

# SEASONAL AND SPATIAL BLUBBER DEPTH CHANGES IN CAPTIVE HARBOR SEALS (*PHOCA VITULINA*) AND STELLER'S SEA LIONS (*EUMETOPIAS JUBATUS*)

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Pinniped blubber supports multiple functions including thermoregulation, reproduction, and buoyancy. Although blubber depth is frequently used as an indicator of health, the effect of sample site and seasonality are rarely taken into account. We monitored blubber depth via imaging ultrasound at 10 sites monthly for 1 year in 2 adult Steller's sea lions (*Eumetopias jubatus*) and 3 adult harbor seals (*Phoca vitulina*). Blubber of harbor seals was thicker and more variable than blubber of sea lions, and was thickest in winter. Changes in harbor seal blubber at all sites tracked variation due to season and mass. Sea lion blubber changed with mass only at specific sites, with no seasonal effect. The differing effects of season, mass, and location on the body must be carefully considered in both species before any interpretation of condition.

Key words: blubber, *Eumetopias jubatus*, harbor seal, *Phoca vitulina*, Steller's sea lion, ultrasound

Fat is a crucial tissue for marine mammals, because it provides energy (e.g., Mellish et al. 1999a), supports thermoregulation (e.g., Willis et al. 2005), and influences buoyancy (Beck et al. 2000; Biuw et al. 2003) and in some cases hydrodynamic structure (Hamilton et al. 2004). Conflicting resource allocation can occur with the needs of growth (Noren and Mangel 2004), reproduction (Arnould and Warneke 2002), lactation (Mellish et al. 1999b), maintenance energy (Mellish and Iverson 2001), and thermoregulation (e.g., season—Nilssen et al. 2001; Rosen and Renouf 1997; Willis et al. 2005). Pinnipeds utilize both marine and terrestrial habitats such that these demands can fluctuate frequently.

In addition to overall management of fat stores, there may be mechanisms by which there is specific target utilization, such that some areas are preferentially depleted during times of energy expenditure before other more critical areas. That is, there may be a regional map for the allocation and mobilization of blubber stores in pinnipeds, as has been suggested for cetaceans (Doidge 1990; Koopman 1998; Koopman et al. 2002).

Despite the importance of blubber depth to so many aspects of marine mammal life, extended study of individuals is extremely difficult because of their primarily aquatic existence. Previous studies of regional and seasonal variation in blubber depth in pinnipeds have largely been limited to cross-sectional sampling (Nilssen et al. 2001; Pitcher 1986) or carcass analysis (e.g., Nilssen et al. 1997; Ryg et al. 1990). Longitudinal studies of adult pinnipeds in a known, controlled environment are extremely difficult to conduct, logistically complex, and subsequently rare. In addition, the pinnipeds include species with differing body morphology and life-history traits that may have implications for blubber storage and mobilization constraints. For instance, the leaner otariids fast for brief but repeated periods, which may result in preferred sites of fat deposition and mobilization. The comparably fatter phocids tend to fast for longer periods and can range into higher latitudes. This may place a higher premium on overall insulation and a more uniform fat distribution.

We concurrently examined the depth of multiple regional blubber stores in 2 captive adult Steller's sea lions (*Eumetopias jubatus*) and 3 captive adult harbor seals (*Phoca vitulina*) on a monthly basis for 1 year. The primary objectives of this study were to compare blubber depth at 10 different sites on the body, assess overall and regional variation in blubber depth throughout the year, and compare patterns of general blubber

