Supplementary Materials for

Summer Declines in Activity and Body Temperature Offer Polar Bears Limited Energy Savings

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Materials and Methods

Captures

Helicopter captures were performed in 2008 (August, October), 2009 (April–May, August, October), and 2010 (April–May). We searched for bears along the coast, on barrier islands, and up to 150 km offshore on sea ice (when present) between Barrow, Alaska (71°N, 157°W) and the Alaska-Yukon Territory border (69°N, 141°W). In October 2009 we also captured bears on sea ice between 70–79°N and 132–170°W, from the US Coast Guard Cutter *Polar Sea*. We immobilized bears with a mixture of tiletamine hydrochloride and zolazepam hydrochloride (Telazol; Warner-Lambert Co., Morris Plains, NJ) at estimated doses of 6 mg/kg of body mass, delivered in projectile syringes fired from a dart gun (*33*). During immobilization and processing we monitored rectal temperature and respiration rate. We weighed bears by suspending them in a net from a digital load scale hoisted from a tripod. Age was determined by counting cementum annuli in extracted vestigial premolars (*34*). Procedures for capturing, sampling, and instrumenting bears were approved by institutional animal care and use committees at the University of Wyoming and US Geological Survey (USGS) Alaska Science Center, and permitted by the US Fish and Wildlife Service (USFWS; Permit #MA690038). Use of trade names is for descriptive purposes only and does not imply endorsement by the US Government. This research was funded in part by the US Environmental Protection Agency (EPA) but because it was not reviewed by the EPA, no official endorsement should be inferred.

Location transmitters and collar data

Bears were instrumented in April–May (2009) and August (2008, 2009) and recaptured in October or the following spring. At recapture, instrumentation (see below) was retrieved and animals were released. Bears received one of four possible telemetry transmitters, either attached to collars (models TGW-3680 or TGW-4689H; Telonics, Mesa, AZ) or glued to the fur (SPOT or MK-10; Wildlife Computers, Redmond, WA). Collars automatically released 3–7 months after deployment and transmitters attached to fur detached during the molt or earlier. Collars recorded locations with Global Positioning System (GPS) technology (hourly; estimated error < 31 m; *35*) or Doppler technology (typically every two days; estimated error: < 400 m, class 3; 401–1000 m, class 2; 1001–2499 m, class 1; *36*). Glue-on transmitters were Doppler only. Limits to Argos satellite downloads yielded incomplete location datasets (*36*). Complete records were obtained from GPS collars retrieved from recaptured bears ($n = 17$).

Both collar models were equipped with a temperature sensor (measurements every 30 or 60 minutes, resolution 1°C). TGW-4689H also included an internal accelerometer, sensitive to motion in 3 planes, which recorded the total number of seconds of activity during the previous thirty minutes, every half hour. To 16 collars we attached an external accelerometer (Actiwatch; Mini-Mitter Respironics, Bend, OR) sensitive to motion in all planes, which recorded an acceleration score (a unitless index of acceleration intensity) every 2 minutes (*37*).

Temperature logger data

For recording abdominal temperature we used iButton (DS1922L, hourly measurements, resolution 0.0625°C; Maxim Integrated, San Jose, CA) loggers coated with impermeable paraffin wax and attached to a loop of sterile suture (0 gauge, non-dissolvable). Loggers were implanted into five bears fitted with location transmitters and activity loggers, and five bears with transmitters only. We shaved an area 10 × 6 cm on the ventral midline of each bear, approximately 80% of the distance from the xiphoid process to the umbilicus. We injected 1 mL of xylocaine into subcutaneous tissue throughout the shaved region, scrubbed the skin and surrounding fur with povidone-iodine. We then used sterile surgical tools to make a 7 cm incision through skin and subcutaneous adipose tissue to expose the linea alba. We made a 5 cm incision through the linea alba, pushed the logger through the incision and off to the side, and secured the logger to the underside of the linea alba, adjacent to the peritoneum, with a single stitch using the loop of suture. We closed the linea alba with interrupted single stitches, the adipose tissue with continuous stitches (00 gauge suture), and the skin with interrupted cruciate or mattress stitches. We used identical surgical procedures when recovering the loggers from recaptured bears.

Abdominal temperatures closely reflect intraperitoneal, or “core” temperature. In previous studies, measurements of abdominal temperature of polar bears (recorded from loggers in the same anatomical location as in our study; *38*, *39*) were nearly identical to intraperitoneal temperatures of polar bears in other studies (*22*, *40*). The peritoneum itself tends to be very thin (< 1 mm in humans; *41*) and offers little insulation.

To record rump temperature, we used Tidbit V2 loggers (measurements every 5 or 10 minutes, resolution 0.02°C; Onset Computer Corporation, Bourne, MA) coated with wax and attached to a loop of sterile suture. Loggers were implanted in seven bears instrumented with transmitters and activity loggers. As described in Durner et al. (*6*), we made an incision through the skin approximately 15 cm to one side and 5 cm ventral of the base of the bear’s tail. We separated the subcutaneous adipose tissue and secured the logger to the surface of the gluteus maximus muscle using the loop of suture. Loggers were recovered using identical procedures.

After abdominal and rump loggers were retrieved, we placed them in a temperature-controlled chamber (CL-740A; Omega Engineering Inc., Stamford, CT) and created 4–5 point calibration curves for the range of temperatures recorded from each bear. Next, we left loggers in an environmental chamber (Conviron, Pembina, ND) held at a steady temperature for eight weeks and confirmed that measurements did not drift over time.

Calculating smoothed body temperatures

We created smoothed values of abdominal and rump temperatures using seasonal trend decomposition with the “stl” (seasonal trend loess) command in the base statistical package in Program R (*54*). The seasonal window was periodic and the loess window was 25% of the average sample size of bear records extending from May to October.

Comparing data from bears on shore and ice

To ensure capture effects and incision healing did not influence results, for all analyses we censored all data collected within 120 hours (5 days) after capture, encompassing the period during which polar bears return to regular movement patterns (*42*, *43*), and within 1 hour prior to recapture. Data of movement rate, acceleration scores, collar temperature, rump temperature, and body mass for bear 20741, which engaged in a nine-day swim in August–September 2008, were previously reported in a companion study (*30*). Such a reported long-distance swim is unique (*13*) thus we excluded these data from calculations and statistical tests of mean movement rate and activity (Fig. 2 and table S1). However, we used these data in models to identify the variables that predicted acceleration scores (table S3) and to evaluate the relationship between acceleration scores and body temperatures (table S5).

To assess activity trends over time, we calculated a single activity variable: the proportion of time spent active. To derive this proportion from measurements of the number of seconds of activity per 30 minutes, we divided the count by 1800. For acceleration scores, we first converted the scores to the number of seconds of activity per 30 minutes. To achieve this conversion, we calculated a mean acceleration score in half-hour blocks. Next, we pooled data for seven bears which had both types of activity measurements and regressed the number of seconds of activity during the previous half hour against the mean acceleration score for that half-hour (total pooled measurements, n = 27,579). The relationship appeared linear for small values but increasingly non-linear at high values, thus we used automated segmented regression (*44*) and identified a mean acceleration score of 1128 as the breakpoint between linear segments (fig. S4A). For scores below this value, the two types of activity data were related by this equation:

N = number of seconds of activity over the previous half-hour
M = mean acceleration score over the previous half-hour
$N = (M \times 0.838) + 38.645$

All monthly means of 30-minute mean acceleration scores were < 1128, thus we used the above equation to convert these data into monthly means of the number of seconds of activity over the previous half-hour. For bears with both types of activity data, the monthly means of the proportion of time spent active based on measured seconds of activity were similar to the monthly means of the proportion of time spent active based on acceleration scores converted to seconds of activity (n = 30, pooled data from seven bears; fig. S4B). This indicates the converted data adequately represents the time spent active.

We calculated monthly means of the time spent active (after pooling measured and converted data), movement rate, and smoothed abdominal temperature for each bear, for each month in which it had ≥ 96 hours of measurements. Each monthly mean was categorized as “Shore” or “Ice” based on GPS and Doppler (class 2 and 3) locations. Three bears with location and activity data moved between habitats in July–October, and we calculated a monthly mean for both Shore and Ice accordingly. We compared Shore and Ice monthly means where $n \geq 3$ for each group, using the Welch t-test (*45*).

Modeling influence of environmental variables on activity

We used ARIMA (autoregressive, integrated, moving average) approaches (“arima” command, base statistical package in Program R; *46*) to model the influence of three environmental predictor variables on both types of activity data: daily mean of the number of seconds of activity per half-hour, and daily mean of the acceleration scores. Individual models were built for each bear.

The first model (ARIMA structure [1,0,1]) was built with the predictor "Whale" (only applied to bear locations on shore), a variable between 0–1, describing the daily proportion of hourly GPS locations < 500 m from the site of a whale carcass, ≤ 60 days after the landing of a whale at that site (*47*, *48*). Although bears may scavenge on these carcasses year-round (*49*), they likely consume the majority of tissue shortly after whales are landed (*50*).

In the second model (ARIMA structure [1,0,1]) we used the predictor "Air Temperature" (only applied to locations on shore), a daily mean of hourly air temperatures recorded < 200 km from each bear location at Alaskan weather stations in Kaktovik, Deadhorse, or Barrow (www.weatherspark.com).

In the third model (ARIMA structure [1,0,1]) we used the predictor "Shelf" (only applied to locations on the sea ice), a binary variable indicating whether the daily mean bathymetry value of bear locations was ≥ 300 m. Shelf edges are abrupt in this region of the Arctic and habitat studies indicate that bears select for shallow waters (*51*, *52*). Water depths at bear locations were assigned based on the International Chart of the Arctic Ocean 3.0 (*53*).

<u>Correlating activity and body temperatures</u>

Abdominal temperature was recorded hourly and rump temperature every 5 or 10 minutes, but neither was synchronized with the hourly measurement of other variables (e.g., seconds of activity in the previous half-hour). Thus, for correlating temperatures with activity, we used linear interpolation to estimate body temperatures at the exact time activity was measured.

We evaluated the correlation between activity and body temperatures using seemingly-unrelated-time-series models, with commands in the "dlm" (dynamic linear models) package in Program R (*55*, *56*). Models were developed, by bear, with two activity variables matched with interpolated values of the two body temperature variables (abdominal and rump temperature) at an hourly scale. Activity included: a) seconds of activity in the previous half hour, and b) mean acceleration score over the previous half hour.

