

Supplemental Material 1. Bioenergetic Model

SI.1. Model overview

We used a bioenergetic model to estimate energy requirements of Steller sea lions throughout their life. The overall goal was to use estimates of energy requirements in conjunction with prey energy density to estimate prey consumption. We chose to develop a new model, instead of using values from an existing one by Winship et al. (2002), since there have been additional data published on Steller sea lion energetics in the past two decades. While there were some similarities between our model and the one of Winship, we used slightly different approaches to characterize some of the energetic costs. These differences provide a useful comparison for how variation in model structure affects bioenergetic model output. Energy requirements were estimated for 500 sea lions of each sex from birth to death (18 years for males and 24 years for females). We present results for all possible female reproductive states including non-reproductive, pregnant, lactating, and lactating and pregnant.

We modeled three primary energetic costs throughout a Steller sea lion's lifetime once they became independent (non-pups): field metabolic rate (FMR), digestion (when not included in the FMR measurement), and growth. We refer to the sum of these costs as the net energy requirement or net energy intake. Costs associated with reproduction were calculated separately and added to the net costs for a non-reproductive adult female, resulting in separate and combined estimates for gestation and lactation. Pup costs, those costs above and beyond what we assumed a female could provide, were calculated based on estimates of milk intake. We also included costs associated with fecal and urinary production, since animals lose energy through these pathways and thus need to consume more prey than estimated from their net requirements. The collective sum of all costs is referred to as the gross energy requirement or gross energy intake.

SI.2. Field metabolic rate

An individual's metabolic rate comprises the bulk of its daily energy expenditure. As such, bioenergetic model output tends to be sensitive to metabolic rate parameters. Field metabolic rate (FMR) is typically assumed to include the costs associated with thermoregulation and locomotion; it may or may not include the cost of digestion (heat increment of feeding, HIF)

depending on how data were collected. We used four different methods to quantify FMR and thus provide a range around model output that reflected our uncertainty in this parameter. Body mass for each sea lion used in FMR equations was calculated per day (see *SI.3.* for further details). Considerable data on Steller sea lion metabolic rates exist, having been measured in a variety of experiments using sea lions in managed care (Fahlman et al. 2008, Gerlinsky et al. 2013, Goundie et al. 2015, Rosen et al. 2017), as well as in free-ranging animals (Brandon 2000, Hoopes et al. 2014). Most studies have focused on resting (RMR) or diving (DMR) metabolic rates, with the only empirical measurement of FMR coming from a doubly labeled water (DLW) study of 10 adult females during early lactation.

Methods included: (1) DLW (Method 1); (2) two separate allometric equations (Methods 2 and 3); and (3) RMR measurements derived from animals in human care in conjunction with habitat-specific metabolic rates and time-activity budgets (Method 4). Not all methods were used for every age class because of data limitations and because not all measurements were likely to reflect energy expenditure for some age groups. For example, FMR estimated from DLW is conditioned on the behavior of the animal during the measurement interval, in this case lactating females, which may have very different behavior in terms of the amount of time spent at land or at sea than other age groups. A detailed description of each method is provided below. Parameter values can be found in Table S1.1. Unit conversions are shown within the equation as needed so that the output of all methods was in MJ day⁻¹.

SI.2.1. Method 1

Metabolic measurements were obtained from Brandon (2000), who measured FMR using DLW in ten adult females during early lactation at Chirikof (central Gulf) and Lowrie (Southeast Alaska) Islands. We used the average value (\pm SE) of $3.45 \text{ W kg}^{-1} \pm 0.182$ since there were no differences in metabolic rates between the two islands. This method was just used for adult females because a lack of mass-corrected or habitat-specific (land vs at-sea) metabolic rates make it difficult to apply to other groups.

S1.2.2. Methods 2 and 3

We used the allometric equation from Williams et al. (2020) and one generated in this study specifically from otariid data to estimate *FMR* (Fig. S1.1). In Williams et al. (2020), the equation was derived from marine mammal carnivores using measurements from DLW as well as estimates from bioenergetic models.

$$FMR_2 = \frac{651.2 \cdot M^{0.87}}{1000} \quad (Eq\ S1)$$

This equation did not include the data from Brandon (2000).

For the second equation, we used published estimates of otariid at-sea *FMR* to generate allometric equations for at-sea and onshore *FMR*, under the assumption that at-sea *FMR* was 1.8 times *FMR* on land (Costa & Gentry 1986). When the Nagy equation (Nagy 1980) was used to convert CO₂ production to O₂ consumption, we divided values by a correction factor of 1.3 so that they better reflected the two-pool method of Speakman (Speakman et al. 1993), as estimates using the Nagy equation are consistently higher. The correction factor was derived from northern fur seal (*Callorhinus ursinus*) data from McHuron et al. (2019). For Costa & Gales (2003), we divided by a correction factor of 1.15–1.17 because they provided estimates of *FMR* using both equations, but only provided at-sea *FMR* using the Nagy equation. We used $M^{0.75}$ in the linear regression since we were using the equation to predict outside of the range of body masses used to derive the equations (Fig. S1.1). Habitat-specific *FMRs* were multiplied by the time (in days) spent in each habitat per foraging cycle (at-sea trip duration + subsequent time spent on land) and then renormalized to a daily rate. The resulting equations were

$$FMR_{3:Sea} = 1.449 \cdot M^{0.75} - 1.753 \quad (Eq\ S2)$$

$$FMR_3 = \left(FMR_{3:Sea} \cdot \frac{sea_{hr}}{24} + \frac{FMR_{3:Sea}}{1.8} \cdot \frac{land_{hr}}{24} \right) \cdot \frac{24}{sea_{hr} + land_{hr}} \quad (Eq\ S3)$$

S1.2.3. Method 4

We used estimates of *RMR* to quantify *FMR* on land, and the cost of transport (*COT*), travel speeds, and trip duration to quantify *FMR* at sea, similar to the approach of Olivier et al. (2022). As above, these were combined with foraging trip and land durations and renormalized to a single day (MJ day⁻¹).

$$FMR_4 = \left(COT \cdot M^{0.75} \cdot Speed \cdot sea_{hr} + RMR \cdot M^{0.75} \cdot \frac{land_{hr}}{24} \right) \cdot \frac{24}{sea_{hr} + land_{hr}} \quad (Eq\ S4)$$

This approach is unlikely to include digestion costs since *COT* and *FMR* were derived from post-absorptive animals, and so the *HIF* was added as described in Text S1.6.

S1.3. Growth

We used the Richards growth curves from Winship et al. (2001) to estimate body mass at each age of an individual's life, once they had transitioned from a nursing pup to an independent juvenile, with costs assumed to occur continuously throughout the year. We used sex-specific equations and similar to Winship et al. (2002), introduced variability into growth by multiplying resulting mass estimates by a value drawn from a normal distribution with of a mean \pm SD of 1 ± 0.5 . All modeled sea lions thus exhibited the same growth curve shape but grew at slightly different rates and had different asymptotic body masses (Fig. S1.2). The daily cost of growth was calculated by multiplying daily mass differences by body composition estimates, using standard energy density values for lipid and protein.

$$E_{Growth} = \Delta M \cdot \%M_{Lipid} \cdot 39.3 + \Delta M \cdot \%M_{Protein} \cdot 24.5 \quad (Eq\ S5)$$

where ΔM is the change in mass in kg, $\%M_{Lipid}$ and $\%M_{Protein}$ are the proportion of growth that is lipid and protein, respectively, and 39.3 MJ kg⁻¹ (lipid) and 24.5 MJ kg⁻¹ (protein) are energy density values for lipid and protein.