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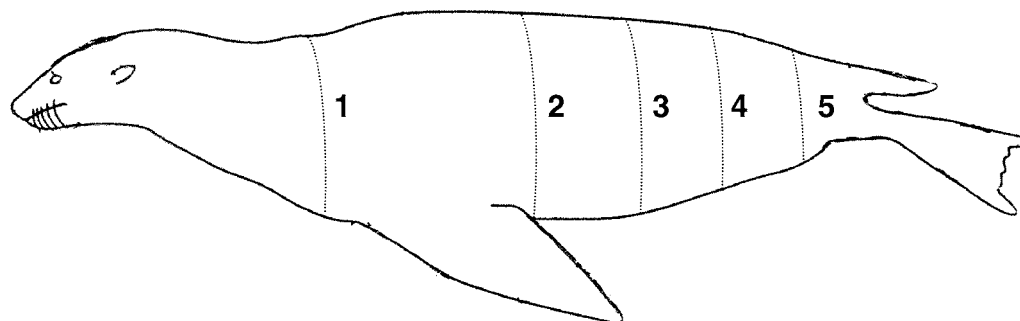


FIG. 1.—Locations of ultrasound blubber depth measurements in 3 adult captive harbor seals (*Phoca vitulina*) and 2 captive Steller's sea lions (*Eumetopias jubatus*) as displayed on a Steller's sea lion. Measurements were taken from the dorsal (D1–D5) and lateral (L1–L5) midline while the animal was in the prone position.

depth and spatial blubber depth between harbor seals and Steller's sea lions.

## MATERIALS AND METHODS

Captive adult pinnipeds were studied at the Alaska SeaLife Center, Seward, Alaska. Harbor seal subjects included 2 males (PV-01 and PV-02), aged 7 and 19 years, respectively, and 1 female (PV-03), aged 7 years. The 2 female Steller's sea lions (EJ-01 and EJ-02) were both 10 years of age. Measurements were collected monthly from November 2003 to October 2004. All data were obtained under behavioral control during routine training sessions. No restraint or anesthesia methods were employed. Mass was obtained to the nearest 0.5 kg via voluntarily positioning on a platform scale. Animals were held in outdoor habitat enclosures such that they were exposed to ambient weather conditions.

All animals were on a maintenance diet based on body mass and appetite until February 2004. As part of a separate study, 2 of the 3 harbor seals (PV-02 and PV-03) were then placed on a tracking diet, such that PV-03 was fed high-fat herring ad libitum. PV-02's resultant diet was calculated as an equivalent dietary mass scaled for metabolic size ( $M^{0.75}$ ) and consisted of low-fat herring instead of high-fat herring. Therefore, PV-01 and PV-03 were considered subject to a regular or optimal diet, whereas PV-02 was considered subject to a suboptimal diet. However, blubber depth readings for PV-02 did not differ from those of PV-01 or PV-03 such that all 3 animals were subsequently considered together in the model described below.

Skin plus blubber depth was measured at 10 sites along the body with a SonoSite Vet180 portable imaging ultrasound (SonoSite, Inc., Bothell, Washington) with a C60/5 2-MHz, 60-mm broadband transducer set at 4.2- to 4.9-cm depth reading and 0.01-cm resolution, calibrated at the factory, as described in Mellish et al. (2004). Blubber depth was measured between digital markers visually positioned on the displayed image in real time by the ultrasound operator. Marker positioning was accomplished after a visual assessment of backscatter intensity while moving the transducer across the target area, to distinguish subdermal blubber from cutis and muscle. The image was saved with the blubber measurement as part of a jpg file for future review if necessary. Validation of this approach by

comparison to direct blubber biopsies, and examples of blubber measurements for the relatively homogeneous and heterogeneous blubber layers of harbor seals and Steller's sea lions are discussed in Mellish et al. (2004). A single operator was used for all data collection to minimize variation in blubber depth due to differences in technique and site positioning. Location of the sites used in this study are shown in Fig. 1, as modified from Gales and Burton (1987) and Rosen and Renouf (1997). The site on the head was not utilized in this study because of difficulties in obtaining accurate readings from this site in unrestrained animals. Sites were not marked because of the public display required of the animals, but were determined as follows: dorsal (D1–D5) measurements were taken approximately 1 cm to the right of the spine, whereas lateral (L1–L5) measurements were taken along the corresponding lateral midline (i.e., halfway between the ventral and dorsal surfaces). Sites D/L2 and D/L5 were used as anchors (e.g., standard axillary and pelvic girth), with the remaining sites taken at a standard proportion of the remaining body. For instance, site D/L1 was taken equidistant from the rear arch of the cranium and the shoulders, whereas D/L3 and 4 were taken at equidistant sites between D/L2 and 5 (Fig. 1). Images were downloaded with SonoSite Image Manager software (SonoSite, Inc.). All animal procedures were conducted under National Marine Fisheries Service permit 881-1443 and Alaska SeaLife Center Animal Use Protocol 02-015.