For these models we used adjusted abdominal and rump temperatures, which only included interpolated values within 4 SD of the smoothed temperature; this excluded most outliers of cold temperatures recorded during swimming events (described below). The initial models correlating both measures of activity to rump temperature were unstable and could not provide inferences, likely because rump temperature declined substantially during some periods of inactivity. Thus, we censored the data to only include rump temperature measured when the mean acceleration score during the previous half-hour was ≥ 30. We used mean acceleration scores because all bears with rump temperature measurements had these data, but not all had measurements of number of seconds of activity. We selected this cutoff (≥ 30) after inspecting the data and observing periods of several hours where scores were mostly 0, indicating motionless bears, but which were interrupted by occasional large acceleration scores (e.g. up to 100), likely representing resting interspersed with small movements such as grooming. We reasoned that half-hour means of scores recorded during resting were unlikely to exceed 30. Pooled half-hour means of acceleration scores from all bears ranged from 0–4933, with a grand mean (95% CI) across all bears of 454 ± 6.

Cold abdominal and rump temperatures during inactivity and swimming

We identified periods of inactivity as ≥ 2 hours with mean hourly movement rate < 0.01 m/s and mean acceleration scores < 30, and during these periods we counted the instances of hourly, interpolated abdominal and rump temperatures that were < 35.0°C. We used interpolated temperature measurements to match the timing of recording of movement rates and activity.

We identified periods of swimming from locations in open water, or time periods occurring between sequential locations moving to or from an island. All identified swimming events occurred near shore during summer, reducing the potential for occurrence of ice floes large enough for bears to walk on but small enough to escape satellite detection. We verified that during each swim, surrounding water had no sea ice and collar temperatures were between -3°C and +12°C, the range of feasible temperatures of surface water in this region of the Arctic. If a swim began between hourly locations, we evaluated acceleration scores during that period. The start of a swim was marked by elevated, steady scores with little variation. The end of a swim was typically marked by a sudden increase in variability of scores, likely reflecting a bear shaking or rolling on the ground or ice to shed water from its fur. During periods of swimming, we counted the instances of abdominal temperature (measured hourly) and rump temperature (measured every 5 or 10 minutes) that were < 35.0°C. Many potential swimming events were discarded because they did not meet all criteria. Similarly, we did not attempt to identify swimming events for bears on the sea ice because ice data were too coarse to determine whether bears were walking on ice or swimming between floes.

Evaluating the cooling rate of abdominal loggers

The maximum passive cooling rate of tissue occurs after death, and equations describing cooling of human cadavers are used to estimate time of death in forensic sciences (*57*). These equations have been modified to reflect cooling after death of marine mammal carcasses, using experimental data collected from intraperitoneal loggers implanted into California sea lion (*Zalophus californianus*) carcasses immersed into temperature-controlled water (*58*). Agreement between modeled and experimental data indicates that the primary influences on cooling rate are carcass size and water temperature (*58*), suggesting that these equations can reasonably be applied to polar bears. We calculated a theoretical cooling curve for bear 21150, under the pretense that it died on October 3^{rd}, using these assumptions: bear temperature at time of death of 38.0°C, matching the actual abdominal temperature recorded at that time; body mass of 174 kg, based on a linear rate of change between August 10^{th} (when this bear was measured at 123 kg) and October 18^{th} (measured at 188 kg); and immersion in moving water of 4°C (typical coastal Arctic sea water in summer). We compare the theoretical curve to observed data from the live bear in Fig. 4.

Supplementary Text

Estimating heat loss and skin temperature of polar bears while swimming

We calculated surface area of a bear as 0.09/(body mass in kg)$^{0.67}$ and assumed 98% of that area (everything but the head) was submerged (*59*). Heat losses from the head (radiative, convective, respiratory) were ignored, as they have been shown to be minor (*22*, *59*) in comparison to conductive heat loss in water. We assumed the water temperature was 4°C, the bear was swimming at the typical rate of 0.56 m/s (*13*), and conductance across the skin and fur was 128.6 $W/m^2/°C$. The latter is based on an increase in conductance across polar bear skin and fur (summer pelage) of 3.4×10^{-4} $calories/cm^2/second/°C$ for every 0.1 m/s increase in water speed (*60*). In calculations we varied the skin surface temperature from 5°C to 30°C.

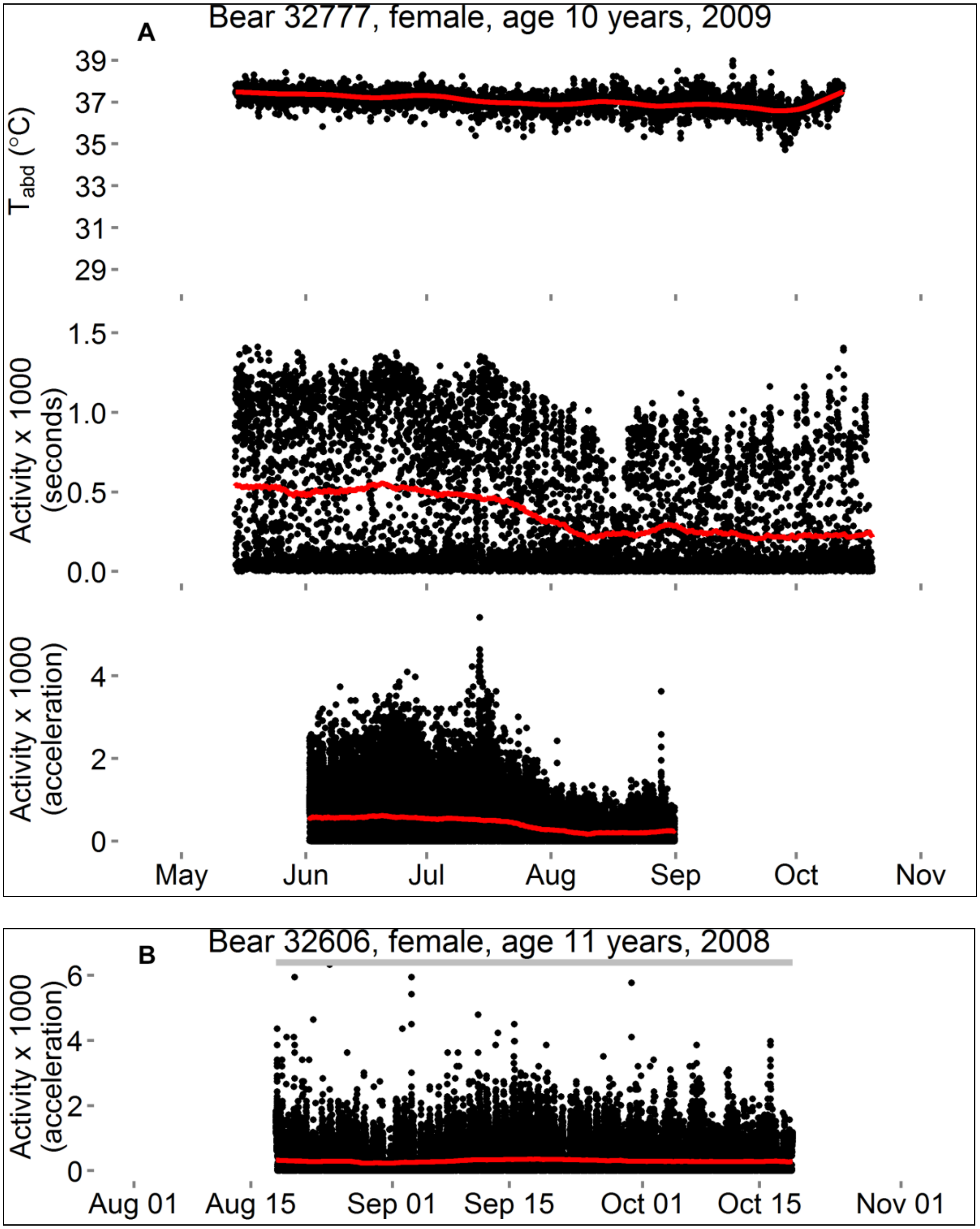
Polar bears swim using alternate pectoral paddling, which is more efficient than quadrapedal paddling (*61*). Polar bear metabolic rates while swimming have not been measured, but may be similar to their metabolic rates while walking. For ferrets (*Mustela putorius furo*), the only other mammal known to predominantly use alternate pectoral paddling, rates differ by < 15% between swimming and walking (*61*, *62*). In a previous captive experiment, 125-kg and 155-kg polar bears had metabolic rates of 125 W and 175 W at rest, and 528 W and 891 W when walking at 1.0 m/s (*63*). Under the assumption that metabolic rates of walking and swimming are identical, linear interpolation yields rates of 351 W and 576 W for travel at 0.56 m/s. The mean mass-specific cost at this swimming speed is thus 2.79 W/kg, and a 300-kg bear would then have a metabolic rate of 837 W. Under these assumptions, bears require skin surface temperatures < 6°C to avoid conductive heat losses that exceed metabolic heat production (fig. S5).

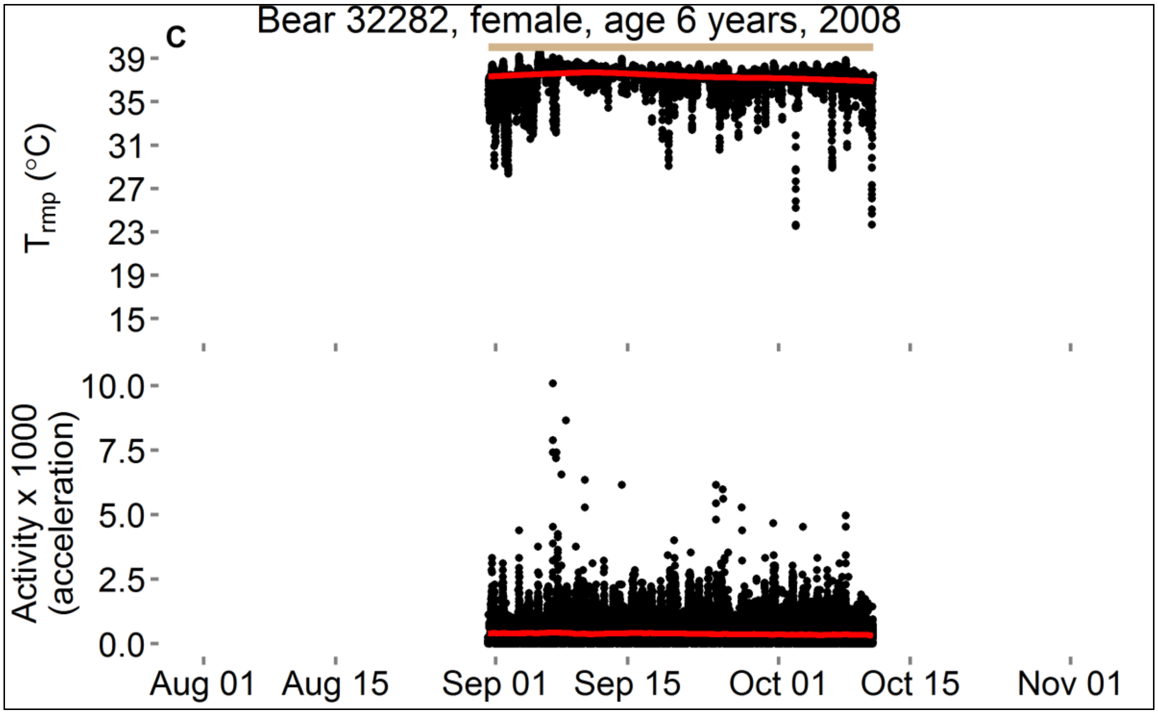
Body temperature during pregnancy and winter hibernation

