APPENDIX C

Tidal lung volume (V_t)

Calves: 0-2 months old

Tidal lung volume for calves younger than three months old was estimated using results from a Bayesian regression analysis of tidal lung volume as a function of expiration duration (E_d in seconds) and body length (L in meters) ($Vt = 0.0038 Ed^{1.55} L^{1.63}$, $R^2=0.94$) using published data (Sumich 1986).

$$\ln V_t = \beta_0 + \beta_1 \ln L + \beta_2 \ln E_d + \varepsilon \text{ where } \varepsilon \sim N(0, \sigma^2) \quad \text{(C.1)}$$

The multiple linear regression model has four unknown parameters ($\beta_{0\text{-}2}$ and σ^2). Data were three series of 110 time-expiration flow rate records. Two from calves provided by Kooyman and one from a captive calf (“Gigi II”) at 13 months of age provided by Wahrenbrock (Sumich 1986). Since data were limited (data from three individuals estimating four parameters), data points were treated as independent instead of creating a hierarchical analysis estimating the relationship for each individual. Posterior intercept and slope parameters were highly correlated with each other (Table C1), and uncertainty increased for longer animals and longer expiration durations (Fig. C1).

When running Monte Carlo simulations to estimate *Vt*, distributions on newborn body length and expiration duration for ages 0–2 months were based on direct measurements (Rice and Wolman 1971, Rice 1983, Sumich 1986, Perryman and Lynn 2002) (Table 1, main text). Expiration duration measurements were obtained from 32 gray whale calves from birth to lagoon departure at three months (Sumich 1986). Body length for newborn calves (Table 1, main text) was based on measurements of 133 late term fetuses and neonates collected and stranded in winter lagoons and nearby open coasts (Rice and Wolman 1971, Rice 1983, Sumich 1986). Body lengths for older calves (1–7 months old) were estimated using the equation in Sumich et al. (2013), $L = 8.85e^{-e^{(-0.47-0.068t)}}$, R^2=0.911 from a Gompertz growth curve. This equation describes the pattern of length increase with age from birth through the second summer (~90 weeks of age), where t is age in weeks (Table 1, main text). Length of gray whale calves of reasonably well-known ages include 112 photogrammetrically measured calves of approximately 15 weeks old, accompanying their mothers on their first spring northward migration (Perryman and Lynn 2002); weanlings harvested during their first summer that were independently foraging; animals from the smallest non-calf peak in the length frequency distribution of the Perryman and Lynn (2002) sample that were considered to be yearlings; and second summer whales harvested in the Chukotka native subsistence fishery (Sumich et al. 2013).

When running Monte Carlo simulations to estimate V_t, no data were available to recalculate the relationship of length with age so no uncertainty was estimated for this relationship. However, we assumed length at age varied the same as when calves are born (S.D. = 0.5) and the regression of V_t on E_d and L explains a large and significant portion of the observed variation in V_t, $R^2 = 0.94$ (Sumich 1986).

Calves 3–7 months old and adult females

Since the relationship in Eq. (C1) has not been established for older calves, tidal lung volumes for calves three months old and older, and adult females were estimated using results from a Bayesian analysis of tidal lung volume as a function of mass (M in kg) from published data (Sumich 1986). The relationship between mass (M in kg) and tidal volume was originally calculated by Stahl (1967) for terrestrial mammals (rat-human size range: $V_t = aM^{1.04}$, R = 0.99) and modified by Sumich (1986) for gray whales: $V_t = 0.014 \cdot M^{1.04}$. The constant value of *0.014* was obtained from the relationship between V_t and M of four gray whale calves at 0-3 months old.

$$\ln V_t = \beta_0 + \beta_1 \ln M + \varepsilon \text{ where } \varepsilon \sim N(0, \sigma^2) \qquad \text{(C.2)}$$

The linear regression has three unknown parameters (β_0, β_1, and σ^2). Since data were limited (data from three individuals estimating three parameters), data points were treated as independent instead of creating a hierarchical analysis estimating the relationship for each individual.

Posterior intercept and slope parameters were highly correlated with each other (Table C2), and tidal volume uncertainty was high, particularly for larger calves (Fig. C2). Therefore, we set a conditional upper bound on calf V_t, not allowing a calf's sampled V_t to exceed the sampled V_t of the corresponding mother. Tidal volume of adult females was estimated without uncertainty in parameters since such exponential uncertainty led to almost no resolution in tidal volume for larger animals. Instead, we used joint modal (maximum likelihood) values of β_0, β_1, and the error variance.

TABLE C1. Posterior marginal distributions of parameters relating tidal volume to total body length and expiration duration. $\ln V_t = \beta_0 + \beta_1 \ln L + \beta_2 \ln E_d + \varepsilon$ where $\varepsilon \sim N(0, \sigma^2)$.