All data are shown as mean  $\pm$  SE unless otherwise noted. To examine the influence of time of year, the 12 months were divided into 3 seasons: reproductive (R, May–July), molt (M, August–September), and winter (W, October–April) as per Pitcher (1986). We assumed that individual seals were a random sample from each species and modeled mass and individual fat layer thicknesses over season using linear mixed models. We used software provided in the package lme (D. M. Bates and D. Sarkar, 2004; *Linear Mixed-Effects Models Using S4 Classes*; available from <http://www.r-project.org>) within the statistical program R (R Development Core Team 2004). It is well known that masses of harbor seals and sea lions differ almost by an order of magnitude; furthermore, an exploratory analysis indicated different seasonal patterns for each species. For ease of interpretation, we modeled mass and

**TABLE 1.**—Mean blubber thickness (cm) at 10 sites in 3 captive (2 males and 1 female) harbor seals (*Phoca vitulina*) and 2 captive female Steller's sea lions (*Eumetopias jubatus*) from November 2003 to October 2004. CV = coefficient of variation.

| Site | Harbor seal      |      |        | Steller's sea lion |      |        |
|------|------------------|------|--------|--------------------|------|--------|
|      | $\bar{X} \pm SE$ | d.f. | CV (%) | $\bar{X} \pm SE$   | d.f. | CV (%) |
| D1   | 2.6 $\pm$ 0.1    | 31   | 4.11   | 1.7 $\pm$ 0.1      | 18   | 4.22   |
| D2   | 1.8 $\pm$ 0.2    | 33   | 9.06   | 1.5 $\pm$ 0.1      | 20   | 3.54   |
| D3   | 2.3 $\pm$ 0.3    | 33   | 11.6   | 1.9 $\pm$ 0.1      | 20   | 4.75   |
| D4   | 2.4 $\pm$ 0.2    | 32   | 7.92   | 1.8 $\pm$ 0.1      | 20   | 3.18   |
| D5   | 2.3 $\pm$ 0.1    | 33   | 5.84   | 1.6 $\pm$ 0.1      | 19   | 7.61   |
| L1   | 2.2 $\pm$ 0.1    | 31   | 6.18   | 1.7 $\pm$ 0.1      | 19   | 5.79   |
| L2   | 2.7 $\pm$ 0.4    | 32   | 12.79  | 2.4 $\pm$ 0.1      | 20   | 4.35   |
| L3   | 2.6 $\pm$ 0.3    | 33   | 11.91  | 2.3 $\pm$ 0.1      | 20   | 3.23   |
| L4   | 2.6 $\pm$ 0.2    | 33   | 7.76   | 2.3 $\pm$ 0.1      | 20   | 2.95   |
| L5   | 2.2 $\pm$ 0.2    | 33   | 7.49   | 1.6 $\pm$ 0.1      | 19   | 5.31   |

blubber thickness for each species separately using the following model:

$$y_{ijk} = b_j + b_i + b_{ij} + e_{ijk},$$

where  $y_{ijk}$  is the  $k$ th measurement (of mass or blubber thickness) in the  $j$ th season from  $i$ th seal, and  $e_{ijk}$  is the error term for the  $k$ th observation (of mass or blubber thickness) from the  $j$ th season from  $i$ th seal. The  $b_{ij}$  terms represent separate seasonal effects for individuals. If these were not statistically significant ( $P < 0.05$ ), we assumed that there was minimal evidence of interaction, and did not include the terms in the model. It is assumed that:

$$b_i \sim N(0, s_1^2), b_{ij} \sim N(0, s_2^2), \text{ and } e_{ijk} \sim N(0, s^2).$$