To estimate the composition of growth, we generated a linear regression equation using existing data on the lipid composition (as a percent of body mass) as a function of age (Davis et al. 1996, Kumagai et al. 2006, Rea et al. 2007, 2016, Calkins et al. 2013). Values ranged from 7.2% to 31.4% with a general decline in percent lipid composition with age ($r^2 = 0.16$). At or above 13 years, we assumed that the mean value of lipid remained constant regardless of age (Table S1.3). We selected age-specific values for each sea lion by randomly sampling from a normal distribution, where the mean was calculated from this equation with a standard deviation of 0.019. We randomly sampled water composition for each sea lion from a normal distribution and then assumed that protein made up the remaining amount of tissue growth after accounting for lipid and water (Table S1.3).

Estimated growth costs only represent the energy stored within the new tissue. It was assumed that the energy invested in growing new tissue was incorporated in the FMR estimate. Growth costs were assumed to encompass somatic growth. They do not reflect seasonal fluctuations in energy reserves because reserves accumulated in one season are spent in another season, such as the fat reserves that adult males accumulate to spend time on land fasting during the breeding season (Kastelein et al. 1990, Boyd & Duck 1991, Allen 2009). Thus, these costs are already inherently incorporated within our estimates of FMR, although they may not entirely account for energy investment in tissue growth and catabolism.

S1.4. Gestation

Gestation costs included the Heat Increment of Gestation (*HIG*), the metabolic cost associated with growing/maintaining the fetus and associated tissues, and the energy stored in the fetus and associated tissues. The *HIG* was calculated using the equation from Brody (1938)

$$HIG = 18.41 \cdot M_{Birth}^{1.2} \quad (Eq\ S6)$$

where M_{Birth} is mass at birth in kg and the output is the cost across the entire pregnancy in MJ. Birth masses were drawn from sex-specific distributions (Table S1.4). We used estimates of daily fetal mass to convert the *HIG* into daily costs so that they were relative to the size of the fetus.

$$HIG(t) = HIG \cdot \frac{M_{Fetus}(t)}{\sum_t^{255} M_{Fetus}} \quad (Eq\ S7)$$

where $M_{Fetus}(t)$ is the mass of the fetus for a given day of gestation in kg. Fetal mass for each day of active gestation, assumed to be 255 days in total, was calculated using modified equations for male and female northern fur seal (*Callorhinus ursinus*) fetuses at least 35 days of age (Trites 1991)

$$M_{Fetus}(t) = \frac{\sigma(-1.224 + 0.207\sqrt{t})^{2.75} \cdot 3.0 \cdot \frac{M_{Birth}}{\bar{M}_{Birth}}}{\varphi(-1.183 + 0.201\sqrt{t})^{2.75} \cdot 3.2 \cdot \frac{M_{Birth}}{\bar{M}_{Birth}}} \quad (Eq\ S8)$$

where the values of 3.0 and 3.2 are multipliers to account for the fact that Steller sea lions are heavier at birth than northern fur seals. The far right-hand side of the equation is the ratio between birth mass of an individual sea lion and the average sex-specific birth mass, which was used as multiplier on overall growth to introduce variation into the growth curve (Fig. S1.3).

While there have been several fetal growth curves developed using Steller sea lion data (Winship

2000, Esquible et al. 2019), fetal sample sizes from these studies ($n = 19 - 23$) were small compared with the northern fur seal study ($n = 7,003$) and temporal coverage across gestation was incomplete.

The energy stored in the fetus was estimated based on the birth mass and the lipid and protein composition at birth (see Eq. S5, Table S1.4). We assumed that the energy stored in the fetus represented 90% of the total stored energy associated with pregnancy, with the remaining 10% stored in the placenta and other tissues. This value was selected based on placental mass and energy density data from other pinniped species (Lavigne & Stewart 1979, Anderson & Fedak 1987, Boyd & McCann 1989, Lydersen 1995). This cost was allocated to each day of gestation using the same approach as described above for the metabolic cost of gestation (Eq. S7).

S1.5. Lactation

The cost of lactation is primarily due to the energy contained within milk, as there is no evidence of a metabolic cost to produce milk in pinnipeds (Costa & Trillmich 1988). The total cost of lactation thus depends on lactation duration and milk intake rates of the pup, which here is a function of pup body mass. Initial lactation durations of 365 days (80% probability) or 730 days (20% probability) were randomly assigned to each pup based on evidence indicating that most pups weaned by two years of age (Maniscalco 2014, Hastings et al. 2021). Daily pup body mass was calculated based on the assigned birth masses and a pup growth rate that was randomly sampled from distributions depending on pup age (<5 months or > 5 months) and lactation duration (<1 year or > 365 or ≤ 365 ; Table S1.4). To avoid unrealistic combinations of pup growth and lactation duration, initial lactation durations were truncated to the age at which a pup reached 125 kg; if 125 kg was not reached then the initial duration was retained. This value of 125 kg was based on the estimated mass a pup would reach by one year of age if it grew based on the mean growth rate values during early (0.4 kg day^{-1}) and late ($0.201 \text{ kg day}^{-1}$) lactation, which is consistent with data from free-ranging pups indicating that all but one dependent pup weighed between 62.5 kg and 115.5 kg at 10 months of age (Rehberg et al. 2018). Daily milk intake rates were estimated based on body mass and mass-specific milk intake estimates derived from Steller sea lions early in lactation (Table S1.4). We set an upper limit on daily milk production by the female of 58 MJ (Arnould & Hindell 2002). It is not known if independent

foraging occurs in Steller sea lion pups, although young-of-the year do exhibit shallow diving and have been observed playing with prey (Trites & Porter 2002). Mammals generally exhibit peaks in milk energy production that can occur well before weaning (Riek 2021), thus it is not unreasonable to assume that such limits also occur in Steller sea lions.

Surplus energy above the limit of 58 MJ day⁻¹ was assumed to be met by the pup through foraging. Since there are differences in digestive efficiencies between milk and prey, actual energy needs were assumed to be 95% of surplus energy calculated from milk intake rates, with fecal and urinary energy losses calculated as they were for non-pup age classes (see Text S1.6).

S1.6. Net and gross energy requirements

Net energy, E_{Net} , initially represented the sum of FMR and growth. For all metabolic methods except Method 4, they also included the *HIF*. Gross energy requirements (E_{Gross}), the amount of energy a sea lion needs to consume, are higher because not all energy within prey is available and some energy is lost to urine production. They were calculated as

$$E_{Gross} = \frac{FMR+}{1-((1-DE)+UEL+HIF)} \quad (Eq\ S9)$$

where *DE* is digestive efficiency, and *UEL* is urinary energy loss, where *DE*, *UEL*, and *HIF* are all calculated relative to gross energy intake (Table S1.5). Values for all three parameters were drawn from a uniform distribution since they depend on the proximate composition of prey and so there is not a single normal distribution of values. Values for the *HIF* were set at zero for Methods 1–3. For Method 4, E_{Net} was recalculated to include the *HIF* after the calculation of E_{Gross} so that values were comparable across all metabolic methods.