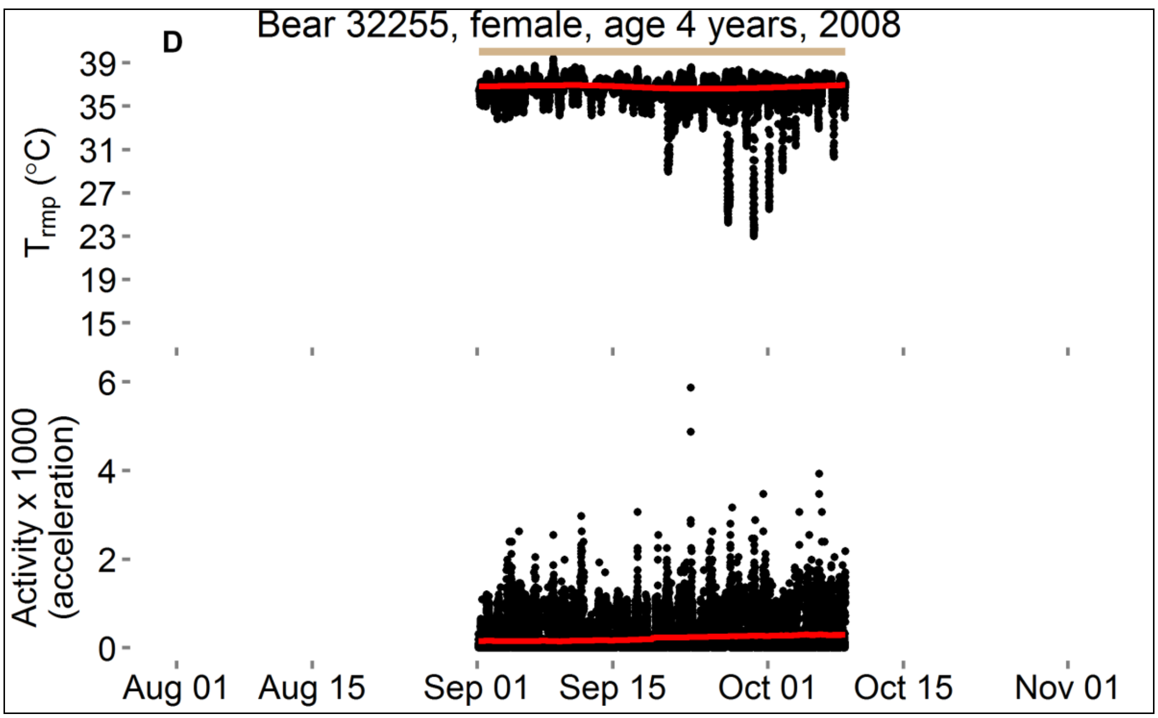
Bear 20529 was implanted with an abdominal temperature logger on August 11th 2009 and poor weather prevented her recapture in October. She was recaptured with two cubs-of-the-year on April 5th 2010. Her logger ceased recording when the memory filled on January 19th. Her temperature profile is shown in figures S1 and S2B. Similar to other bears, her temperature declined through August until mid-September. It then abruptly increased in early October, suggesting blastocyst implantation and the need for high and stable temperatures during fetal development (*26*, *64*). She likely entered a maternity den on November 3rd, as indicated by Doppler locations clustered in the same area from November 3rd to 23rd, when the location transmitter failed. Her temperature declined slightly through November then fell abruptly around November 28th, suggesting a 55–60 day gestation with a small and progressive reduction in core temperature, identical to brown bears (*26*). From December 6th to January 19th, her mean (± 95% CI) hourly temperature was 35.0°C (± 0.02°C).

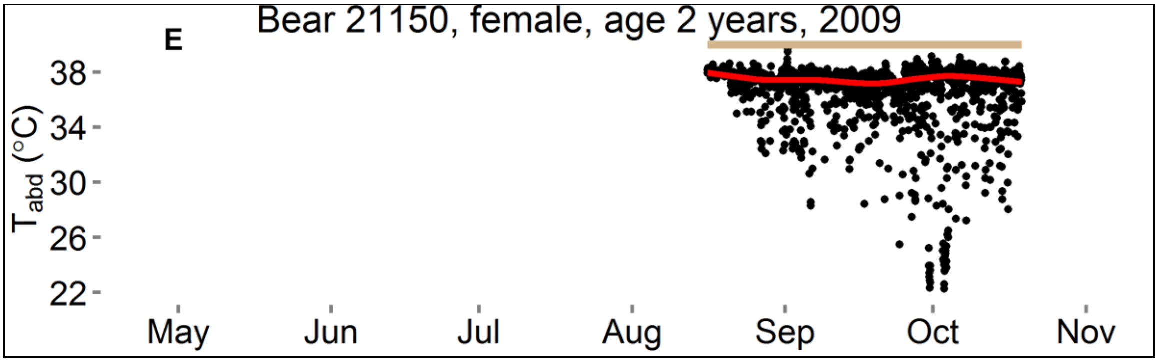
Describing greater temperature swings in the rump than in the abdomen

The mean of the maximum hourly increase recorded by rump loggers (+11.8°C; from n = 7 bears) was greater than the mean of the maximum hourly increase recorded by abdominal loggers (+5.0°C; n = 10), based on a Mann-Whitney Rank Sum text (p = 0.003, U = 4.0, T = 94.0). Similarly, the mean hourly decrease was also larger for rump (-10.4°C; n = 7) than abdominal (-5.0°C; n = 10) loggers (t-test, p = 0.006, t = -3.23, df = 15).

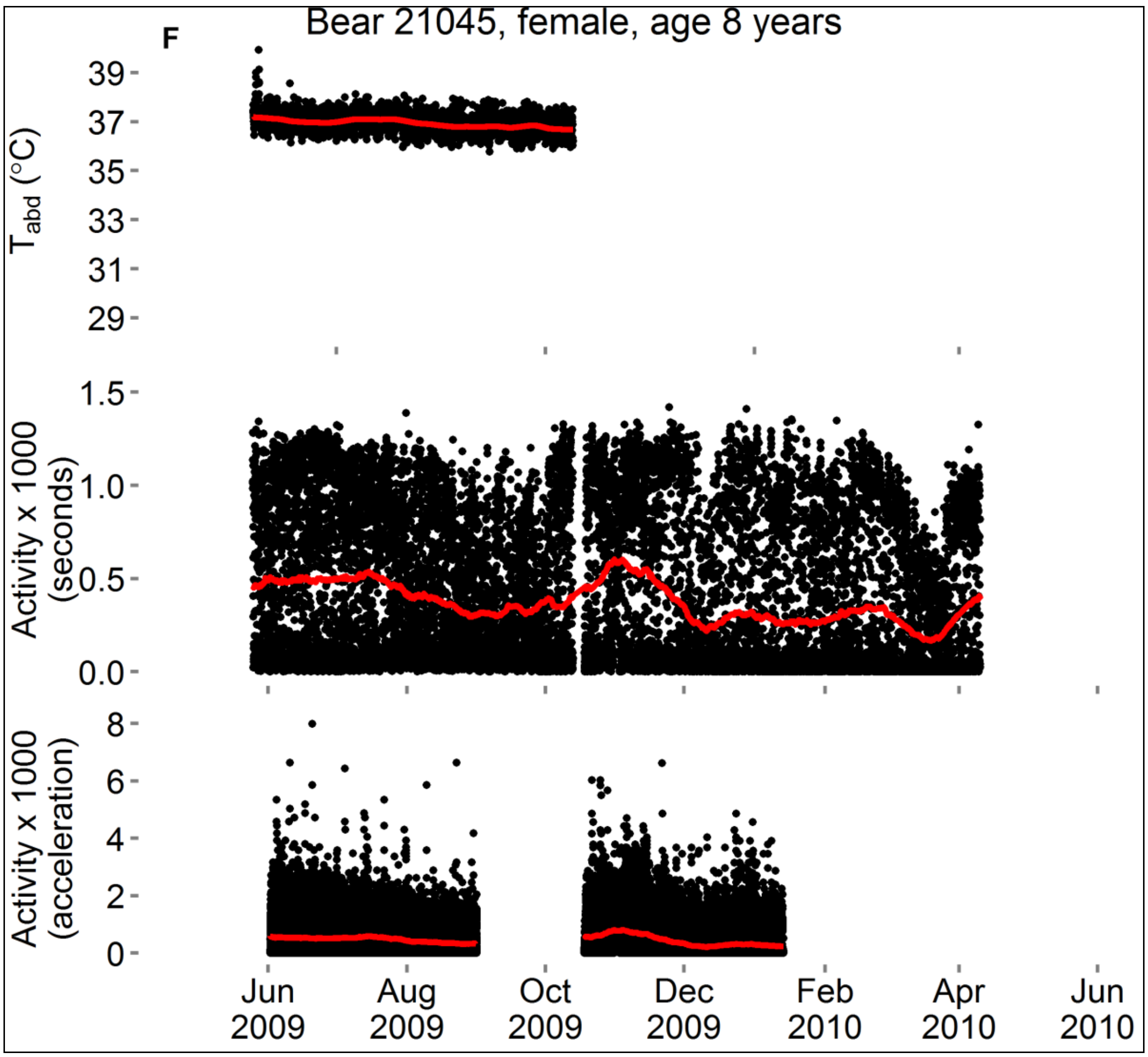

A
Bear 32777, female, age 10 years, 2009
T_{abd} (°C)
39
37
35
33
31
29
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
Activity x 1000 (acceleration)
4
2
0
May
Jun
Jul
Aug
Sep
Oct
Nov
B
Bear 32606, female, age 11 years, 2008
Activity x 1000 (acceleration)
6
4
2
0
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01


