASS/SL (American Society of Mammalogists 1967, Stewart and Lavigne 1984, Pitcher 1986, Read 1990, Lunn and Boyd 1993, Ben-David 1997, Pitcher *et al.* 1998). LMD-index, developed as an estimator of percent blubber content for phocid seals (Ryg *et al.* 1990), was also correlated with %SCULP. LMD-index ($\sqrt{L/M*D}$) is calculated from standard length (*L*), body mass (*M*), and dorsal blubber thickness at 60% of standard length (*D*) measurements. We substituted BL for *D*, as *D* was not measured on the animals we sampled. LMD-index was developed for phocid seals; therefore we use it solely as an index of fatness rather than an estimator of blubber content. We also estimated correlation coefficients separately for sexes, seasons, and lactation status to determine if the relationships between the surrogates and %SCULP were similar among the groups.

We used multiple regression to estimate the relationship between %SCULP (*n* = 98) and the variables age, sex, season of collection, lactation status, and LMD-index and to develop an estimator of %SCULP. We began developing the model by including all main effects and most 2-way interactions and a single 3-way interaction (Table 1). Some interactions were not appropriate (*e.g.*, sex*lactation status) and were not included. Sex, lactation status, and season were binary variables (*i.e.*, intercept terms) and age and LMD were continuous predictors (*i.e.*, slopes). Based on preliminary analyses, we used a piece-wise regression for age allowing the age slope to differ for animals <5 yr and

Table 2. Correlation coefficients relating %SCULP to potential alternative condition indices for Steller sea lions by sex, season, and lactation status.

Groupings	MASS	MASS/SL	AG/SL	BL	BL/SL	BL/ MASS	LMD- index
All	-0.33 ^c	-0.37 ^c	0.10	0.38	0.65 ^c	0.76 ^c	0.76 ^c
Sex-M	-0.31 ^a	-0.36 ^a	0.00	0.28	0.57 ^c	0.70 ^c	0.71 ^c
Sex-F	-0.48 ^c	-0.47 ^c	0.16	0.42	0.69 ^c	0.82 ^c	0.81 ^c
Season-0	-0.28 ^b	-0.33 ^b	0.18	0.48	0.72 ^c	0.77 ^c	0.81 ^c
Season-1	-0.49 ^a	-0.52	-0.11	0.12	0.32	0.74 ^c	0.79
Non-lactating	-0.34 ^b	-0.37 ^b	0.10	0.37	0.65 ^c	0.77 ^c	0.85 ^c
Lactating	0.02	0.03	0.24	0.45	0.45 ^b	0.44 ^b	0.45 ^a

^a $0.05 < P > 0.01$.

^b $0.01 < P > 0.001$.

^c $P < 0.001$.

animals ≥ 5 yr. We included quadratic terms for age for the two age categories. Unimportant predictors ($P > 0.10$) were dropped one at a time based on the Wald F statistic until only significant predictors remained in the final model. To clarify relationships suggested by the regression analyses, we compared least squares means of %SCULP among age, sex, and season categories.

RESULTS

BL/MASS and LMD-index were most closely correlated with %SCULP, each explaining 58% of the variation in %SCULP for the entire sample (Table 2, Fig. 1, 2). Either BL/MASS or LMD-index had the highest correlation coefficients for all of the sex, season, and lactation categories. The correlation coefficients for both BL/MASS and LMD-index were relatively high and consistent among subgroups, except for lactating females (Table 2).

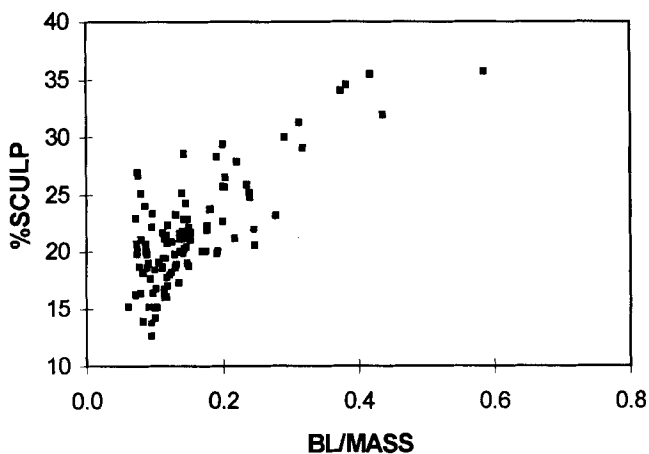


Figure 1. Relationship of %SCULP and BL/MASS for sample of 107 Steller sea lions.