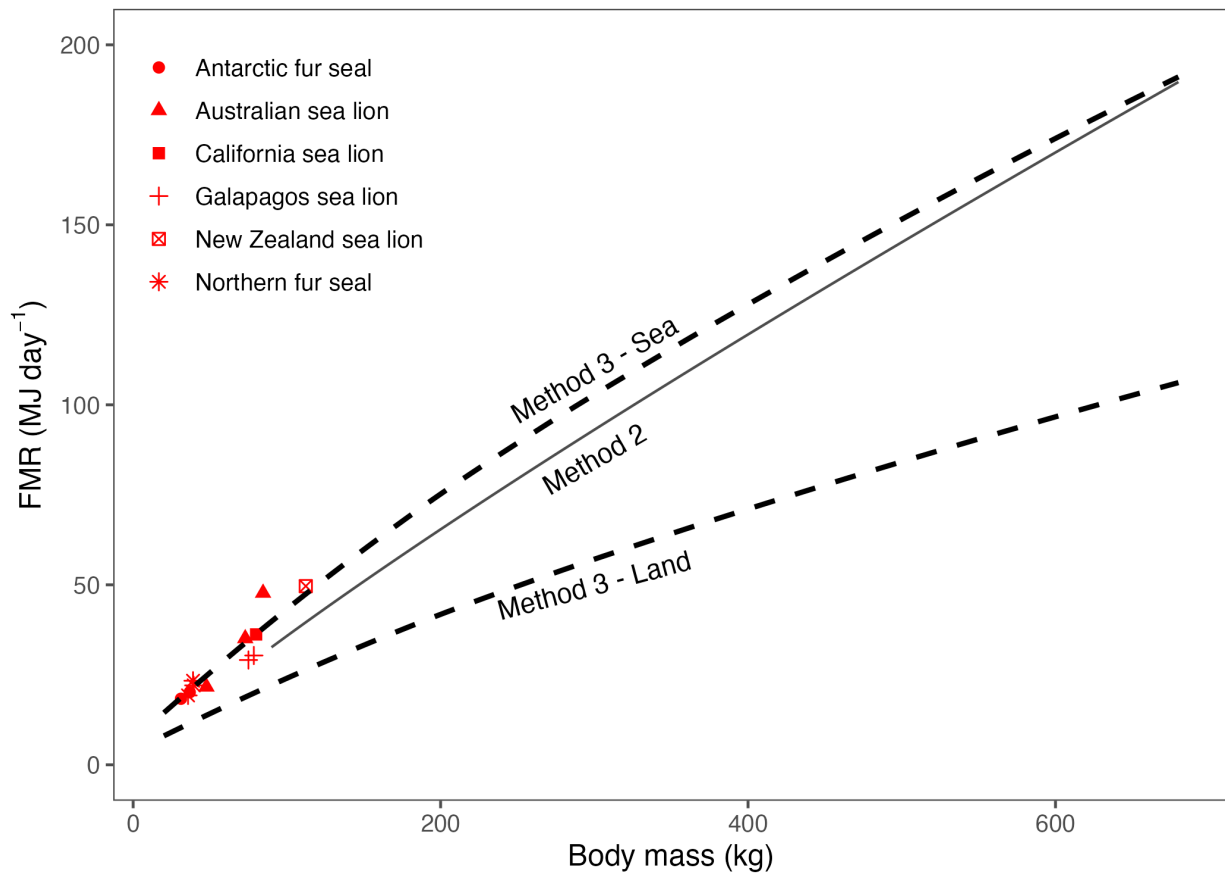


Figure S1.1. The two allometric relationships describing the relationship between field metabolic rate (FRM, MJ day⁻¹) and body mass used in the bioenergetic model. The equation for Method 2 was from Williams et al. (2020), while the equation for Method 3 was derived from estimates of at-sea FMR collected from free-ranging juvenile and lactating female otariids. Equations are : $y = 651M^{0.87}$ (Method 2) and $y = 1.449M^{0.75} - 1.753$ (Method 3 - Sea) where M is body mass in kg. Points represent the data used to derive the Method 3 relationship. See Table S1.2 for Method 3 sources.

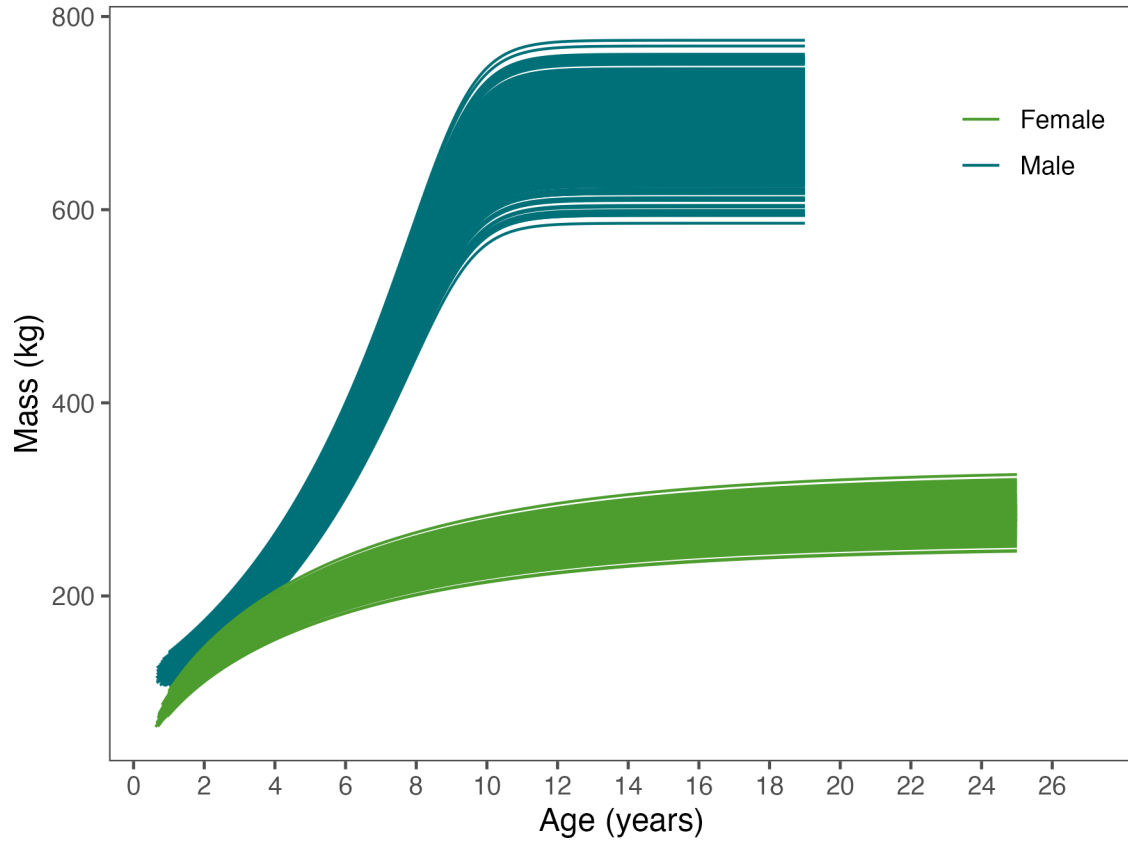


Figure S1.2. Body mass as a function of age for male and female Steller sea lions in the bioenergetic model. Data were generated using mass-at-age equations from (Winship et al. 2001). Inter-individual variation in growth was introduced by multiplying resulting mass estimates by a value drawn from a normal distribution with of a mean \pm SD of 1 ± 0.5 .