Bear 32282, female, age 6 years, 2008
C
T_{rmp} (°C)
39
35
31
27
23
19
15
Activity x 1000 (acceleration)
10.0
7.5
5.0
2.5
0.0
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01

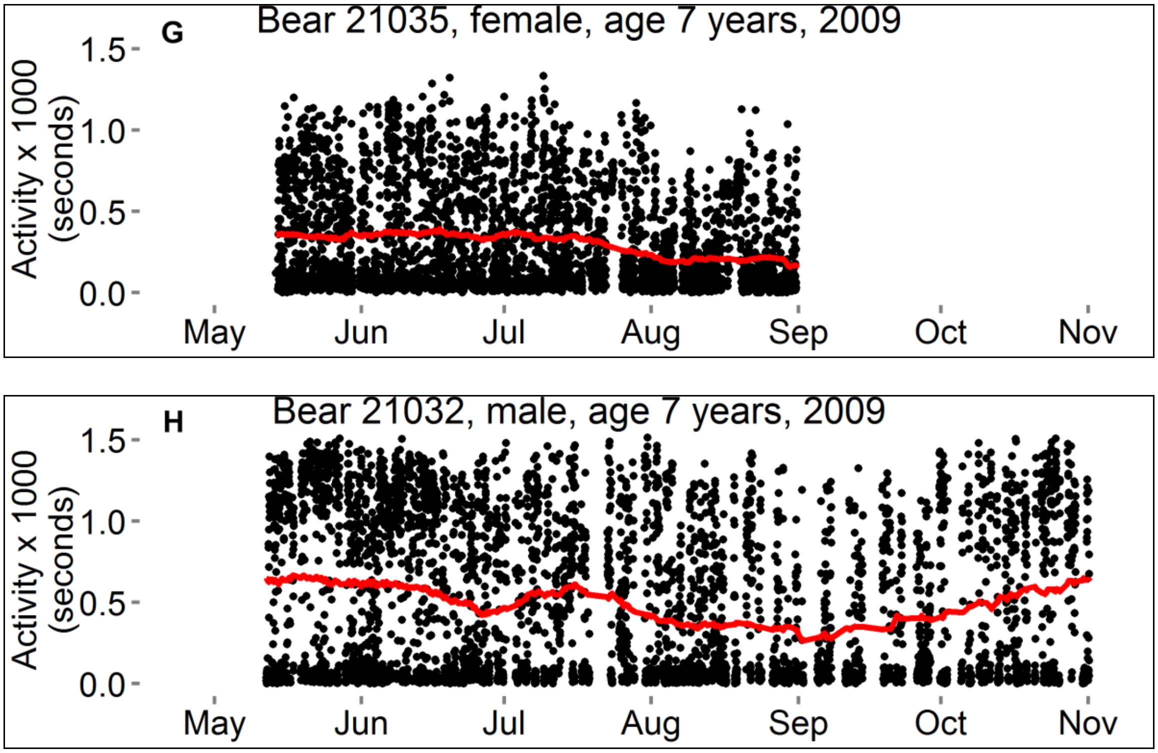

Bear 32255, female, age 4 years, 2008
D
T_{rmp} (°C)
39
35
31
27
23
19
15
Activity x 1000 (acceleration)
6
4
2
0
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01

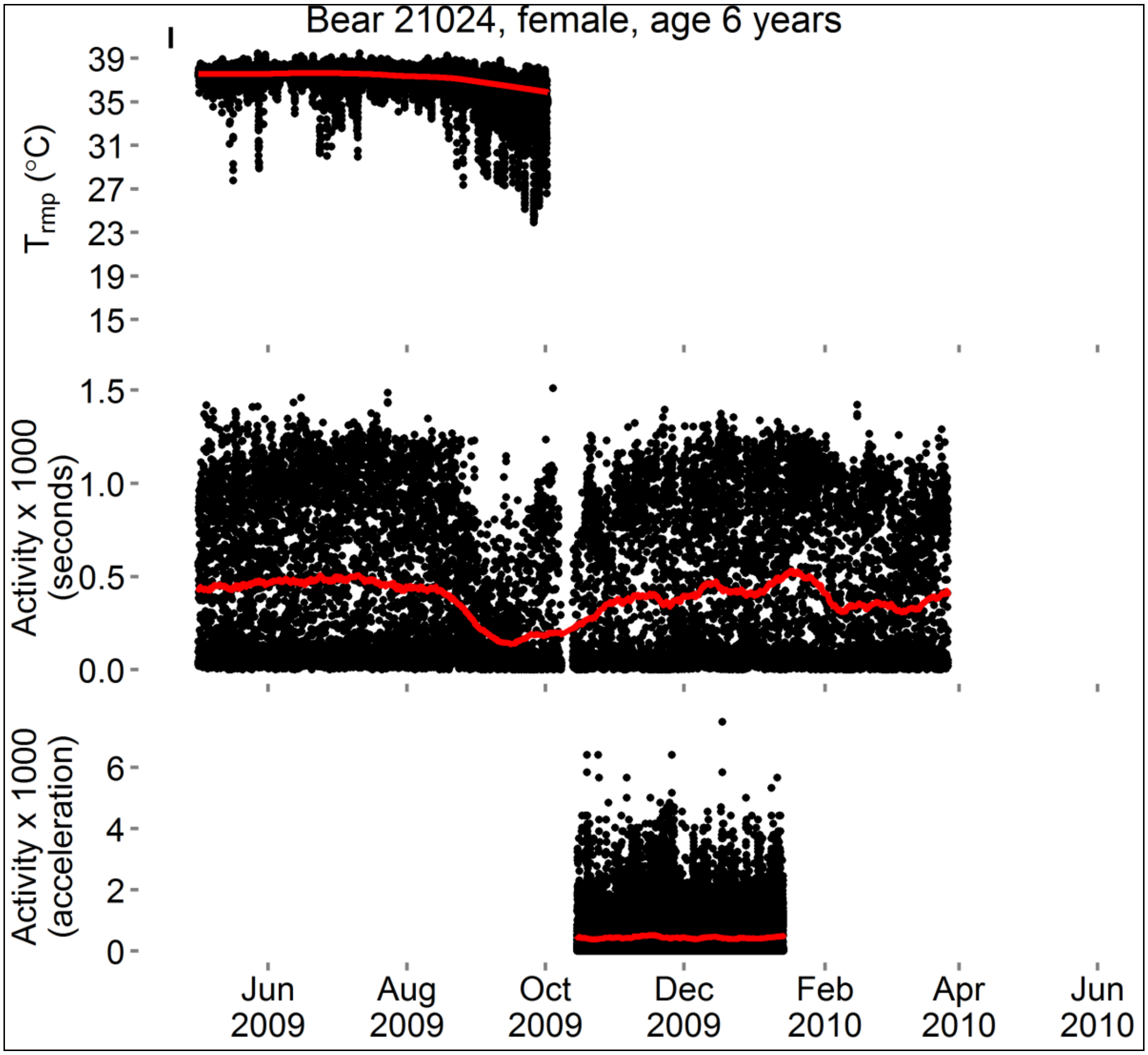


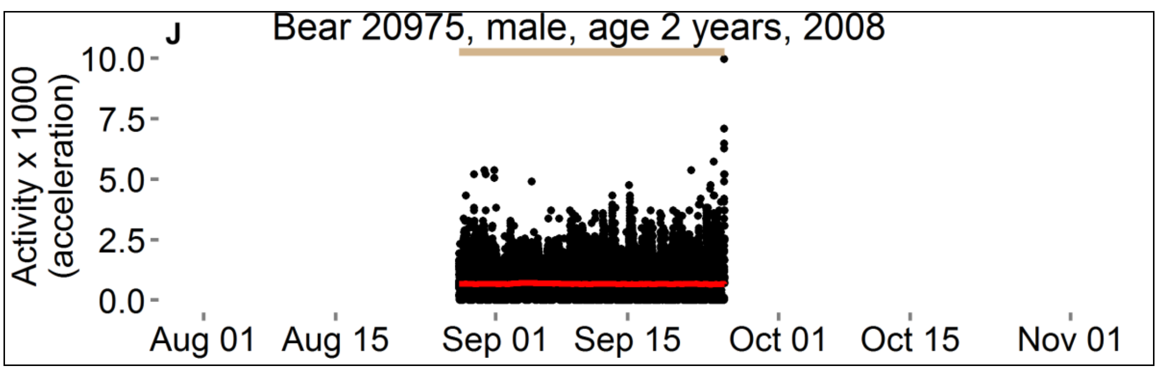
E
Bear 21150, female, age 2 years, 2009
Tabd (°C)
38
34
30
26
22
May
Jun
Jul
Aug
Sep
Oct
Nov