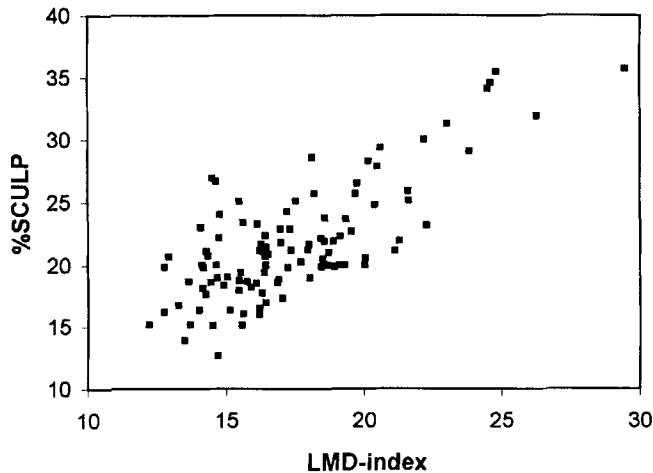


Figure 2. Relationship of %SCULP and LMD-index for sample of 107 Steller sea lions.

The final multiple regression model ($r^2 = 0.745$, $P = 0.001$) for predicting %SCULP included functions of season, age, sex, and LMD-index (Table 3). Steller sea lions <5 yr of age had higher average %SCULP values than those ≥ 5 yr (22.4% vs. 20.1%, $P = 0.019$, Fig. 3). %SCULP declined with age for sea lions <5 yr (Table 3, Fig. 3). Both younger and older males had, on average, higher %SCULP values during the winter/spring period than during summer/fall (<5 yr: 24.1% vs. 18.8%, $P = 0.002$; >5 yr: 25.0% vs. 16.3%, $P = 0.021$). For females, average %SCULP was similar during the two seasonal periods for both younger (summer/fall = 20.7%, winter/spring = 22.6%, $P = 0.568$) and older animals (summer/fall = 19.7%, winter/spring = 19.6%,

Table 3. Parameter estimates for a multiple regression model predicting %SCULP from 98 Steller sea lions from the Gulf of Alaska. The estimates following age_yo*age and LMD are slopes; other estimates are intercepts for the appropriate groups.

Term	Group	Estimate	P (H_0 : estimate = 0)
Age_yo*age	Young (<5 yr)	-1.11	0.001
	Old (≥ 5 yr)	0.06	0.469
Season*sex*age_yo	Summer/fall, male, young	-0.87	0.625
	Summer/fall, male, old	2.00	0.42
	Summer/fall, female, young	-0.07	0.892
	Summer/fall, female, old	2.16	0.418
	Winter/spring, male, young	0.72	0.692
	Winter/spring, male, old	10.27	<0.001
	Winter/spring, female, young	0.54	0.758
	Winter/spring, female, old	3.91	0.051
LMD-index	All	0.969	<0.001

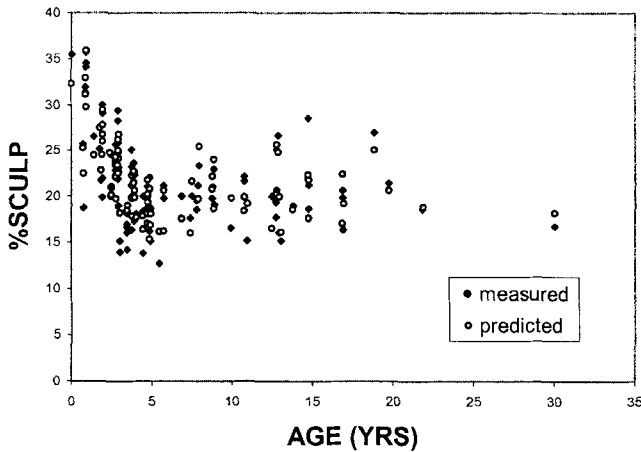


Figure 3. Measured and predicted values (from multiple regression model) of %SCULP by age for 98 Steller sea lions.

$P = 0.950$). LMD was positively related to %SCULP with the same relationship for all age and sex classes.

DISCUSSION

We prefer LMD-index rather than BL/MASS as a condition index for Steller sea lions even though both had similar correlation coefficients with %SCULP. LMD-index had a more linear relationship to %SCULP and the intercept term was not different from 0 for the entire data set and for all subgroups except lactating females (Fig. 1, 2). A linear index passing through the origin is desirable as it indicates a proportional relationship (Lancia *et al.* 1994).