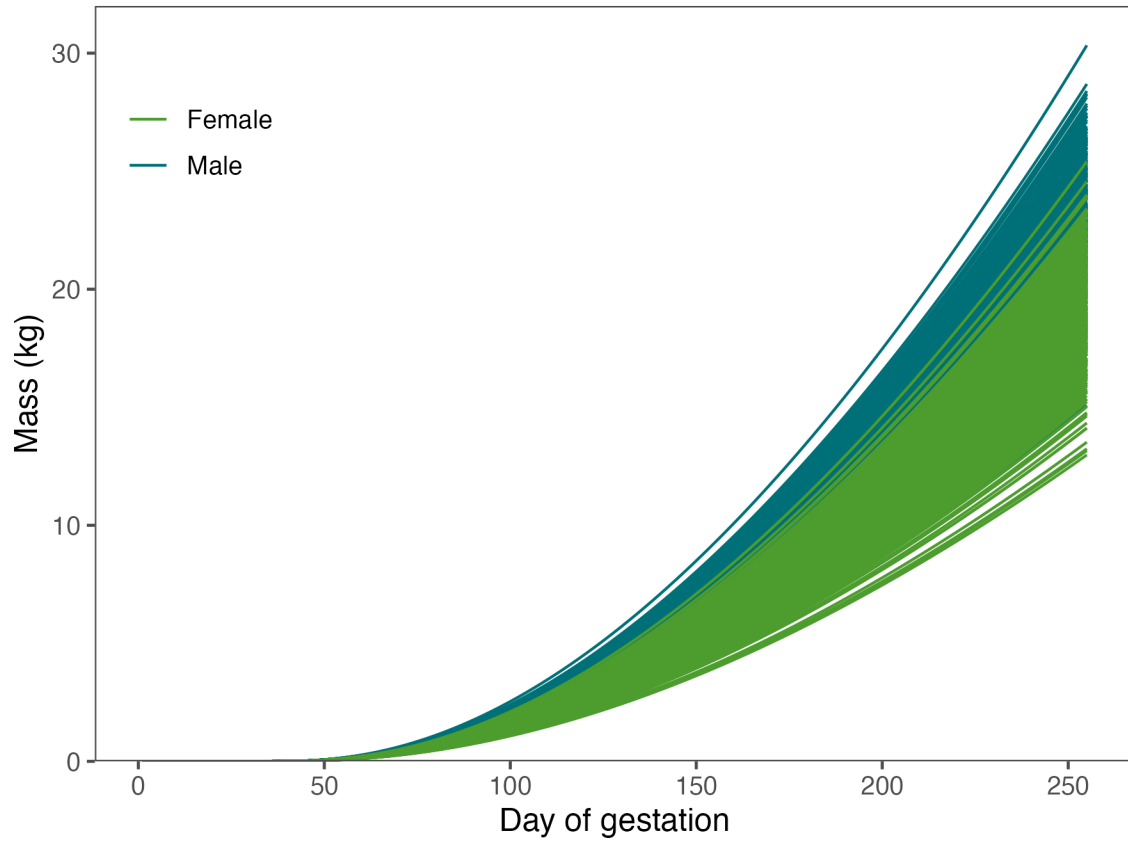


Figure S1.3. Fetal mass as a function of day of gestation for male and female Steller sea lions in the bioenergetic model. See Eq. S8 for equations.

Table S1.1. Parameter values and sources for equations for each FMR method. SSL-specific refers to whether the value comes from Steller sea lions (Yes) or another species/s (No).

Parameter	Value/Equation	Units	SSL-specific	Citation
<i>Method 1</i>				
FMR	3.45 ± 0.182 (2.55 - 4.41)	W kg ⁻¹	Yes	(Brandon 2000)
<i>Methods 2 and 3</i>				
Method 2 - FMR	$y = 651.2M^{0.87}$	kJ day ⁻¹	No	(Williams et al. 2020)
Method 3 - at-sea FMR	$y = 1.449M^{0.75} - 1.753$	MJ day ⁻¹	No	Table S1.2, Fig. S1.1
Method 3 - onshore FMR	$y = \frac{1.449M^{0.75} - 1.753}{1.8}$	MJ day ⁻¹	No	Table S1.2, Fig. S1.2
Trip duration (sea, land)				
Adult	23.8, 19.0	hours	Yes	(Merrick & Loughlin 1997)
Juvenile	14.0, 10.5	hours	Yes	(Lander et al. 2011)
<i>Method 4</i>				
RMR	0.785	MJ day ⁻¹ kg ^{-0.75}	Yes	(Gerlinsky et al. 2013)
Travel speed	1.5	m s ⁻¹	Yes	(Olivier et al. 2022)
Cost of transport	8.33	J kg ^{-0.75} m ⁻¹	No	(Dassis et al. 2012)
Trip duration (sea, land)	as above			

Table S1.2. Data used to develop the allometric relationship of Method 3 for estimating field metabolic rate (FMR). Multiple estimates are sometimes provided for a single study if separate values were presented, such as by season, pup status, or foraging habitat.

Species	At-sea FMR (W kg ⁻¹)	At-sea FMR _{Adj} (W kg ⁻¹)	Body mass (kg)	Daily FMR _{sea} (MJ day ⁻¹)	Citation
Australian sea lion	7.65	6.54	84.5	47.74	(Costa & Gales 2003)
Australian sea lion	6.46	5.57	72.9	35.11	(Costa & Gales 2003)
Australian sea lion	-	-	47.7	21.66	(Fowler et al. 2007)
California sea lion	5.24	-	80.0	36.22	(McHuron et al. 2018)
Galapagos sea lion	5.84	4.49	75.0	29.11	(Villegas-Amtmann et al. 2017)
Galapagos sea lion	5.82	4.47	78.5	30.36	(Villegas-Amtmann et al. 2017)
New Zealand sea lion	6.65	5.11	112.3	49.63	(Costa & Gales 2000)
Antarctic fur seal	6.34	-	36.8	20.16	(Arnould et al. 1996b)
Antarctic fur seal	6.83	-	31.1	18.35	(Jeanniard du Dot et al. 2018)
Northern fur seal	6.94	-	38.9	23.35	(McHuron et al. 2019)
Northern fur seal	6.48	-	39.4	22.06	(Jeanniard du Dot et al. 2018)
Northern fur seal	6.25	-	35.7	19.28	(Jeanniard du Dot et al. 2018)

Table S1.3. Parameter values used to estimate the energetic costs of growth. SSL-specific refers to whether the value comes from Steller sea lions (Yes) or another species (No).

Parameter	Value/Equation	Units	SSL-specific	Citation
Energy density				
Lipid	39.3	MJ kg ⁻¹	No	
Protein	24.5	MJ kg ⁻¹	No	
Lipid composition				
< 13 years	$y = -0.00869 \cdot \text{age} + 0.2028$	% body mass	Yes	See supp. text
≥ 13 years	0.0898	% body mass	Yes	See supp. text
Water composition	0.65 ± 0.03075	% body mass	Yes	(Davis et al. 1996)

Table S1.4. Parameter values used to estimate the energetic costs of gestation and lactation of Steller sea lions in the bioenergetic model.

Parameter	Value/Equation	Units	SSL-specific	Citation
Birth mass	18.7 ± 2.08 (F)	kg	Yes	(Brandon et al. 2005)
	22.4 ± 2.36 (M)			
Gestation duration	255	days	Yes	(Pitcher & Calkins 1981, Pitcher et al. 2001)
Gestation start date ^a	October 11		Yes	(Pitcher & Calkins 1981, Pitcher et al. 2001)
% lipid at birth	5.6	% body mass	Yes	(Brandon et al. 2005)
% water at birth ^b	72.1	% body mass	Yes	(Brandon et al. 2005)
Milk energy delivery	0.0741	MJ kg ⁻¹ day ⁻¹	Yes	(Davis et al. 2002)
Maximum milk energy	58.0	MJ day ⁻¹	No	(Arnould et al. 1996a)
Pup growth rates				
High (<5 months)	0.4 ± 0.145	kg day ⁻¹		(Brandon et al. 2005)
Low (<5 months)	0.23 ± 0.176	kg day ⁻¹		(Brandon et al. 2005)
Late (>5 months)	0.201 ± 0.079	kg day ⁻¹		(Rehberg et al. 2018)

^aCalculated based on mean birth dates and assumed 8-month active gestation

^bUsed in conjunction with % lipid to estimate % protein

Table S1.5. Parameter values used to estimate the gross energy intake. Values for individual sea lions were drawn from uniform distributions, with a single value assigned to each sea lion.