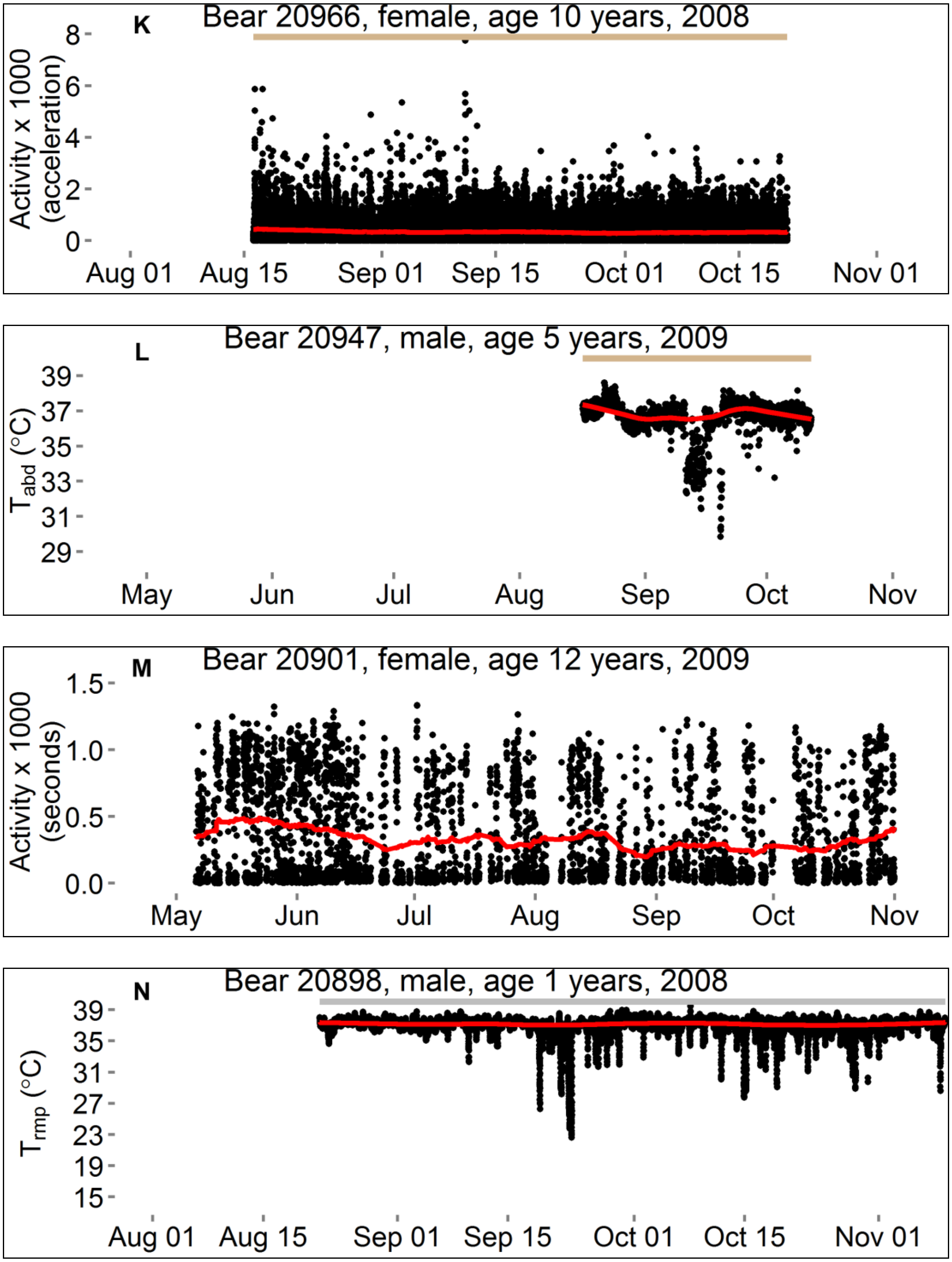


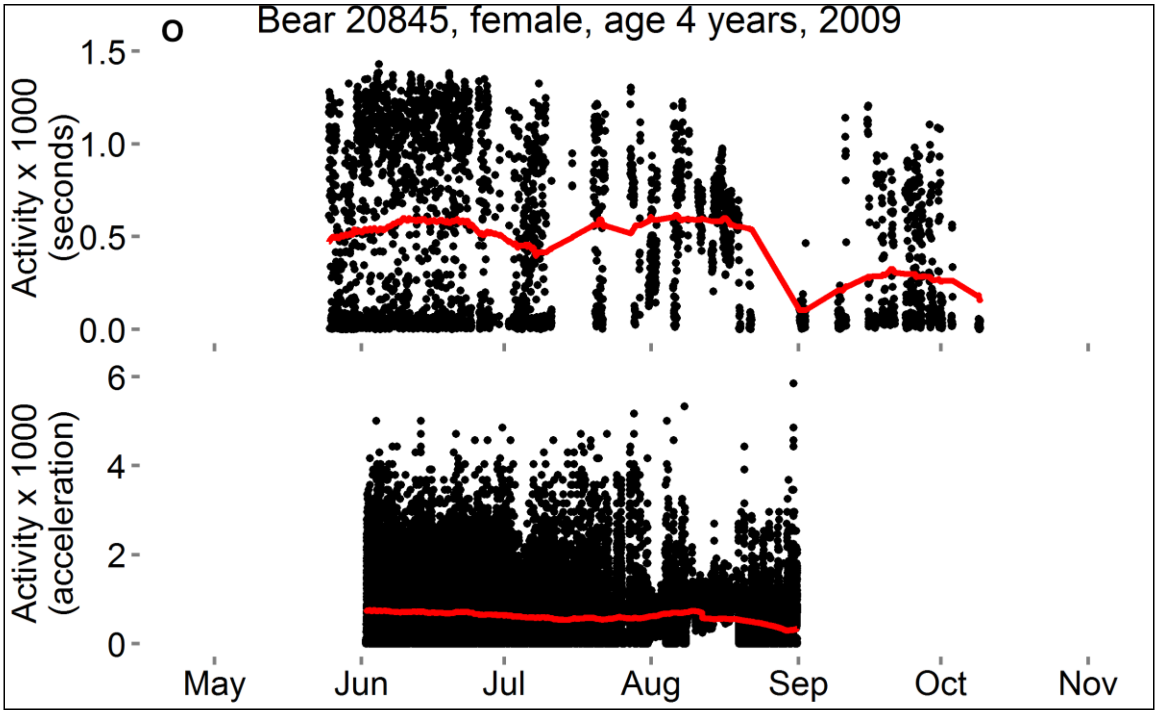
F
Bear 21045, female, age 8 years
Tabd (°C)
39
37
35
33
31
29
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
Activity x 1000 (acceleration)
8
6
4
2
0
Jun 2009
Aug 2009
Oct 2009
Dec 2009
Feb 2010
Apr 2010
Jun 2010

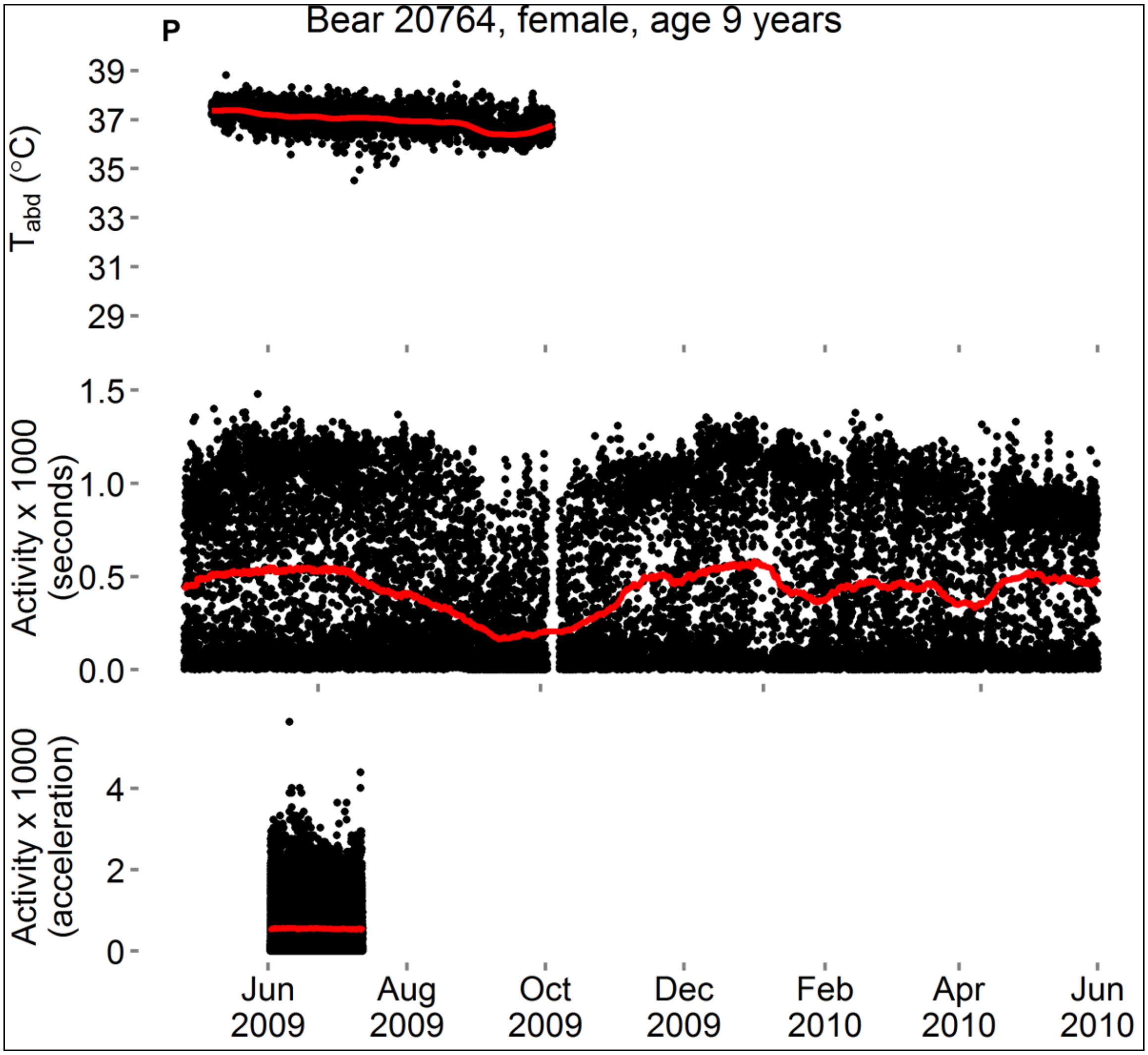

G
Bear 21035, female, age 7 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov
H
Bear 21032, male, age 7 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov

