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SUPPLEMENTARY INFORMATION

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# Fasting season length sets temporal limits for global polar bear persistence

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for

# Fasting season length sets temporal limits for global polar bear persistence

by

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**Supplementary Table 1 | State variables and parameters of the polar bear dynamic energy budget (DEB) model.**

| State variable | Definition | | Units | Notes |
|---|---|---|---|---|
| **Individual level – input variables** | | | | |
| $M_0$ | Total body mass at fast-initiation ($t$=0) | | kg | |
| $L_0$ | Straight-line body length at fast-initiation ($t$=0) | | m | |
| **Individual level – modelled variables*** | | | | |
| $M(t)$ | Total body mass over time | | kg | |
| $L(t)$ | Straight-line body length over time | | m | As we only consider fully grown adults, $L(t) \equiv L_0$ |
| $E(t)$ | Body energy reserves over time | | MJ | |
| **Population level – input variables** | | | | |
| $G_{(M0,L0)}(subpop,year)$ | Distribution of fast-initiating masses and lengths ($M_0$, $L_0$) of all bears in a given subpopulation and year | | --- | |
| **Parameter** | **Definition** | **Estimate** | **Units** | **Source** |
| **Body composition** | | | | |
| $\Phi$ | Proportion of storage mass that is fat | AM#: 0.499<br>AF#: 0.627 | --- | Supplementary Fig. 3 & ref. [53] |
| $\alpha$ | Energy density of a bear's storage mass | AM#: 21.62<br>AF#: 26.14 | MJ kg$^{-1}$ | calculated from $\Phi$ using eqns. 12 and 13A from ref. [53] |
| $\rho_{STR} \cdot k$ | Proportionality constants relating structural mass to straight-line body length | 14.94 | kg m$^{-3}$ | [53] |
| **Somatic maintenance** | | | | |
| $m$ | Energy required to maintain one kilogram of lean tissue for one day | 0.077 | MJ kg$^{-1}$ d$^{-1}$ | Supplementary Fig. 3 |
| **Movement** | | | | |
| $a$ | Postural cost of standing | 0.0820 | MJ kg$^{-1}$ d$^{-1}$ | [56] |
| $b$ | Allometric exponent | 1 | -- | [56] |
| $c$ | Incremental cost of locomotion | 0.0024 | MJ kg$^{-1}$ d$^{-1}$ | [56] |
| $d$ | Allometric exponent | 1 | --- | [56] |
| $v$ | Mean movement speed | 1 | km d$^{-1}$ | assumed |
| **Lactation** | | | | |
| $\lambda$ | Rate of energy allocation to lactation | AFC#: 10.9<br>AFY#: 2.6 | MJ d$^{-1}$ | [19] |