Parameter	Value	Units	SSL-specific	Citation
Digestive efficiency	90.4 - 95.4	% GEI	Yes	(Rosen & Trites 2000a)
Urinary energy loss	8.9 - 17.8	% GEI	No	(Gomez et al. 2016)
Heat Increment of Feeding	9.9 - 15.7	% GEI	Yes	(Rosen & Trites 1997, 2000b)

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Supplemental Material 2. Results

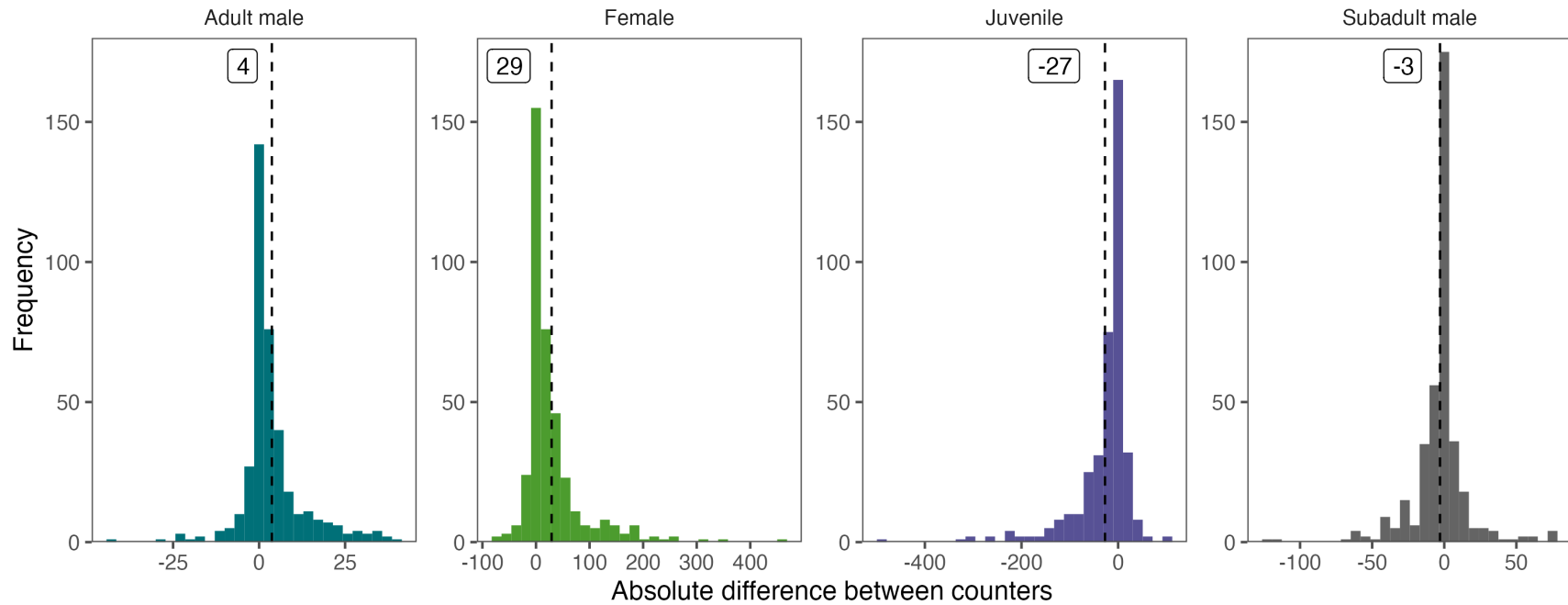


Figure S2.1. Absolute difference between independent counters in assigning sea lions to one of five age-sex classes (pup not shown). Differences were calculated at the site and year level. Dashed lines represent the mean for each age-sex class, with the specific value displayed in the text box.

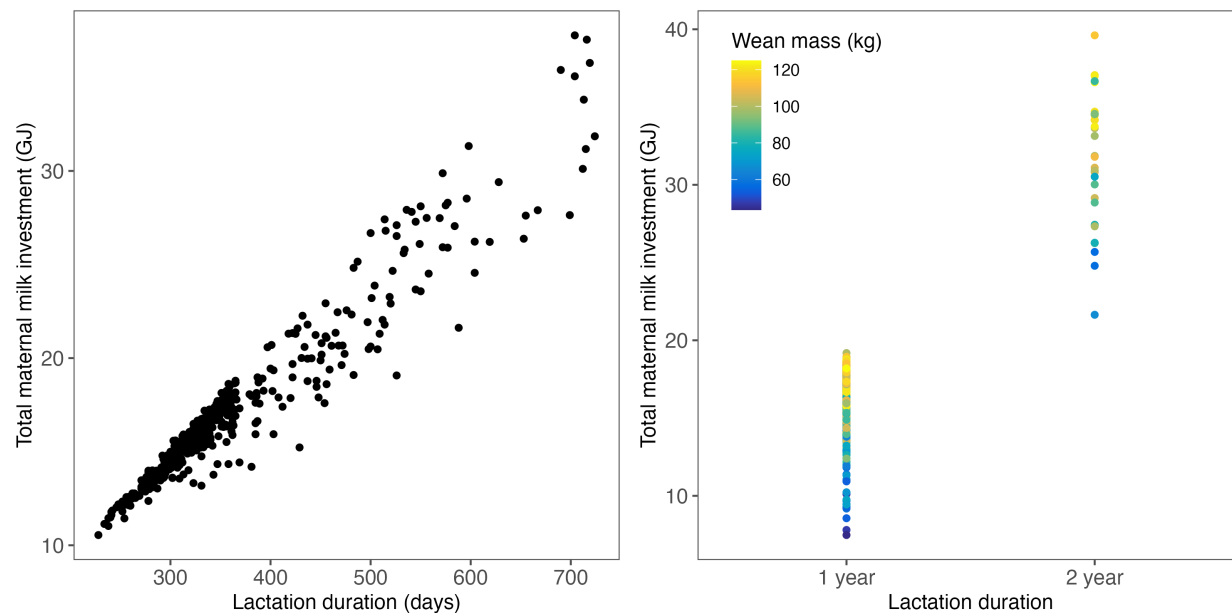


Figure S2.2. Changes in total maternal milk energy investment as a function of lactation duration for pups that reached the 125 kg limit (left) and for those that did not (right). Once pups reached the maximum wean mass limit, lactation was terminated, whereas if they did not then lactation occurred at the predetermined duration (either one or two years). Each point represents a single pup.

Table S2.1. Estimates of the mean \pm SD daily gross and net energy requirements (MJ day⁻¹) of female Steller sea lions by age, separated by the four different methods used to estimate field metabolic rates as described in Supplemental Material 1. The average body mass (kg) for each age is also provided. Estimates for age-zero represent weaned pups.

Age	Mass	Gross				Net			
		1	2	3	4	1	2	3	4
0	83		40.5 \pm 2.7	41 \pm 2.6	41.9 \pm 2.9		32.1 \pm 1.8	32.5 \pm 1.7	33.3 \pm 1.8
1	110		50.7 \pm 5.1	50 \pm 4.5	50.6 \pm 4.8		40.2 \pm 3.7	39.7 \pm 3.3	40.2 \pm 3.3
2	143		62.8 \pm 4.6	60.5 \pm 4.1	60.7 \pm 4.5		49.8 \pm 3.1	48 \pm 2.7	48.2 \pm 2.9
3	168		71.7 \pm 4.6	68.1 \pm 4	67.9 \pm 4.6		57 \pm 3	54 \pm 2.5	53.9 \pm 2.8
4	188		78.7 \pm 4.8	73.8 \pm 4.2	73.5 \pm 4.8		62.5 \pm 3	58.6 \pm 2.4	58.3 \pm 2.8
5	204	77 \pm 4.9	84.2 \pm 4.9	77.7 \pm 4.2	77.5 \pm 5	61.2 \pm 3.2	66.9 \pm 3	61.7 \pm 2.4	61.5 \pm 2.9
6	217	81.8 \pm 5.1	88.8 \pm 5.1	81.4 \pm 4.4	81.1 \pm 5.2	65 \pm 3.3	70.5 \pm 3.1	64.6 \pm 2.5	64.3 \pm 2.9
7	228	85.8 \pm 5.3	92.5 \pm 5.3	84.4 \pm 4.5	84 \pm 5.3	68.1 \pm 3.4	73.5 \pm 3.2	67 \pm 2.5	66.7 \pm 3
8	237	89.2 \pm 5.5	95.7 \pm 5.4	86.9 \pm 4.6	86.4 \pm 5.5	70.8 \pm 3.5	75.9 \pm 3.2	69 \pm 2.6	68.6 \pm 3.1
9	244	92 \pm 5.6	98.3 \pm 5.6	89 \pm 4.7	88.4 \pm 5.6	73 \pm 3.6	78 \pm 3.3	70.6 \pm 2.6	70.2 \pm 3.2
10	251	94.4 \pm 5.8	100.5 \pm 5.7	90.7 \pm 4.8	90.1 \pm 5.7	74.9 \pm 3.6	79.8 \pm 3.4	72 \pm 2.7	71.5 \pm 3.2
11	256	96.4 \pm 5.9	102.4 \pm 5.8	92.2 \pm 4.9	91.5 \pm 5.8	76.5 \pm 3.7	81.3 \pm 3.4	73.2 \pm 2.7	72.6 \pm 3.3
12	261	98.1 \pm 6	104 \pm 5.9	93.5 \pm 4.9	92.8 \pm 5.8	77.9 \pm 3.8	82.5 \pm 3.5	74.2 \pm 2.7	73.6 \pm 3.3
13	265	99.6 \pm 6.1	105.3 \pm 5.9	94.5 \pm 5	93.8 \pm 5.9	79.1 \pm 3.8	83.6 \pm 3.5	75 \pm 2.8	74.4 \pm 3.3