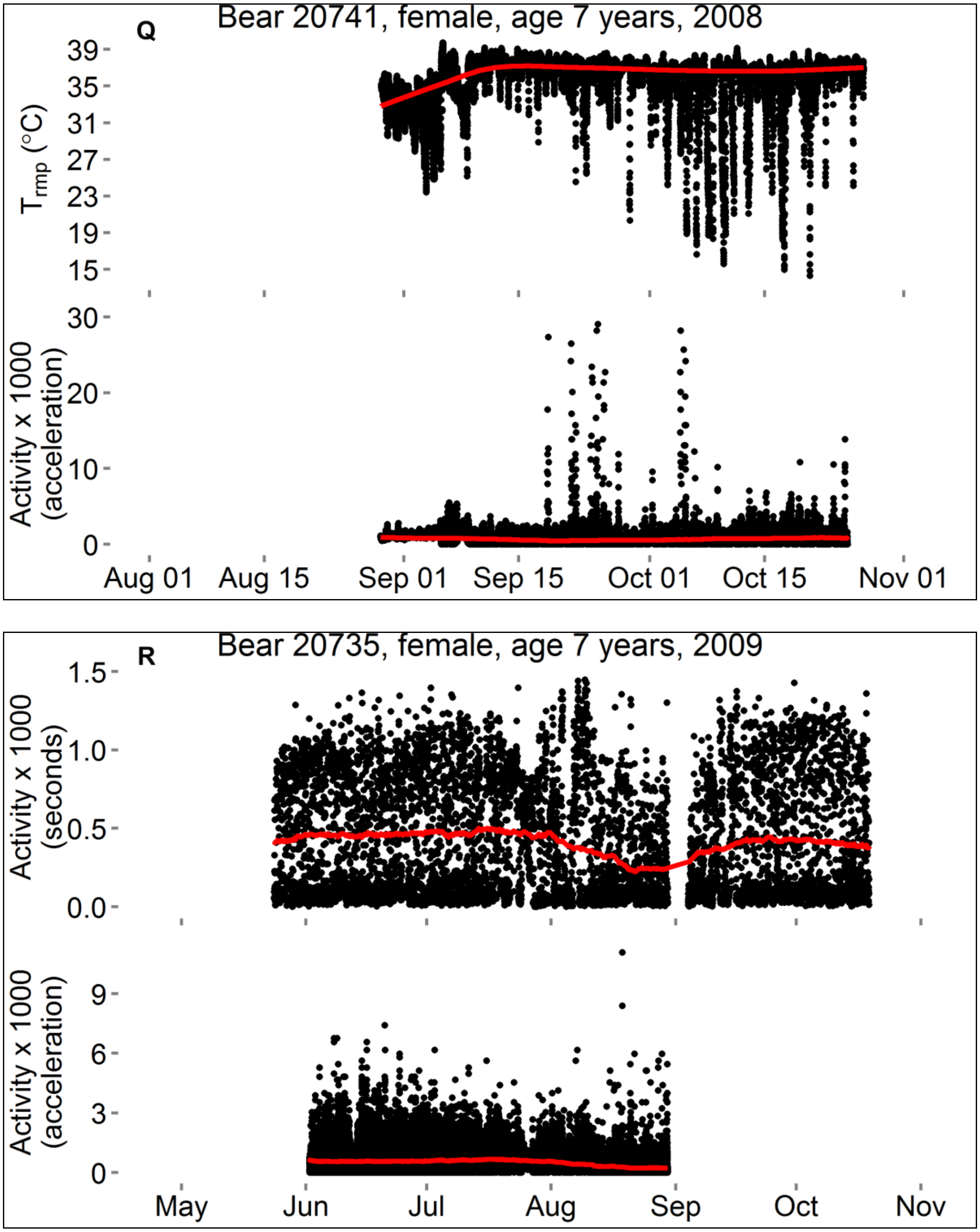

I
Bear 21024, female, age 6 years
T_rmp (°C)
39
35
31
27
23
19
15
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
Activity x 1000 (acceleration)
6
4
2
0
Jun 2009
Aug 2009
Oct 2009
Dec 2009
Feb 2010
Apr 2010
Jun 2010

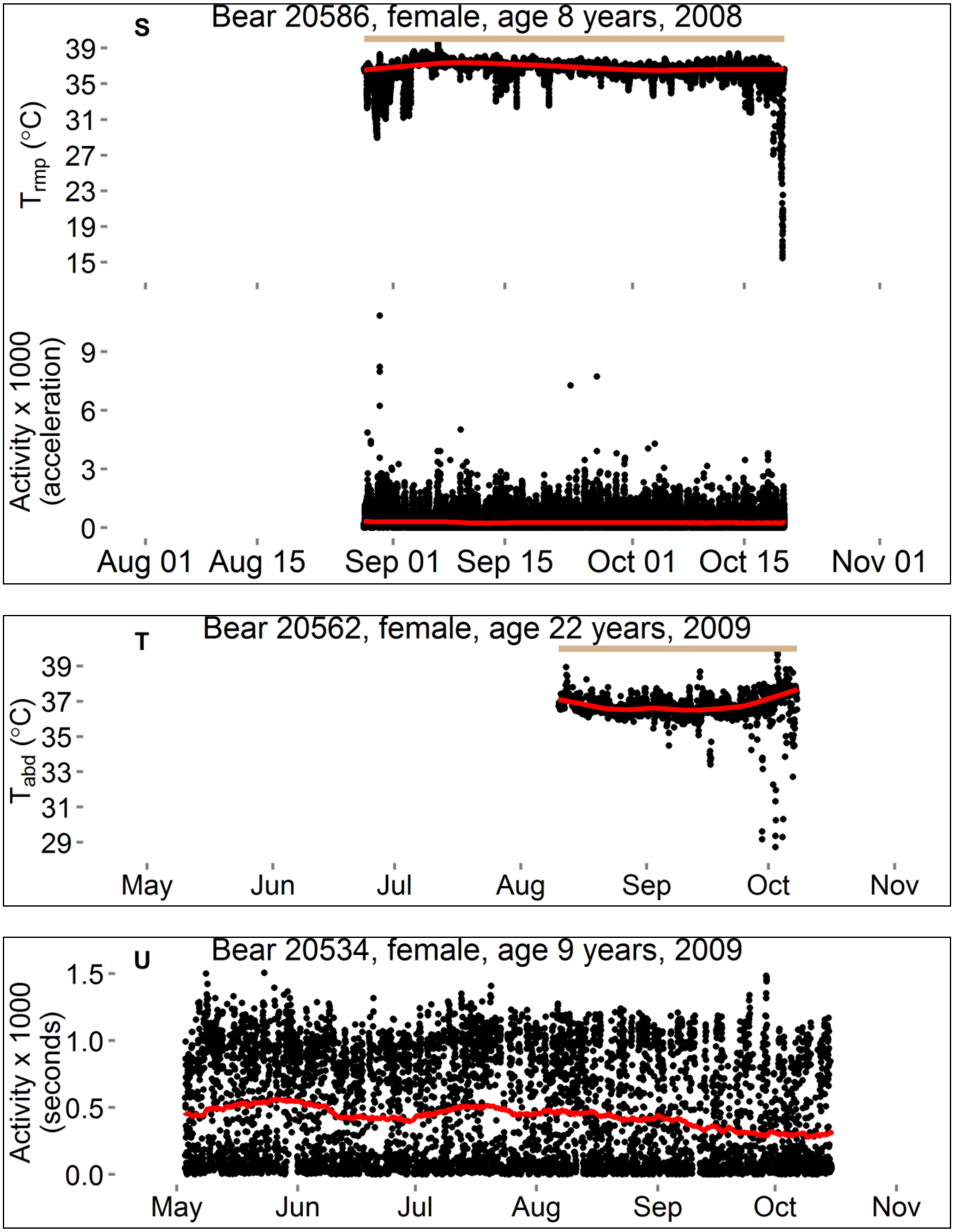

J
Bear 20975, male, age 2 years, 2008
Activity x 1000 (acceleration)
10.0
7.5
5.0
2.5
0.0
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01

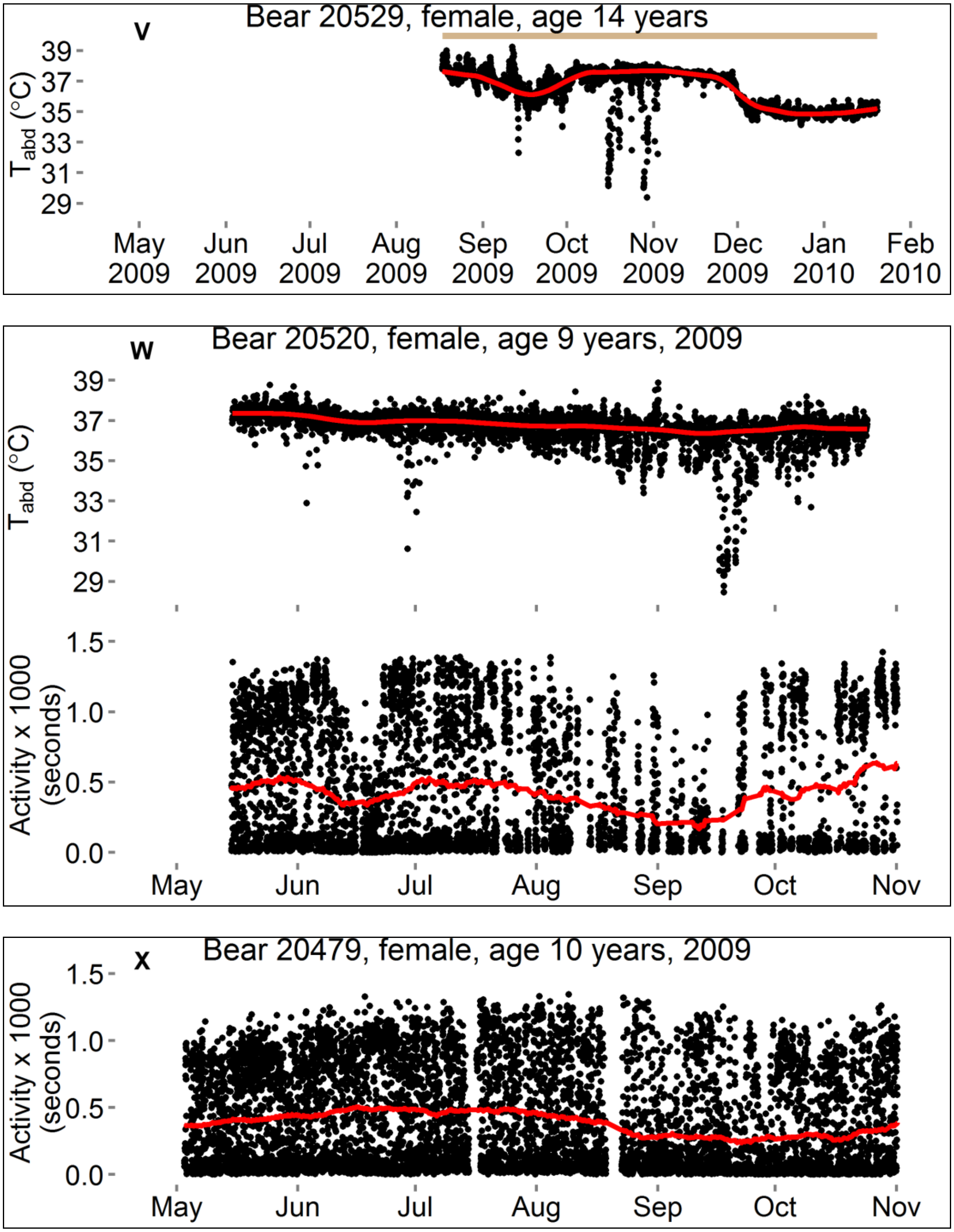

K
Bear 20966, female, age 10 years, 2008
Activity x 1000 (acceleration)
0
2
4
6
8
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01
L
Bear 20947, male, age 5 years, 2009
T_{abd} (°C)
29
31
33
35
37
39
May
Jun
Jul
Aug
Sep
Oct
Nov
M
Bear 20901, female, age 12 years, 2009
Activity x 1000 (seconds)
0.0
0.5
1.0
1.5
May
Jun
Jul
Aug
Sep
Oct
Nov
N
Bear 20898, male, age 1 years, 2008
T_{rmp} (°C)
15
19
23
27
31
35
39
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01