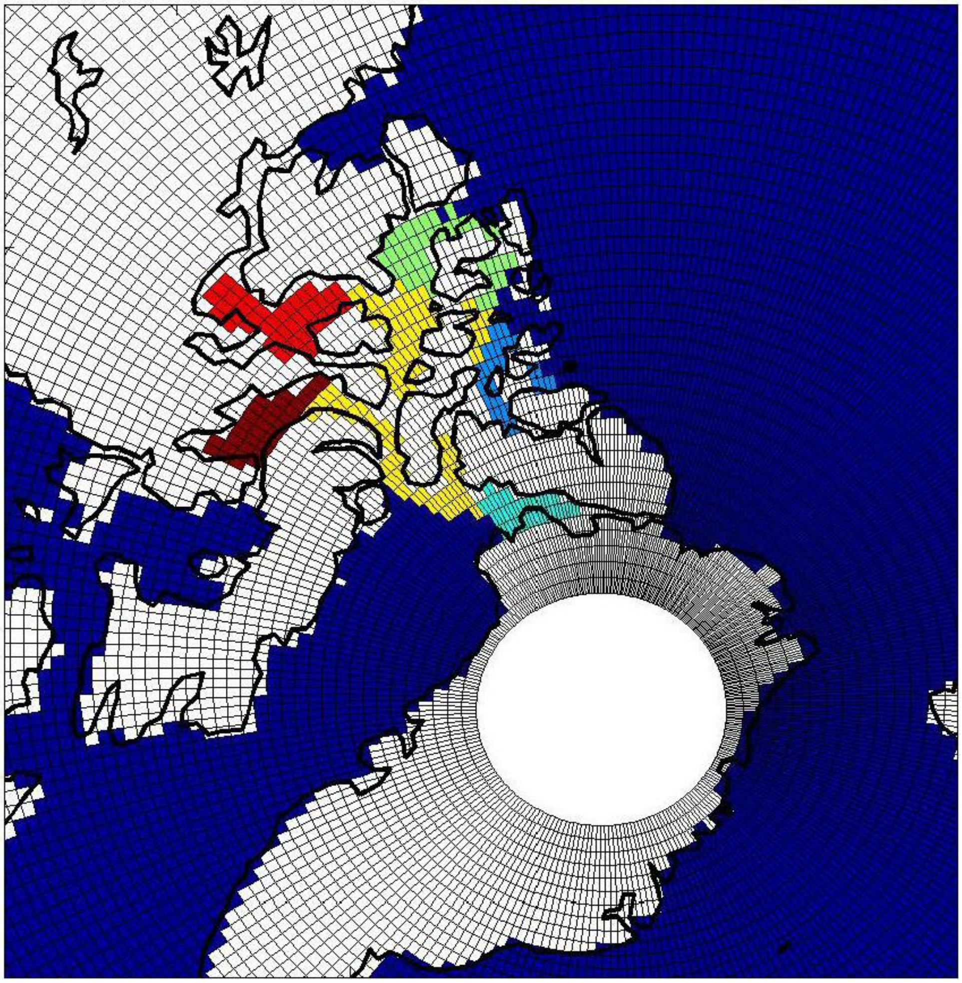
* cf. ref. [53] for a comprehensive list of auxiliary state variables that are also estimated by the DEB model but which are not explicitly reported here (e.g. lean body mass over time, $LBM(t)$).

# AM: adult males; AF: all adult females, whether or not with offspring; AFC: adult females with dependent cubs; AFY: adult females with dependent yearlings

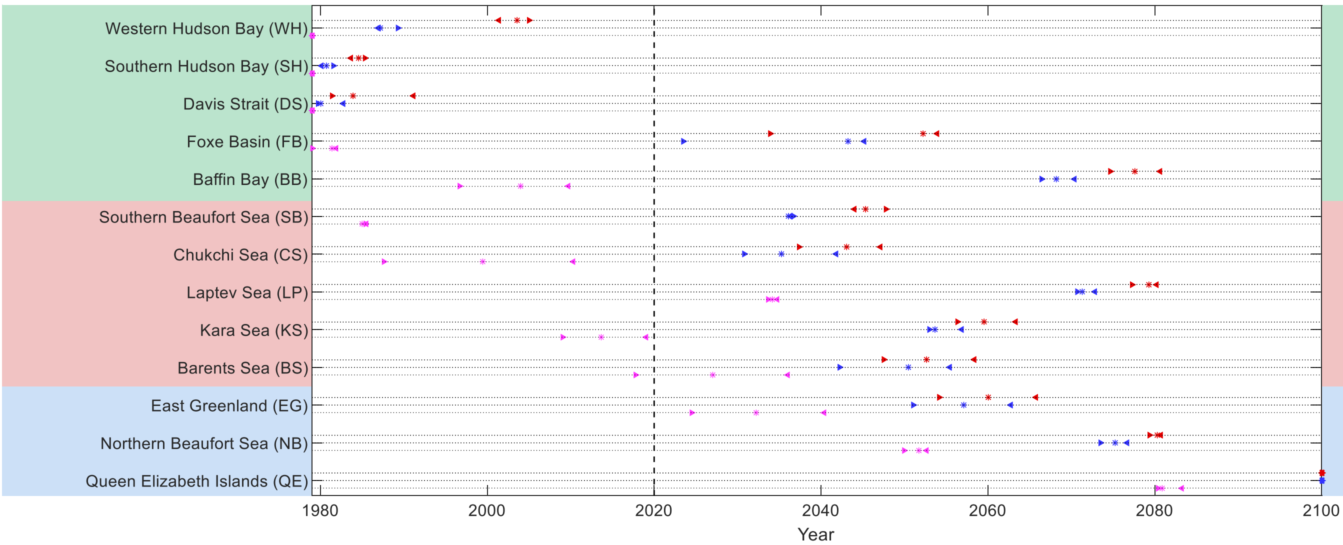
**Supplementary Table 2 | Summary statistics of the body masses and body lengths of polar bears at on-shore arrival in $WH_{89\text{-}96}$, i.e. of $G_{(M0,L0)}(WH_{89\text{-}96})$.**