Age	Mass	Gross				Net			
		1	2	3	4	1	2	3	4
14	268	100.9 ± 6.2	106.5 ± 6	95.4 ± 5	94.7 ± 6	80.1 ± 3.9	84.5 ± 3.5	75.8 ± 2.8	75.1 ± 3.4
15	271	101.9 ± 6.2	107.5 ± 6	96.2 ± 5.1	95.4 ± 6	80.9 ± 3.9	85.3 ± 3.6	76.4 ± 2.8	75.7 ± 3.4
16	274	102.9 ± 6.3	108.3 ± 6.1	96.9 ± 5.1	96.1 ± 6	81.7 ± 3.9	86 ± 3.6	76.9 ± 2.8	76.2 ± 3.4
17	276	103.6 ± 6.3	109 ± 6.1	97.4 ± 5.1	96.6 ± 6.1	82.3 ± 4	86.6 ± 3.6	77.4 ± 2.8	76.7 ± 3.4
18	278	104.3 ± 6.4	109.7 ± 6.2	97.9 ± 5.1	97.1 ± 6.1	82.8 ± 4	87.1 ± 3.6	77.8 ± 2.9	77.1 ± 3.4
19	279	104.9 ± 6.4	110.2 ± 6.2	98.4 ± 5.2	97.5 ± 6.1	83.3 ± 4	87.5 ± 3.7	78.1 ± 2.9	77.4 ± 3.4
20	281	105.4 ± 6.4	110.7 ± 6.2	98.7 ± 5.2	97.8 ± 6.1	83.7 ± 4	87.9 ± 3.7	78.4 ± 2.9	77.6 ± 3.5
21	282	105.9 ± 6.5	111.1 ± 6.2	99 ± 5.2	98.1 ± 6.2	84 ± 4	88.2 ± 3.7	78.6 ± 2.9	77.9 ± 3.5
22	283	106.2 ± 6.5	111.4 ± 6.3	99.3 ± 5.2	98.4 ± 6.2	84.3 ± 4.1	88.4 ± 3.7	78.8 ± 2.9	78.1 ± 3.5
23	284	106.6 ± 6.5	111.7 ± 6.3	99.5 ± 5.2	98.6 ± 6.2	84.6 ± 4.1	88.7 ± 3.7	79 ± 2.9	78.3 ± 3.5
24	285	106.8 ± 6.5	111.9 ± 6.3	99.7 ± 5.2	98.8 ± 6.2	84.8 ± 4.1	88.9 ± 3.7	79.2 ± 2.9	78.4 ± 3.5

Table S2.2. Estimates of the mean \pm SD daily gross and net energy requirements (MJ day⁻¹) of male Steller sea lions by age, separated by the three different methods used to estimate field metabolic rates as described in Supplemental Material 1. The average body mass (kg) for each age is also provided. Estimates for age-zero represent weaned pups.

Age	Mass	Gross			Net		
		2	3	4	2	3	4
0	122	54.7 \pm 3.1	53.5 \pm 2.9	53.9 \pm 3.4	43.4 \pm 1.9	42.5 \pm 1.6	42.8 \pm 1.9
1	139	61 \pm 4.7	59 \pm 4.1	59.2 \pm 4.6	48.4 \pm 3.2	46.8 \pm 2.8	47 \pm 3
2	170	73 \pm 5.6	69.2 \pm 4.9	69.2 \pm 5.4	57.9 \pm 3.9	54.9 \pm 3.3	54.9 \pm 3.5
3	210	87.5 \pm 6.7	81.3 \pm 5.7	80.9 \pm 6.3	69.4 \pm 4.6	64.5 \pm 3.8	64.2 \pm 4.1
4	258	104.8 \pm 8.1	95.3 \pm 6.7	94.6 \pm 7.3	83.2 \pm 5.6	75.7 \pm 4.5	75.1 \pm 4.8
5	317	125.5 \pm 9.6	110.8 \pm 7.7	110.1 \pm 8.5	99.7 \pm 6.7	87.9 \pm 5.1	87.4 \pm 5.5
6	390	150.1 \pm 11.4	129.6 \pm 8.9	128.5 \pm 9.9	119.1 \pm 7.9	102.9 \pm 5.9	102 \pm 6.4
7	475	178.1 \pm 13.1	150.5 \pm 10	149 \pm 11.1	141.4 \pm 8.9	119.5 \pm 6.6	118.2 \pm 7.1
8	565	206.2 \pm 13.8	170.9 \pm 10.4	168.8 \pm 11.8	163.7 \pm 9.1	135.7 \pm 6.5	134 \pm 7.2
9	634	226.6 \pm 13.5	185.1 \pm 10.1	182.4 \pm 11.8	179.9 \pm 8.3	147 \pm 5.9	144.7 \pm 6.8
10	667	235.7 \pm 13.4	191.2 \pm 10.1	188 \pm 11.9	187.1 \pm 8	151.8 \pm 5.7	149.2 \pm 6.8
11	678	238.4 \pm 13.6	193 \pm 10.2	189.6 \pm 12	189.3 \pm 8.1	153.2 \pm 5.7	150.5 \pm 6.8
12	681	239.1 \pm 13.6	193.5 \pm 10.2	190.1 \pm 12	189.8 \pm 8.1	153.6 \pm 5.7	150.9 \pm 6.8
13	681	239.3 \pm 13.6	193.6 \pm 10.2	190.2 \pm 12	190 \pm 8.1	153.7 \pm 5.7	150.9 \pm 6.8

Age	Mass	Gross			Net		
		2	3	4	2	3	4
14	681	239.3 ± 13.6	193.6 ± 10.2	190.2 ± 12.1	190 ± 8.1	153.7 ± 5.7	150.9 ± 6.8
15	681	239.3 ± 13.6	193.6 ± 10.2	190.2 ± 12.1	190 ± 8.1	153.7 ± 5.7	150.9 ± 6.8
16	681	239.3 ± 13.6	193.6 ± 10.2	190.2 ± 12	190 ± 8.1	153.7 ± 5.7	151 ± 6.8
17	681	239.3 ± 13.6	193.6 ± 10.2	190.2 ± 12	190 ± 8.1	153.7 ± 5.7	150.9 ± 6.8
18	681	239.3 ± 13.6	193.6 ± 10.2	190.2 ± 12	190 ± 8.1	153.7 ± 5.7	151 ± 6.8

Table S2.3. Estimates of the mean \pm SD daily gross energy requirements (MJ day⁻¹) of pregnant (P), lactating (L), and pregnant and lactation (P+L) Steller sea lions by age, separated by the four different methods used to estimate field metabolic rates as described in Supplemental Material 1. The average body mass (kg) for each age is also provided.