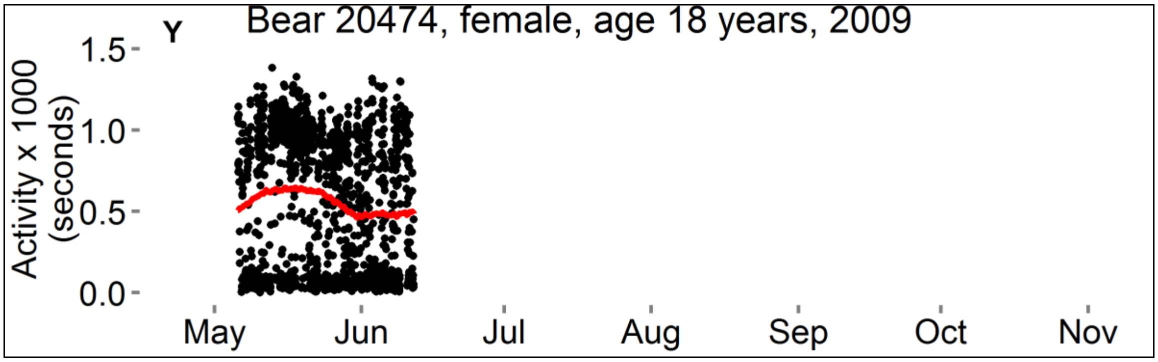

o
Bear 20845, female, age 4 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
Activity x 1000 (acceleration)
6
4
2
0
May
Jun
Jul
Aug
Sep
Oct
Nov

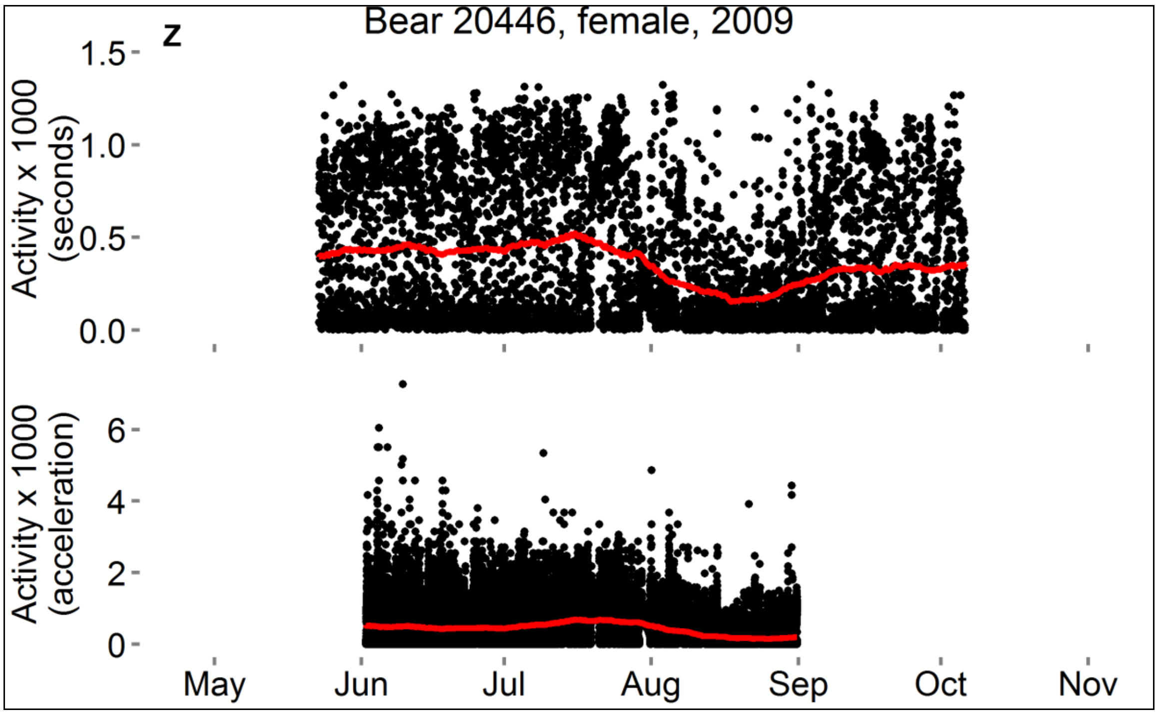

P
Bear 20764, female, age 9 years
39
37
35
33
31
29
T_{abd} (°C)
1.5
1.0
0.5
0.0
Activity x 1000 (seconds)
4
2
0
Activity x 1000 (acceleration)
Jun 2009
Aug 2009
Oct 2009
Dec 2009
Feb 2010
Apr 2010
Jun 2010

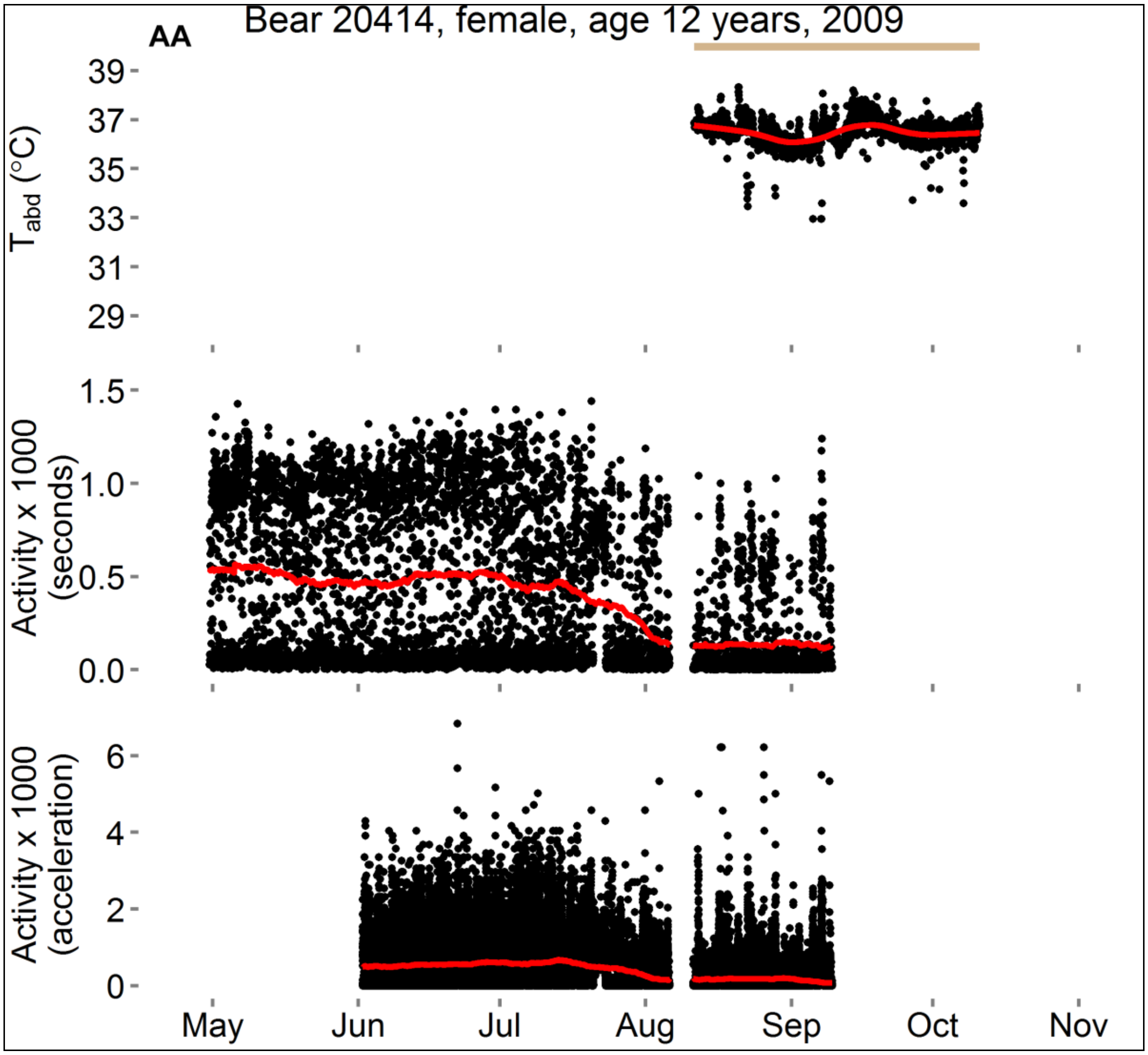

Q
Bear 20741, female, age 7 years, 2008
T rmp (°C)
39
35
31
27
23
19
15
Activity x 1000 (acceleration)
30
20
10
0
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01
R
Bear 20735, female, age 7 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
Activity x 1000 (acceleration)
9
6
3
0
May
Jun
Jul
Aug
Sep
Oct
Nov