| | Sample size | Mean $M_0$ ± 1 s.e. (range in brackets) | Mean $L_0$ ± 1 s.e. (range in brackets) |
|---|---|---|---|
| Adult* males | 76 | 476.7 ± 8.6 kg (260-683 kg) | 2.34 ± 0.01 m (2.15-2.49 m) |
| Solitary adult* females | 41 | 289.0 ± 9.3 kg (181-399 kg) | 1.96 ± 0.01 m (1.80-2.10 m) |
| Adult* females with cubs | 61 | 247.0 ± 2.8 kg (186-296 kg) | 1.98 ± 0.01 m (1.86-2.07 m) |
| Adult* females with yearlings | 22 | 239.7 ± 6.3 kg (210-318 kg) | 1.95 ± 0.01 m (1.84-2.07 m) |

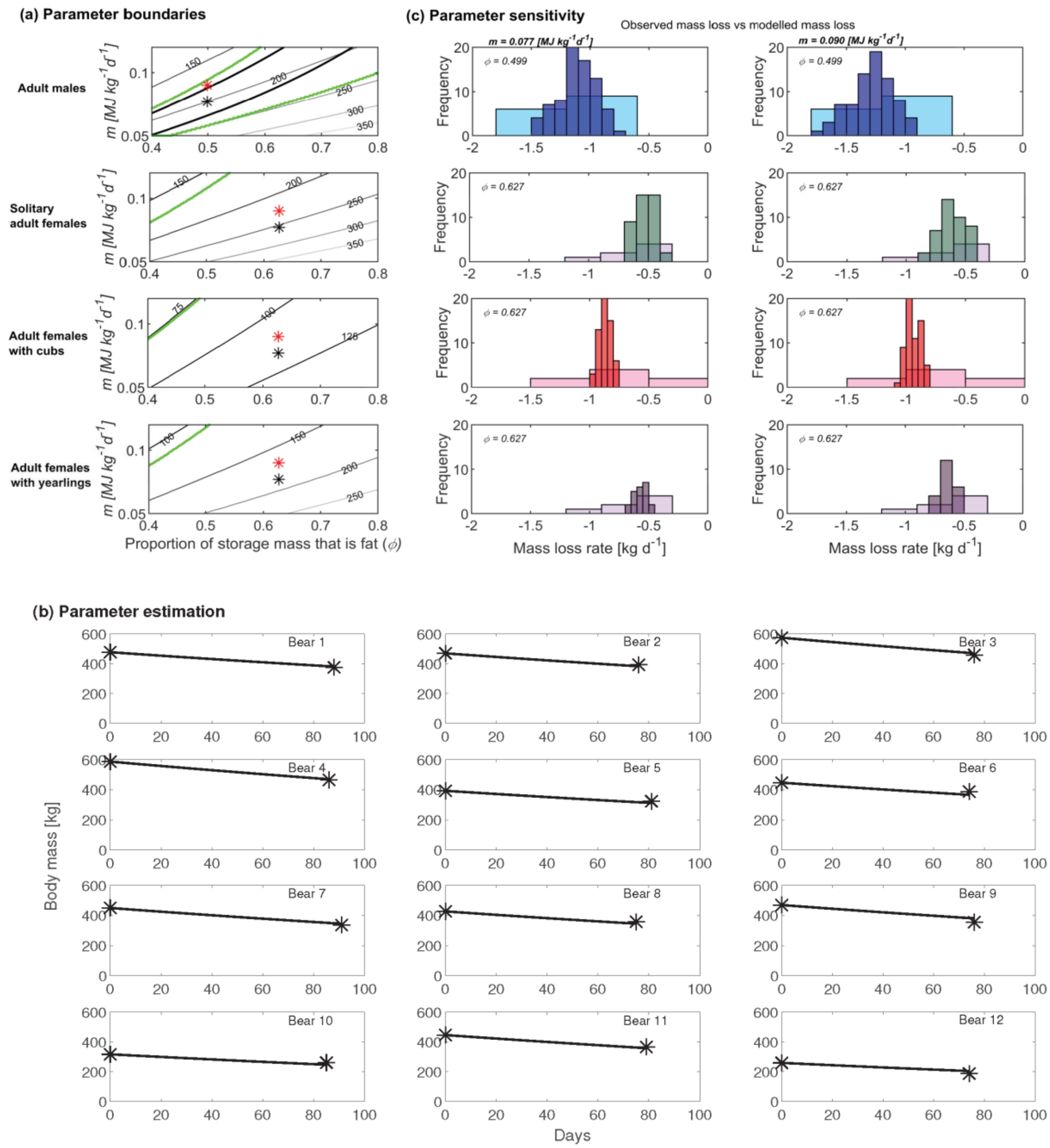
* Males and females are considered adults if at least 7 and 4 years old, respectively, as structural growth is largely completed by this age[22].