Age	Mass	P				L				P+L			
		1	2	3	4	1	2	3	4	1	2	3	4
4	188		81.7 \pm 7.4	76.8 \pm 6.9	77.1 \pm 7.9								
5	204	80 \pm 7.4	87.2 \pm 7.4	80.7 \pm 6.8	81.1 \pm 7.9	129.2 \pm 26.5	136.4 \pm 26.5	129.9 \pm 26.3	139.8 \pm 31.5	132.2 \pm 27.1	139.4 \pm 27.1	132.9 \pm 26.8	143.4 \pm 32.2
6	217	84.8 \pm 7.4	91.8 \pm 7.3	84.4 \pm 6.7	84.6 \pm 7.9	136.5 \pm 22.8	143.4 \pm 22.8	136 \pm 22.5	146.3 \pm 27	139.4 \pm 24.1	146.4 \pm 24.1	139 \pm 23.7	149.8 \pm 28.5
7	228	88.8 \pm 7.4	95.5 \pm 7.3	87.4 \pm 6.7	87.5 \pm 7.9	137.9 \pm 26.6	144.6 \pm 26.6	136.5 \pm 26.3	146.1 \pm 31.6	140.9 \pm 27.1	147.6 \pm 27.1	139.5 \pm 26.8	149.7 \pm 32.2
8	237	92.1 \pm 7.5	98.6 \pm 7.4	89.9 \pm 6.7	90 \pm 8	143.7 \pm 22.8	150.2 \pm 22.7	141.5 \pm 22.4	151.5 \pm 27	146.7 \pm 24	153.2 \pm 24	144.5 \pm 23.7	155.1 \pm 28.4
9	244	95 \pm 7.5	101.3 \pm 7.4	92 \pm 6.7	92 \pm 8	144.2 \pm 26.5	150.5 \pm 26.5	141.2 \pm 26.3	150.7 \pm 31.5	147.2 \pm 27.1	153.5 \pm 27	144.2 \pm 26.8	154.3 \pm 32.1
10	251	97.3 \pm 7.6	103.4 \pm 7.5	93.7 \pm 6.7	93.6 \pm 8	148.9 \pm 22.7	155.1 \pm 22.7	145.3 \pm 22.4	155.2 \pm 27	151.9 \pm 23.9	158 \pm 23.9	148.3 \pm 23.6	158.8 \pm 28.4
11	256	99.4 \pm 7.6	105.4 \pm 7.5	95.2 \pm 6.7	95.1 \pm 8	148.5 \pm 26.6	154.5 \pm 26.6	144.3 \pm 26.3	153.7 \pm 31.6	151.5 \pm 27.1	157.5 \pm 27	147.3 \pm 26.8	157.3 \pm 32.2
12	261	101.1 \pm 7.6	107 \pm 7.5	96.5 \pm 6.8	96.3 \pm 8.1	152.7 \pm 22.8	158.5 \pm 22.7	148 \pm 22.4	157.9 \pm 27	155.7 \pm 23.9	161.5 \pm 23.9	151 \pm 23.6	161.5 \pm 28.4

Age	Mass	P				L				P+L			
		1	2	3	4	1	2	3	4	1	2	3	4
13	265	102.6 ± 7.7	108.3 ± 7.6	97.5 ± 6.8	97.3 ± 8.1	151.8 ± 26.6	157.5 ± 26.5	146.8 ± 26.3	156.1 ± 31.5	154.8 ± 27.1	160.5 ± 27	149.8 ± 26.7	159.7 ± 32.1
14	268	103.8 ± 7.7	109.4 ± 7.6	98.4 ± 6.8	98.2 ± 8.1	155.4 ± 22.8	161 ± 22.7	150 ± 22.4	159.8 ± 27	158.4 ± 23.9	164 ± 23.9	153 ± 23.5	163.3 ± 28.4
15	271	104.9 ± 7.8	110.5 ± 7.6	99.2 ± 6.8	99 ± 8.1	154.1 ± 26.7	159.6 ± 26.6	148.3 ± 26.3	157.6 ± 31.6	157.1 ± 27.1	162.6 ± 27	151.3 ± 26.8	161.2 ± 32.2
16	274	105.9 ± 7.8	111.3 ± 7.6	99.9 ± 6.8	99.6 ± 8.2	157.4 ± 22.8	162.9 ± 22.7	151.4 ± 22.4	161.2 ± 27	160.4 ± 23.9	165.9 ± 23.9	154.4 ± 23.5	164.7 ± 28.4
17	276	106.6 ± 7.8	112 ± 7.6	100.4 ± 6.8	100.2 ± 8.1	155.9 ± 26.6	161.3 ± 26.5	149.7 ± 26.2	159 ± 31.5	158.9 ± 27.1	164.3 ± 27	152.7 ± 26.7	162.5 ± 32.1
18	278	107.3 ± 7.8	112.6 ± 7.6	100.9 ± 6.8	100.6 ± 8.1	158.9 ± 22.8	164.2 ± 22.7	152.5 ± 22.4	162.2 ± 27	161.8 ± 23.9	167.1 ± 23.8	155.4 ± 23.5	165.7 ± 28.3
19	279	107.9 ± 7.8	113.2 ± 7.7	101.4 ± 6.8	101.1 ± 8.2	157.1 ± 26.7	162.4 ± 26.6	150.5 ± 26.3	159.7 ± 31.6	160.1 ± 27.1	165.4 ± 27	153.5 ± 26.7	163.3 ± 32.1
20	281	108.4 ± 7.9	113.7 ± 7.7	101.7 ± 6.8	101.4 ± 8.2	159.9 ± 22.8	165.2 ± 22.7	153.2 ± 22.4	162.9 ± 27	162.9 ± 23.9	168.2 ± 23.8	156.2 ± 23.5	166.5 ± 28.4
21	282	108.9 ± 7.9	114.1 ± 7.7	102 ± 6.9	101.7 ± 8.2	158.2 ± 26.6	163.3 ± 26.6	151.3 ± 26.2	160.5 ± 31.6	161.1 ± 27.1	166.3 ± 27	154.3 ± 26.7	164.1 ± 32.1
22	283	109.2 ± 7.9	114.4 ± 7.7	102.2 ± 6.8	101.9 ± 8.2	160.8 ± 22.8	165.9 ± 22.7	153.8 ± 22.4	163.4 ± 27	163.7 ± 23.9	168.9 ± 23.8	156.8 ± 23.5	167 ± 28.3
23	284	109.6 ± 7.9	114.7 ± 7.7	102.5 ± 6.9	102.2 ± 8.2	158.7 ± 26.7	163.9 ± 26.6	151.7 ± 26.3	160.9 ± 31.6	161.7 ± 27.1	166.9 ± 27	154.7 ± 26.7	164.4 ± 32.1

Age	Mass	P				L				P+L			
		1	2	3	4	1	2	3	4	1	2	3	4
24	285	109.8 ± 7.9	114.9 ± 7.7	102.7 ± 6.9	102.3 ± 8.2	161.3 ± 22.8	166.4 ± 22.8	154.2 ± 22.4	163.8 ± 27.1	164.3 ± 23.9	169.4 ± 23.8	157.2 ± 23.5	167.4 ± 28.4

Table S2.4. Estimates of the mean \pm SD daily net energy requirements (MJ day⁻¹) of pregnant (P), lactating (L), and pregnant and lactation (P+L) Steller sea lions by age, separated by the four different methods used to estimate field metabolic rates as described in Supplemental Material 1. The average body mass (kg) for each age is also provided.