Model verification requires that the residuals be normal, independent, and identically distributed. R and the software package lme provide flexible options for these tasks. Normality of residuals was assessed via a normal probability plot. If heteroscedasticity of residuals was present, we attempted to correct for it using a form of weighting, as suggested in Pinheiro and Bates (2000: chapter 5). Correlation of the residuals, especially within subjects or groups, often a problem in a linear mixed model, was assessed via an autocorrelation function provided within the package lme. If there were statistically significant autocorrelations ( $P = 0.05$ ), we modeled the correlation within the linear mixed model using 1 of either an autoregressive or moving average model. In the case of several competing models, we chose the most parsimonious model using Akaike's information criterion as a guide (e.g., Burnham and Anderson 1998). Statistical significance of factors was determined with likelihood ratio tests (e.g., Venables and Ripley 2002).

Our models of mass and blubber depths on season for both species included a random intercept and a common season effect term. It was not necessary to include separate seasonal effects for individuals. Similarly, we modeled mass on blubber thicknesses with a random intercept and a common slope.

## RESULTS

**Harbor seals.**—Body mass of harbor seals averaged  $61.2 \pm 1.9$  kg, with the heaviest masses recorded in winter ( $62.3 \pm$

**TABLE 2.**—Relationships between overall thickness of blubber (cm) and mass (kg) in 3 captive harbor seals (*Phoca vitulina*) as determined by linear mixed models.

| Site | Slope         | d.f. | t     | P      |
|------|---------------|------|-------|--------|
| D1   | 5.2 $\pm$ 0.9 | 30   | 5.797 | <0.001 |
| D2   | 5.4 $\pm$ 1.6 | 32   | 3.359 | 0.002  |
| D3   | 6.7 $\pm$ 1.4 | 32   | 4.938 | <0.001 |
| D4   | 6.7 $\pm$ 1.3 | 31   | 5.038 | <0.001 |
| D5   | 6.5 $\pm$ 1.3 | 32   | 4.945 | <0.001 |
| L1   | 4.6 $\pm$ 2.6 | 30   | 1.741 | 0.092  |
| L2   | 4.4 $\pm$ 1.4 | 31   | 3.071 | 0.004  |
| L3   | 6.0 $\pm$ 1.1 | 32   | 5.394 | <0.001 |
| L4   | 5.8 $\pm$ 1.1 | 32   | 5.233 | <0.001 |
| L5   | 8.5 $\pm$ 1.4 | 32   | 6.240 | <0.001 |

2.8 kg;  $P = 0.005$ ). There was no difference between the reproductive and molting periods ( $57.7 \pm 2.1$  kg; likelihood ratio test,  $P = 0.55$ ).

Overall depth of seal blubber averaged  $2.4 \pm <0.1$  cm. In general, L2 was the thickest and most variable site, whereas D2 and D1 were the thinnest and least variable locations, respectively (Table 1). Localized changes in depth of dorsal fat (D1–D5) were significantly correlated with changes in mass at all sites (Table 2; Fig. 2). Similarly, lateral sites (L2–L5) changed significantly with changes in mass (Table 2), with the exception of site L1 (Fig. 3). Estimates from the linear mixed model showed that there was a corresponding effect of season on blubber depth as with mass (i.e., heaviest and thickest in winter), with the greatest effect on site L2 ( $P < 0.001$ ; Table 3).

**Steller's sea lions.**—Steller's sea lions averaged  $205.8 \pm 2.1$  kg over the year-long study, but were significantly heavier during the reproductive season ( $212.1 \pm 4.4$  kg) than during winter and molt ( $203.7 \pm 2.2$  kg;  $P = 0.009$ ).