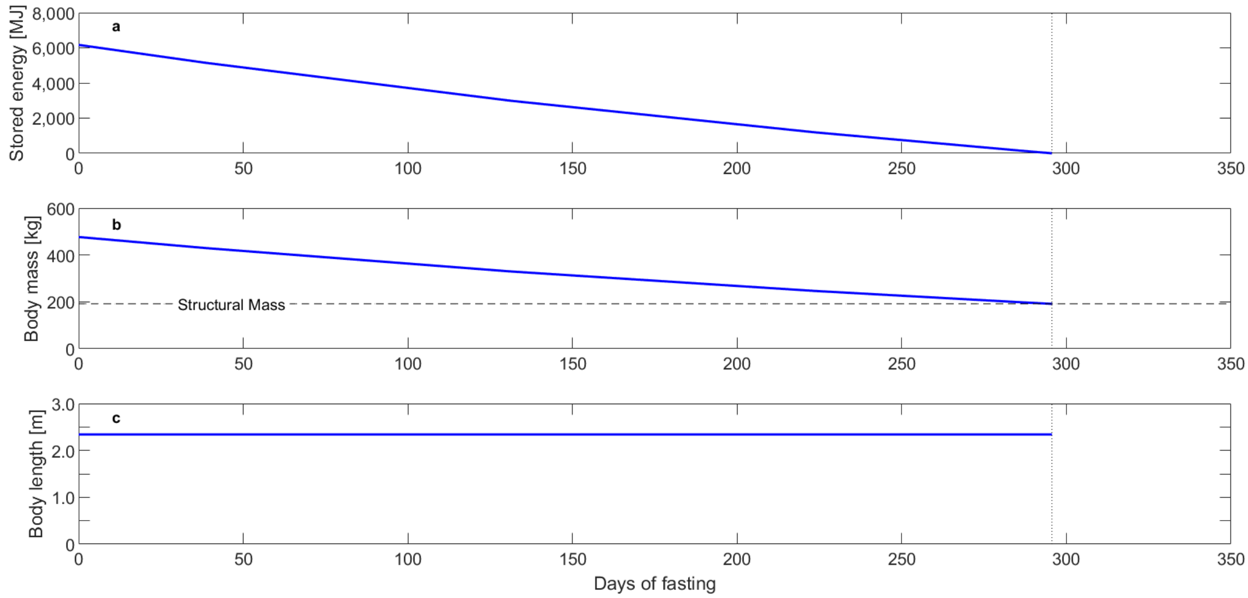
**Supplementary Figure 1 | The ocean and ice grid of CESM1 in the Arctic.** Dark blue indicates an ice/ocean cell, other colors indicate ice/ocean cells for populations in the Archipelago Ecoregion (AE), and white indicates land. Thick black line shows true land contours. Some of the Canadian Archipelago channels in the AE are too narrow to be resolved and are blocked with land in CESM1. Given these blocked channels and the small number of ice/ocean cells for subpopulations in the AE, we excluded AE subpopulation regions from our analysis.