Age	Mass	P				L				P+L			
		1	2	3	4	1	2	3	4	1	2	3	4
4	188		64.8 \pm 5.3	61 \pm 4.9	60.7 \pm 5.1								
5	204	63.5 \pm 5.3	69.3 \pm 5.2	64.1 \pm 4.8	63.9 \pm 5	102.6 \pm 20.7	108.3 \pm 20.6	103.2 \pm 20.5	103 \pm 20.5	105 \pm 21.1	110.7 \pm 21.1	105.5 \pm 20.9	105.3 \pm 21
6	217	67.3 \pm 5.3	72.8 \pm 5.1	67 \pm 4.7	66.7 \pm 4.9	108.3 \pm 17.6	113.8 \pm 17.6	108 \pm 17.4	107.7 \pm 17.4	110.7 \pm 18.7	116.2 \pm 18.6	110.3 \pm 18.4	110 \pm 18.4
7	228	70.5 \pm 5.3	75.8 \pm 5.1	69.4 \pm 4.6	69 \pm 4.9	109.5 \pm 20.7	114.8 \pm 20.6	108.4 \pm 20.5	108 \pm 20.6	111.8 \pm 21.1	117.2 \pm 21	110.7 \pm 20.9	110.4 \pm 20.9
8	237	73.2 \pm 5.3	78.3 \pm 5.1	71.4 \pm 4.6	70.9 \pm 4.9	114.1 \pm 17.6	119.3 \pm 17.5	112.3 \pm 17.3	111.9 \pm 17.4	116.5 \pm 18.5	121.6 \pm 18.5	114.7 \pm 18.3	114.3 \pm 18.3
9	244	75.4 \pm 5.3	80.4 \pm 5.1	73 \pm 4.6	72.5 \pm 4.9	114.5 \pm 20.6	119.5 \pm 20.5	112.1 \pm 20.4	111.6 \pm 20.5	116.8 \pm 21	121.9 \pm 20.9	114.5 \pm 20.8	114 \pm 20.9
10	251	77.3 \pm 5.2	82.1 \pm 5	74.4 \pm 4.5	73.9 \pm 4.9	118.2 \pm 17.5	123.1 \pm 17.4	115.4 \pm 17.2	114.8 \pm 17.3	120.6 \pm 18.4	125.5 \pm 18.4	117.7 \pm 18.2	117.2 \pm 18.2
11	256	78.9 \pm 5.3	83.6 \pm 5	75.6 \pm 4.5	75 \pm 4.9	117.9 \pm 20.7	122.6 \pm 20.6	114.6 \pm 20.4	114 \pm 20.5	120.3 \pm 21	125 \pm 20.9	116.9 \pm 20.8	116.4 \pm 20.9
12	261	80.3 \pm 5.3	84.9 \pm 5.1	76.6 \pm 4.5	76 \pm 4.9	121.2 \pm 17.5	125.8 \pm 17.4	117.5 \pm 17.2	116.9 \pm 17.3	123.6 \pm 18.4	128.2 \pm 18.3	119.9 \pm 18.1	119.3 \pm 18.2

Age	Mass	P				L				P+L			
		1	2	3	4	1	2	3	4	1	2	3	4
13	265	81.4 ± 5.3	86 ± 5.1	77.4 ± 4.5	76.8 ± 4.9	120.5 ± 20.6	125.1 ± 20.5	116.5 ± 20.4	115.9 ± 20.4	122.9 ± 21	127.5 ± 20.9	118.9 ± 20.7	118.3 ± 20.8
14	268	82.4 ± 5.3	86.9 ± 5	78.1 ± 4.5	77.5 ± 4.9	123.4 ± 17.4	127.8 ± 17.4	119.1 ± 17.2	118.4 ± 17.3	125.7 ± 18.4	130.2 ± 18.3	121.4 ± 18.1	120.8 ± 18.2
15	271	83.3 ± 5.3	87.7 ± 5.1	78.8 ± 4.5	78.1 ± 4.9	122.3 ± 20.6	126.7 ± 20.6	117.8 ± 20.4	117.1 ± 20.5	124.7 ± 21	129.1 ± 20.9	120.1 ± 20.7	119.5 ± 20.8
16	274	84 ± 5.3	88.4 ± 5.1	79.3 ± 4.5	78.6 ± 4.9	125 ± 17.5	129.3 ± 17.4	120.2 ± 17.2	119.5 ± 17.3	127.3 ± 18.4	131.7 ± 18.3	122.6 ± 18.1	121.9 ± 18.2
17	276	84.7 ± 5.3	88.9 ± 5.1	79.7 ± 4.5	79.1 ± 4.9	123.8 ± 20.6	128.1 ± 20.5	118.9 ± 20.3	118.2 ± 20.4	126.2 ± 20.9	130.4 ± 20.9	121.2 ± 20.7	120.5 ± 20.8
18	278	85.2 ± 5.3	89.4 ± 5	80.1 ± 4.5	79.4 ± 4.9	126.1 ± 17.4	130.4 ± 17.4	121.1 ± 17.2	120.4 ± 17.3	128.5 ± 18.3	132.7 ± 18.2	123.4 ± 18.1	122.7 ± 18.2
19	279	85.7 ± 5.3	89.9 ± 5.1	80.5 ± 4.5	79.7 ± 4.9	124.7 ± 20.6	128.9 ± 20.6	119.5 ± 20.4	118.8 ± 20.5	127.1 ± 21	131.3 ± 20.9	121.9 ± 20.7	121.1 ± 20.8
20	281	86.1 ± 5.3	90.2 ± 5.1	80.7 ± 4.5	80 ± 4.9	127 ± 17.5	131.1 ± 17.4	121.6 ± 17.2	120.9 ± 17.3	129.4 ± 18.3	133.5 ± 18.2	124 ± 18.1	123.3 ± 18.2
21	282	86.4 ± 5.3	90.5 ± 5.1	81 ± 4.5	80.3 ± 4.9	125.6 ± 20.6	129.7 ± 20.5	120.1 ± 20.3	119.4 ± 20.4	127.9 ± 20.9	132.1 ± 20.8	122.5 ± 20.7	121.8 ± 20.8
22	283	86.7 ± 5.3	90.8 ± 5.1	81.2 ± 4.5	80.4 ± 4.9	127.6 ± 17.4	131.7 ± 17.4	122.1 ± 17.2	121.4 ± 17.3	130 ± 18.3	134.1 ± 18.2	124.5 ± 18	123.7 ± 18.1
23	284	87 ± 5.3	91.1 ± 5.1	81.4 ± 4.5	80.6 ± 4.9	126 ± 20.6	130.1 ± 20.5	120.4 ± 20.4	119.7 ± 20.5	128.4 ± 21	132.5 ± 20.9	122.8 ± 20.7	122.1 ± 20.8

Age	Mass	P				L				P+L			
		1	2	3	4	1	2	3	4	1	2	3	4
24	285	87.2 ± 5.4	91.3 ± 5.1	81.5 ± 4.5	80.8 ± 4.9	128.1 ± 17.5	132.1 ± 17.4	122.4 ± 17.2	121.7 ± 17.3	130.5 ± 18.3	134.5 ± 18.2	124.8 ± 18.1	124 ± 18.2

Table S2.5. Estimates of the total mean amount of energy (MJ) \pm SD that was assumed to be met by the pup during dependency, separated by pup sex. Values are separated into the surplus in milk energy above the 58 MJ maximum provided by the female (Milk), the estimate net energy (Net; 95% of Milk), and the gross energy (Gross). The proportion of pups that were required to supplement is shown (Prop), as means are only based on pups that had non-zero values. The mean number of days across which supplementation occurred is also shown (Days).

Sex	Prop	Days	Milk	Net	Gross
F	0.922	171.9935	2606.2 \pm 1364.2	2475.9 \pm 1296	3119.4 \pm 1633.1
M	0.946	177.6279	2762.5 \pm 1506.3	2624.4 \pm 1430.9	3305.5 \pm 1801.8