Overall depth of sea lion blubber averaged  $1.9 \pm <0.1$  cm. The thickest and most variable blubber sites were located at L2 and D5 (Table 1), respectively. The thinnest and least variable sites were D2 and D4, respectively (Table 1; Fig. 3). Unlike harbor seals, changes in mass of sea lions corresponded with changes in blubber depth at only 3 sites (D3, L2, and L3; Table 4). There was no seasonal effect on blubber depth at any site ( $P > 0.4$ ).

## DISCUSSION

**Complexities in measurement methods.**—Before the increased availability of portable imaging ultrasound, researchers were largely limited to lethal (e.g., carcass analysis—Pitcher 1986) or potentially inaccurate tools in the field (e.g., skin fold calipers—Jonker and Trites 2000). In addition, it has been suggested that blubber in carcass or sculp (skin plus fat) analysis may be different than that measured in vivo, due to “slumping” of the fat tissue (Slip et al. 1992). When accounting for slump, nonimaging ultrasound may overestimate modeled total blubber content by as much as 7% (Slip et al. 1992). When combined with the difficulties of working with large, aggressive animals in less than optimal field conditions,

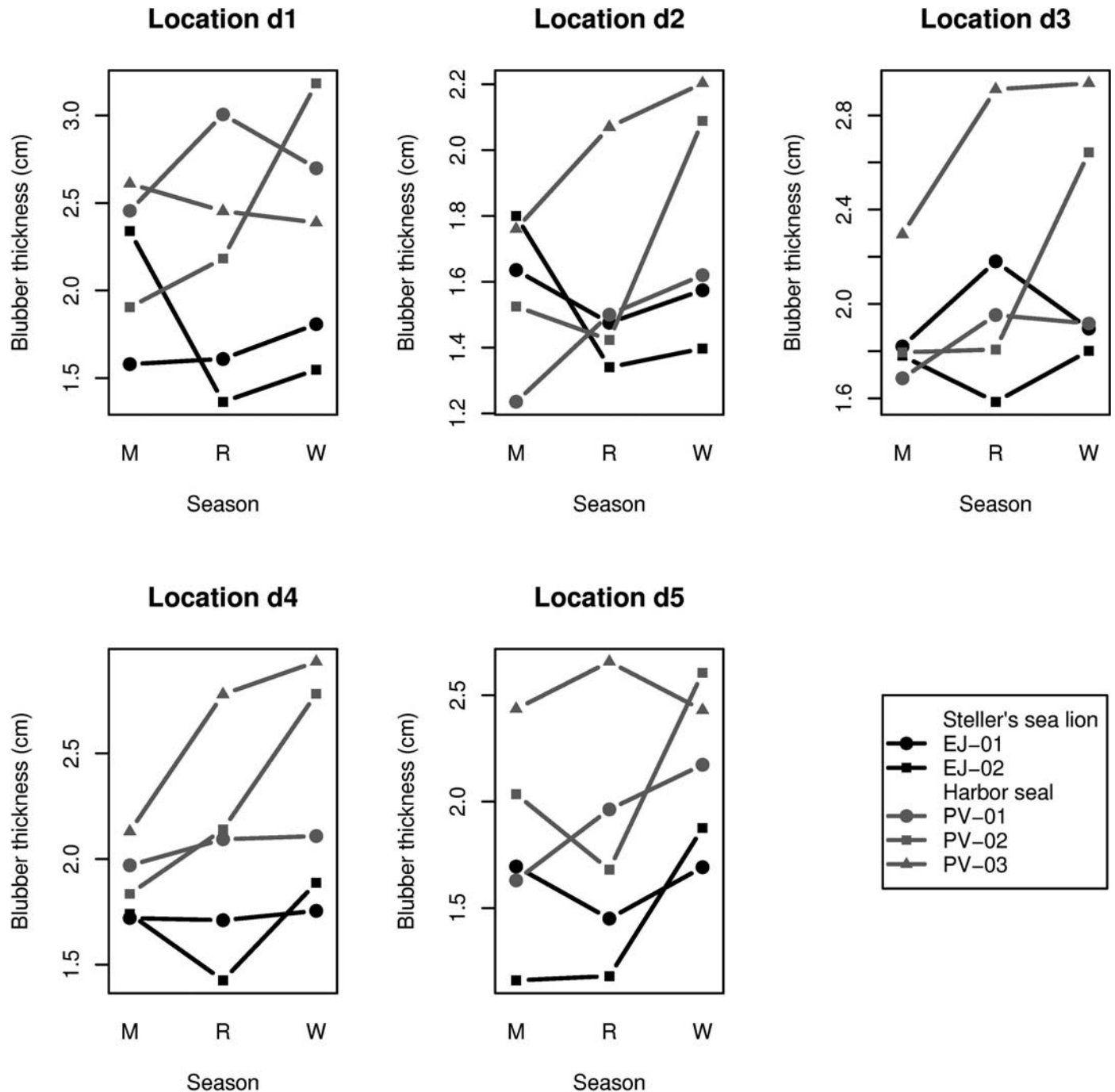


FIG. 2.—Changes in dorsal blubber depth, measured via ultrasound, with mass over season (M = molt, R = reproductive, W = winter) in 3 adult captive harbor seals (*Phoca vitulina*) and 2 adult captive Steller's sea lions (*Eumetopias jubatus*).

researchers are faced with many variables that can both affect their data collected in the field and their subsequent comparison to historical literature. An additional critical decision must often be made as to what kind of information can be collected accurately from a live animal. Portable imaging ultrasound is becoming increasingly accessible to researchers, and indeed can be used to great effect with anesthetized, sedated, or well-restrained animals.

*Species differences in blubber depth.*—Steller's sea lions and harbor seals present an interesting comparison between the

otariids and phocids, because they overlap considerably in habitat and are subject to a similar environment. The otariids tend to be larger yet leaner than the phocid seals, whereas phocids range into higher latitudes, possibly emphasizing thermoregulatory constraints. Phocid seals are more cylindrical in morphology, utilizing hind flippers to a greater extent for swimming than otariids, which tend to rely primarily on strong fore flippers for propulsion. In addition, harbor seal blubber tends to be a uniform, homogenous layer whereas Steller's sea lions have a blubber layer that is commonly fat