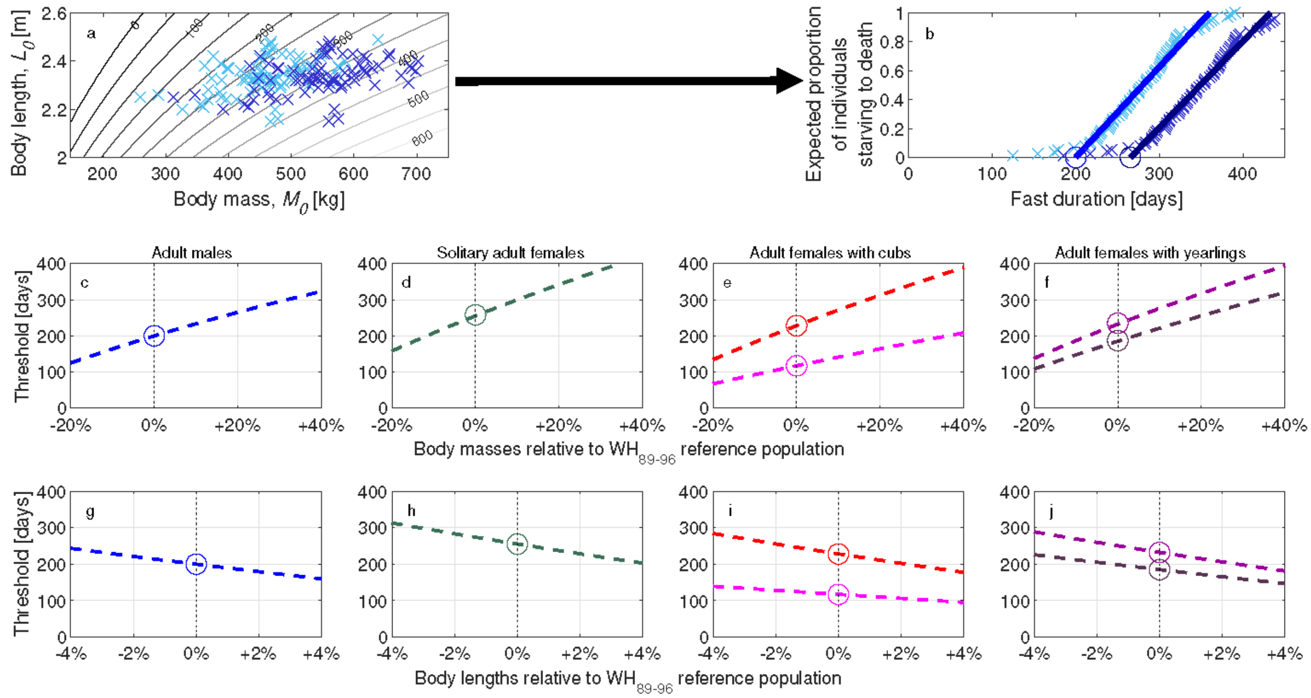

**Supplementary Figure 2 | Sensitivity of the demographic impact analyses to assumptions about the critical sea ice extent threshold that is used for defining the ice-free period length (cf. Extended Data Fig. 1 for the Western Hudson Bay subpopulation region).** The estimated years of first impact on cub recruitment (magenta), adult male survival (blue), and adult female survival (red) are shown for the RCP8.5 scenario for our baseline assumption of a 30% critical sea ice extent threshold (stars) in comparison to assumed critical sea ice extent thresholds of 40% (right-pointing triangle) and 20% (left-pointing triangle), respectively. Offsets for calculating fasting period length from sea ice extent are adjusted for each assumed critical extent to match bear migration dates in Western Hudson Bay, and are 24 days with our baseline assumption (Extended Data Fig. 2), 19 days for a critical sea ice extent threshold of 20%, and 29 days for a critical sea ice extent threshold of 40%. Year of first impact is defined as in Figure 4, and body masses and lengths are assumed to be as in $WH_{89\text{-}96}$.