Parameter	Marginal mean	Marginal standard deviation	Parameter correlation β_2	β_0	σ^2
β_1	1.73	0.17	-0.522	-0.988	0.005
β_2	1.54	0.06	…	0.614	0.006
β_0	1.30	0.32	…	…	-0.004
σ^2	0.11	0.02	…	…	…

TABLE C2. Posterior marginal distributions of parameters relating tidal volume to mass. $\ln V_t = \beta_0 + \beta_1 \ln M + \varepsilon$ where $\varepsilon \sim N(0, \sigma^2)$.

Parameter	Marginal mean	Marginal standard deviation	Parameter correlation β_0	σ^2
β_1	1.55	0.27	-0.997	-0.014
β_0	-8.39	2.11	…	0.016
σ^2	0.79	0.11	…	…

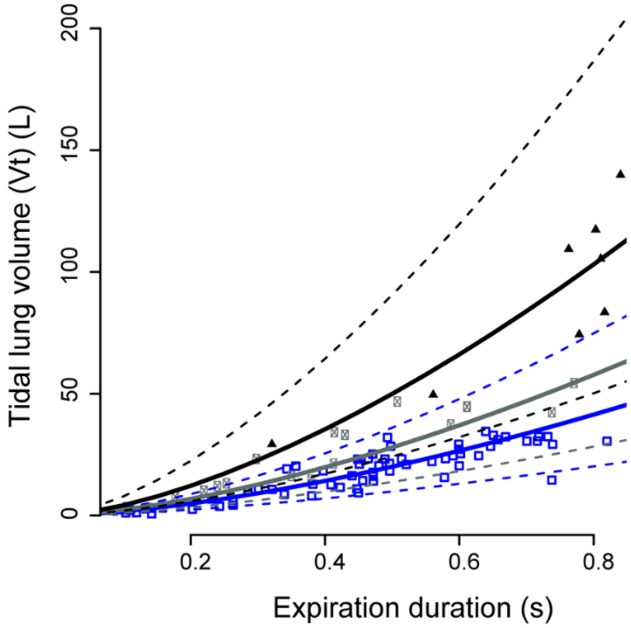

FIG. C1. Tidal lung volume as a function of expiration duration and total body length (Eq. C1). Points are data for three lengths. Open squares identify 4.8 m, solid squares identify 5.8 m and tringles identify 8.0 m. Solid lines are posterior mean values and dashed lines are 95% posterior intervals.

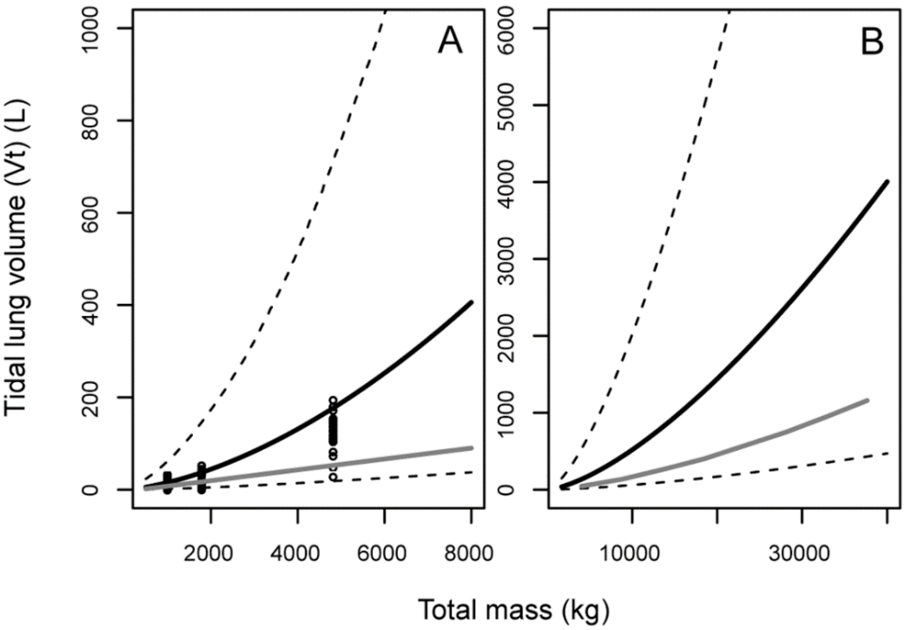

FIG. C2. Tidal lung volume as a function of mass for (A) calves 3+ months old and (B) adult females (Eq. C.2). Points are data for three masses. Solid black line is the posterior mean value and dashed lines are 95% posterior intervals. Solid gray line is an estimate of the modal value of tidal lung volume at a given mass.

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