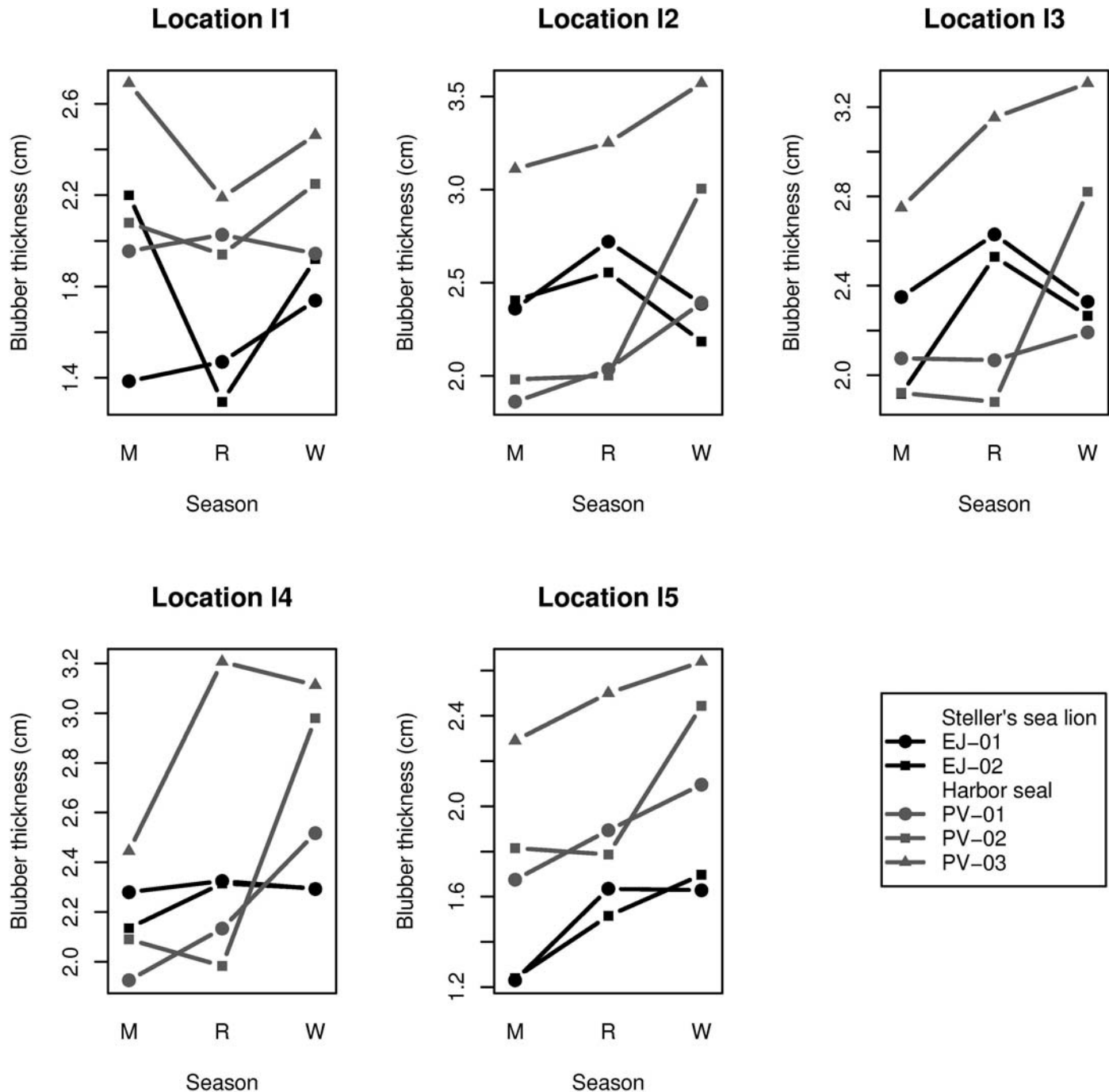


FIG. 3.—Changes in lateral blubber depth, measured via ultrasound, with mass over season (M = molt, R = reproductive, W = winter) in 3 adult captive harbor seals (*Phoca vitulina*) and 2 adult captive Steller's sea lions (*Eumetopias jubatus*).

interspersed with thin interstitial layers of muscle (see Mellish et al. 2004).

Steller's sea lions are typically leaner animals than harbor seals, and overall blubber thickness agreed with this generalization, although several sites were comparable in depth between the 2 species (e.g., D2 and L3; Table 1). Common to both species was the tendency for blubber thickness to parallel changes in mass, although this effect was generalized in harbor seals and localized in sea lions.

*Topographical distribution.*—Within the phocids, there are discrete regional differences that have implications for a trade-off between thermoregulatory needs and other constraints of a largely aquatic lifestyle. Mobile thermal windows allow seals to radiate excess heat anywhere along a more or less uniformly insulated body trunk (Mauck et al. 2003). Although Steller's sea lions had comparably greater differences in regional blubber thickness (Table 1), the thinnest sites still tended to be at the neck and hip region. Sea lions tend to not have

**TABLE 3.**—Relationships between blubber thickness in winter and mass in 3 captive harbor seals (*Phoca vitulina*) as determined by linear mixed models. Difference noted is between depth of blubber in winter and nonwinter.