**Supplementary Figure 3 | Estimation and sensitivity analysis of DEB model parameters.** Given the general data scarcity regarding the energy use and mass loss rates of fasting and resting polar bears, we estimated model parameters using a multistep approach and multiple data sources. First, we determined acceptable boundaries for the key model parameters *m* (energy required to maintain one kilogram of lean tissue for one day) and *Φ* (proportion of storage mass that is fat) by requiring that model simulations for all bears in the $WH_{89\text{-}96}$ sample yielded mass loss rates that fall within the observed ranges of mass loss (green lines, panel a; only the upper boundary is shown for females; the observed mass loss ranges used in these calculations are from the $WH_{89-96}$ data and refs. [19,74,75]: adult males, -0.6 to -1.8 kg $d^{-1}$; solitary adult females, -0.18 to -1.3 kg $d^{-1}$; adult females with cubs, -0.18 to -1.64 kg $d^{-1}$; adult females with yearlings, -0.18 to -1.3 kg $d^{-1}$). Subsequently, we further narrowed the acceptable parameter space by fitting equation (2) to repeated measures of body mass of twelve fasting adult male polar bears using maximum likelihood (panel b), and calculating the best estimate and 95% confidence region for ($m$, $\Phi_{male}$) (black star and thick black lines, panel a). For females, where similar data are unavailable and/or estimations are complicated by unknown reproductive investment (cf. Methods Section "*Estimation of time to death by starvation for individual bears"*), we assumed similar somatic maintenance costs ($m$) as in males but a differing body composition ($\Phi_{female}$) as previously determined in ref. [53] (black stars in panel a). Comparing resultant model projections for the mass loss rates of $WH_{89-96}$ bears (darker color, panel c) against the observed mass loss rates of those $WH_{89-96}$ bears that had two or more body mass measurements at least twenty days apart within the same fasting season (lighter colors, panel c), revealed accurate projections for males but possibly underestimated mass loss rates for females. Thus, we also explored the sensitivity of our impact thresholds (contour lines, panel a) and model projections by considering the highest possible $m$ (red stars, panel a) that still yields acceptable mass loss rates in all bear groups in combination with their sex-specific $\Phi$ (panel c). See Extended Data Figure 9 for the corresponding demographic impact analyses.




**Supplementary Figure 4 | Example DEB-model estimates for changes in the body energy reserves, body mass, and body length of an adult male polar bear through the course of a prolonged fast that ends with death.** Starting values were chosen as $M_0$ = 476.7 kg and $L_0$ = 2.34 m (the $WH_{89\text{-}96}$ means), implying initial energy stores of $E_0$ = 6,168 MJ. (a) Declines in body energy reserves over time; death occurs after 295.6 days (vertical dotted line) when zero energy remains; (b) Corresponding declines in body mass over time; at death (vertical dotted line), total body mass equals structural mass (191.4 kg for this bear; dashed line); (c) Body length remains constant as adult males have already completed structural growth.




**Supplementary Figure 5 | Sensitivity of the survival and recruitment impact thresholds to changes in body mass or body length.** The first row illustrates the method of the sensitivity analysis using the example of adult males that are 20% heavier than adult males in $WH_{89-96}$ but of similar length (i.e. structural mass[53]). (a, b) As Fig. 2a,d, but including starvation time analyses and threshold estimates both for $WH_{89-96}$ adult males (light blue) and when assuming 20% greater body mass for all individuals (dark blue). Second and third rows: sensitivity of survival and recruitment impact thresholds when either (c-f) body masses, or (g-j) body lengths, are varied (sensitivity analyses of the impact thresholds to simultaneous changes in body masses and body lengths are shown in Extended Data Figure 5). Panels (c-f) are the same as Figure 2f, g and Extended Data Figure 4f, g, but are replotted here to enable visual comparison with the threshold sensitivities to body length. Circles highlight the baseline thresholds estimated for $WH_{89-96}$. (c, g) Adult male survival impact threshold; (d, h) solitary adult female survival impact threshold; (e, i) and (f, j) upper and lower estimates for the survival impact threshold of adult females with cubs and yearlings, respectively; of these, the lower estimates double as recruitment impact thresholds. Boundaries of the sensitivity analyses were chosen to encompass among-subpopulation variation in body masses and length[22,68] (Extended Data Fig. 7).

## Supplementary References

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