The LMD-index, developed for phocids, explained only 58% of the variation in %SCULP for Steller sea lions. However by estimating %SCULP with a multiple regression model utilizing LMD-index, with factors of sex, age, and season, the unexplained variation was reduced ($r^2 = 0.745$). The remaining unexplained variance limits the value of the index in evaluating the condition of individual sea lions but may allow for comparisons of relative condition between populations or within the same population over time (Smalley *et al.* 1990). Development of a LMD-index specifically for Steller sea lions, or another otariid such as California sea lions (*Zalophus californianus*), is recommended and would hopefully reduce unexplained variation and allow more precise estimates of %SCULP to be made.

LMD-index requires a measurement of blubber thickness in addition to measures of MASS and SL. BL was measured directly from our samples of collected animals, but can also be measured with ultrasound on immobilized animals (Rosen and Renouf 1997). Fadely (1997) found an 11-cm decrease in length measurements of live-measured harbor seals (*Phoca vitulina*) relative to post-mortem measurements; therefore caution is necessary in comparisons be-

tween samples of live and dead animals from condition indices utilizing length measurements. Another consideration, when using estimates of blubber content or indices which reflect blubber content, is there appears to be a positive correlation between energy density of blubber and total blubber (Gales *et al.* 1994). Therefore the relationship between an index of blubber content and the energy content of the blubber is unlikely to be linear.

Correlations between %SCULP and MASS, MASS/SL, AG/SL, and BL were surprisingly low (Table 1) considering reports of their utility as condition indices for other pinnipeds (Boyd 1984, Lunn and Boyd 1993, Arnould 1995). This may be explained, in part, by the fact Steller sea lions are large pinnipeds with a relatively thin blubber layer.

Findings that younger animals (<5 yr) generally had higher condition indices than older animals was somewhat surprising, given younger animals are making the transition to nutritional independence and are growing rapidly. However, Steller sea lions have extended lactation and juveniles of several age classes have been observed suckling (Pitcher and Calkins 1981, Pitcher *et al.* 1998) which likely aids in maintaining condition. Older animals have high energy demands including gestation and extended lactation for females, and the breeding fast for males.

Findings that males had higher values of %SCULP during winter/spring while female %SCULP values were similar during both seasons is likely associated with differing strategies for reproductive energetics. Adult male Steller sea lions fast during the breeding season, therefore their energy demands must be met from body stores accumulated prior to the breeding season. Energetic costs for reproductive females are spread throughout the year as they are usually pregnant and/or lactating throughout the year and their energetic demands are met by continuous feeding, except for a short postpartum fast. Similarly, Olesiuk and Bigg (1990) found season had a significant effect on both fatness and core mass for adult male Steller sea lions with postbreeding (October) animals being both lighter and leaner than prebreeding animals (April).

Mean %SCULP for the 107 animals with sculp weights was 21.5% (95% CI = $\pm 0.89\%$). Skin was not separated from blubber in the sculps; therefore we cannot directly estimate the percentage of body mass comprised of blubber. Flensed hides from male Steller sea lions collected in British Columbia waters averaged 8–11% of body mass, depending on the season of collection (Olesiuk and Bigg 1990). Assuming a similar relationship, blubber from Steller sea lions in this study averaged about 10%–14% of total body mass. Davis *et al.* (1996) reported lipids comprised about 8% of body mass for post-parturient, adult female Steller sea lions, based on body composition estimates from labeled water. Blubber averaged 5% of total body mass in fall and 17% in spring for adult male Steller sea lions (Olesiuk and Bigg 1990).

Besides the blubber layer, additional lipids are stored throughout the body. For harp seals, Beck *et al.* (1993) found 10.5% of body lipids were stored in depots other than blubber. We are not aware of body composition studies of otariids that partition lipids into various depots. We encourage such research,

as well as studies of the sequence of lipid depot catabolism during periods of negative energy balance.

Steller sea lions, with blubber and total body lipid estimates ranging from 5% to 17% of total body mass, are relatively lean pinnipeds, at least in comparison to some phocids. Blubber comprised 30%–40% of total body mass for harbor seals (St. Aubin *et al.* 1978, Pitcher 1986) and 34%–44% for harp seals (Beck *et al.* 1993). Female Steller sea lions and other otariids have developed different strategies than phocids for providing energy for lactation and pup rearing (Costa 1993), which may, in part, explain differences in body composition. Female phocids must accumulate large stores of energy, primarily in the form of blubber, in order to nurse their young throughout the lactation period with little or no foraging. Phocids have relatively short lactation periods, ranging from 4 to 50 d (Ofstedal *et al.* 1987). In contrast, female otariids forage repeatedly in the general area of the rookery to provide energy for their pups, and have extended lactation ranging from four months to three years (Costa 1993).

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