| Site | Difference (cm) | df. | t     | P      |
|------|-----------------|-----|-------|--------|
| D1   | 0.4 ± 0.2       | 30  | 1.670 | 0.105  |
| D2   | 0.4 ± 0.1       | 32  | 2.881 | 0.007  |
| D3   | 0.4 ± 0.1       | 32  | 2.985 | 0.005  |
| D4   | 0.4 ± 0.1       | 31  | 3.165 | 0.003  |
| D5   | 0.3 ± 0.1       | 32  | 2.302 | 0.028  |
| L1   | 0.1 ± 0.1       | 30  | 0.846 | 0.404  |
| L2   | 0.6 ± 0.1       | 31  | 4.629 | <0.001 |
| L3   | 0.5 ± 0.2       | 32  | 2.955 | 0.006  |
| L4   | 0.5 ± 0.2       | 32  | 3.603 | 0.001  |
| L5   | 0.4 ± 0.1       | 32  | 3.436 | 0.002  |

extended periods of fasting more typical of the phocids and therefore may not require such ample thermoregulatory insurance. Nevertheless, Steller's sea lions show spatially consistent thermal windows along the body trunk consistent with the spatial patterns of insulation (Willis et al. 2005).

**Seasonal influence.**—Harbor seals were heavier and had thickest blubber layers during the winter season, similar to other phocids (e.g., harp seals [Nilssen et al. 2001], Alaskan harbor seals [Pitcher 1986], and Atlantic harbor seals [Rosen and Renouf 1997]). Changes in mass were reflected evenly in all blubber regions, similar to the northern elephant seal (*Mirounga angustirostris*—Slip et al. 1992). Molting male northern elephant seals, a magnitude larger than harbor seals ( $1,487 \pm 300$  kg), lose almost half their body mass in a uniform fashion from blubber stores during the molt (Slip et al. 1992). In contrast, sea lions were heavier during the reproductive season and had no noticeable effect of seasonality on blubber depth. Although the animals in our study were not actively reproducing, they were of reproductive age and therefore may give a clue to underlying natural patterns. These apparently disparate responses to season may be a reflection of life-history constraints. Harbor seals endure an annual cycle of a comparably brief but energetically demanding reproductive period, followed by molt and a season to recoup body energy stores before the subsequent reproductive event. This cycle is supported by Pitcher (1986), who found that young harbor seals (<4 years old) had no seasonal difference in blubber stores, whereas older males were fatter in winter and older females differed in all 3 seasons. In this scenario, breeding-age females were fattest in winter, thinnest in molt, and in-between during the reproductive season. In contrast, Steller's sea lions have a longer reproductive season and lactation can continue for up to 2 years or more, such that the resultant energetic demand may be spread out more equally over a longer time period with shorter contiguous fasting periods.

**Implications for studies of body condition.**—Seasonality may play a larger role in sampling protocols of sea lions than in harbor seals, with the exception of molting in adult harbor seals. The seasonal and regional characteristics of blubber depth in each species must be carefully taken into consideration

**TABLE 4.**—Relationships between thickness of blubber (cm) and mass (kg) in 2 captive female Steller's sea lions (*Eumetopias jubatus*) as determined by linear mixed model.

| Site | Slope          | df. | t      | P     |
|------|----------------|-----|--------|-------|
| D1   | $-2.5 \pm 5.3$ | 17  | -0.462 | 0.650 |
| D2   | $-0.5 \pm 7.2$ | 19  | -0.068 | 0.946 |
| D3   | $12.7 \pm 5.7$ | 19  | 2.221  | 0.039 |
| D4   | $10.1 \pm 5.4$ | 19  | 1.883  | 0.075 |
| D5   | $5.1 \pm 2.5$  | 18  | 2.042  | 0.056 |
| L1   | $3.5 \pm 3.5$  | 18  | 1.009  | 0.327 |
| L2   | $8.8 \pm 2.5$  | 19  | 3.551  | 0.002 |
| L3   | $12.3 \pm 3.5$ | 19  | 3.565  | 0.002 |
| L4   | $7.2 \pm 4.6$  | 19  | 1.572  | 0.132 |
| L5   | $6.9 \pm 3.9$  | 18  | 1.765  | 0.094 |

and placed in proper context before any interpretation of body condition within or between studies.

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