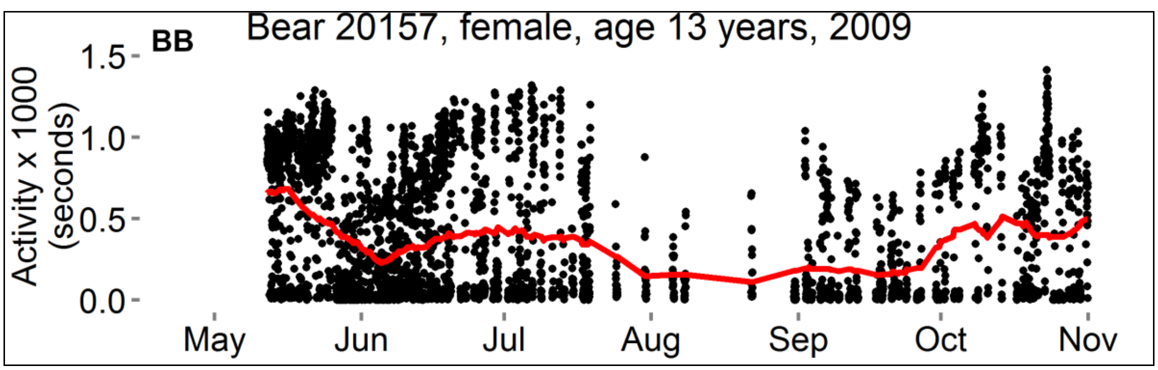

S
Bear 20586, female, age 8 years, 2008
Trmp (°C)
39
35
31
27
23
19
15
Activity x 1000 (acceleration)
9
6
3
0
Aug 01
Aug 15
Sep 01
Sep 15
Oct 01
Oct 15
Nov 01
T
Bear 20562, female, age 22 years, 2009
Tabd (°C)
39
37
35
33
31
29
May
Jun
Jul
Aug
Sep
Oct
Nov
U
Bear 20534, female, age 9 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov


V
Bear 20529, female, age 14 years
T_{abd} (°C)
39
37
35
33
31
29
May 2009
Jun 2009
Jul 2009
Aug 2009
Sep 2009
Oct 2009
Nov 2009
Dec 2009
Jan 2010
Feb 2010
W
Bear 20520, female, age 9 years, 2009
T_{abd} (°C)
39
37
35
33
31
29
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov
X
Bear 20479, female, age 10 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov


Y
Bear 20474, female, age 18 years, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov


Z
Bear 20446, female, 2009
Activity x 1000 (seconds)
1.5
1.0
0.5
0.0
Activity x 1000 (acceleration)
6
4
2
0
May
Jun
Jul
Aug
Sep
Oct
Nov


AA
Bear 20414, female, age 12 years, 2009
T_abd (°C)
39
37
35
33
31
29
Activity x 1000
(seconds)
1.5
1.0
0.5
0.0
Activity x 1000
(acceleration)
6
4
2
0
May
Jun
Jul
Aug
Sep
Oct
Nov


BB
Bear 20157, female, age 13 years, 2009
Activity x 1000
(seconds)
1.5
1.0
0.5
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov

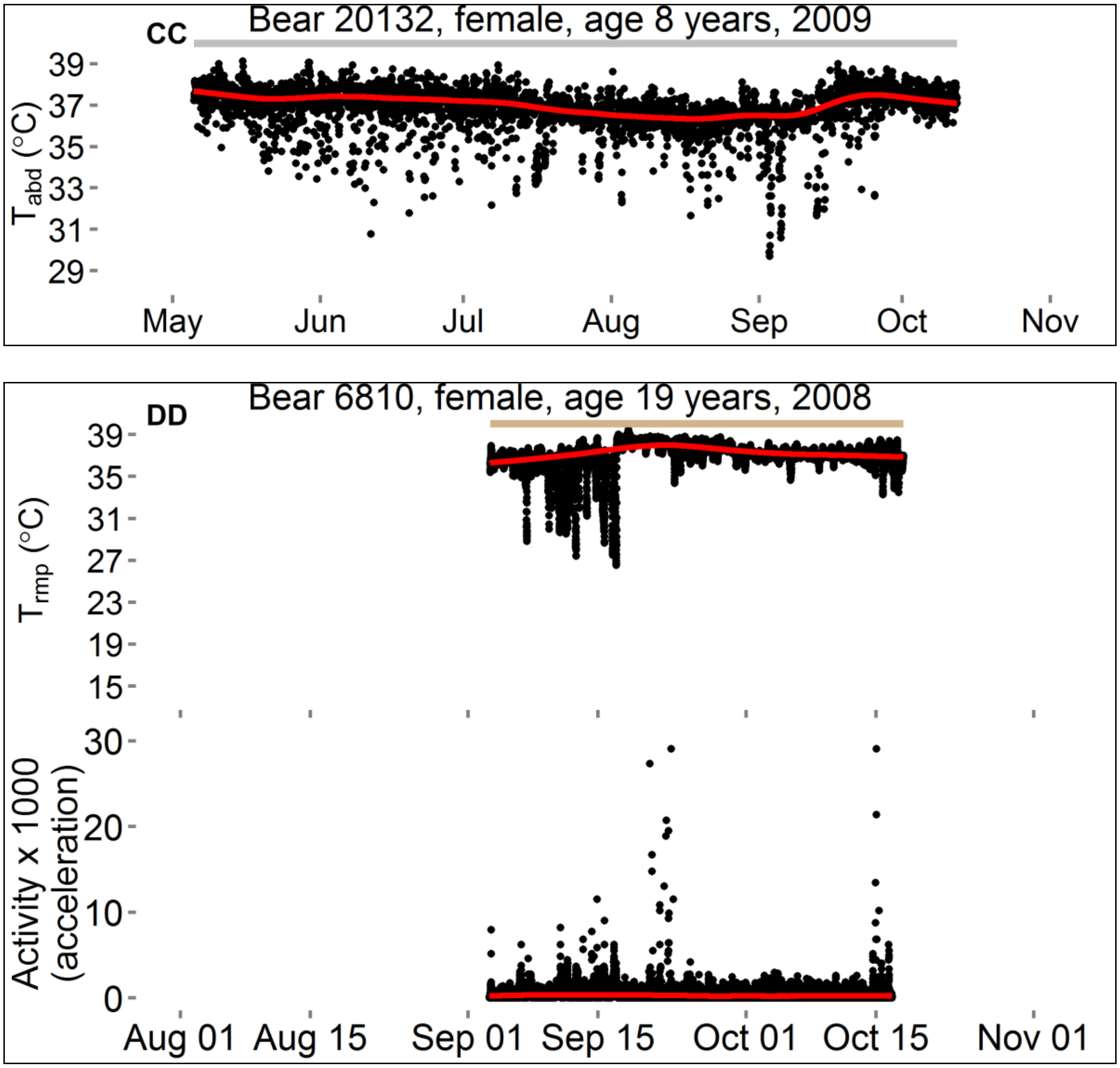


Fig. S1

Activity and body temperatures of polar bears in the Beaufort Sea, 2008–2010. Each panel shows data from 1–3 variables for a single bear. Data censored ≤ 5 days after capture and ≤ 1 hour before recapture. Temperature is either "T_{abd}" (hourly temperature of a logger implanted into the abdomen) or "T_{rmp}" (temperature of a logger implanted beneath subcutaneous adipose tissue on the rump, recorded every 5–10 minutes), and red line is the smoothed trend after seasonal decomposition analysis. Activity is either "Activity (seconds)" (number of seconds of activity in previous half-hour) or "Activity (acceleration)" (acceleration score recorded every two minutes), and red line is moving average at center of 20-day window. For some bears, a horizontal bar spans the dates during which bear location was unknown (gray) or was on shore except for short swims (brown). The absence of a bar indicates the bear was offshore (swimming to or from sea ice, or traveling on sea ice surface). Data from bear 20741 were presented in Durner et al. (*6*).

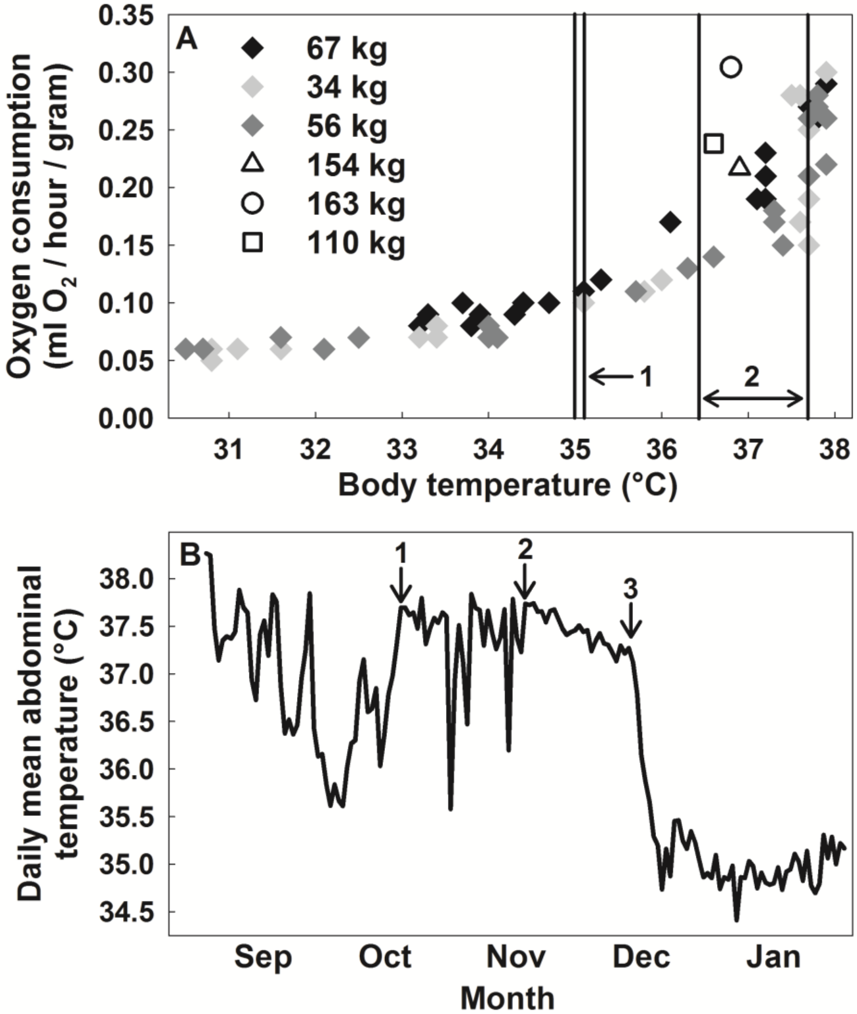


Fig. S2

Metabolic rates and body temperatures of bears. (A) Data from previous studies showing resting metabolic rates as measured by oxygen consumption of black bears (solid diamonds; temperature logger inside peritoneum) and polar bears (open symbols; temperature logger adjacent to peritoneum) of varying body mass (data adapted from Hurst et al. (*38*) and Tøien et al. (*27*)). The spans on the x-axis indicate the range of monthly temperature means from polar bears in our study for December–January (span 1; bear 20529) and May–October (span 2; all other bears). (B) Abdominal temperatures of pregnant polar bear 20529 in our study. At 1, an abrupt increase in her abdominal temperature likely indicated blastocyst implantation, followed by entry into a maternity den (at 2) and parturition (at 3).

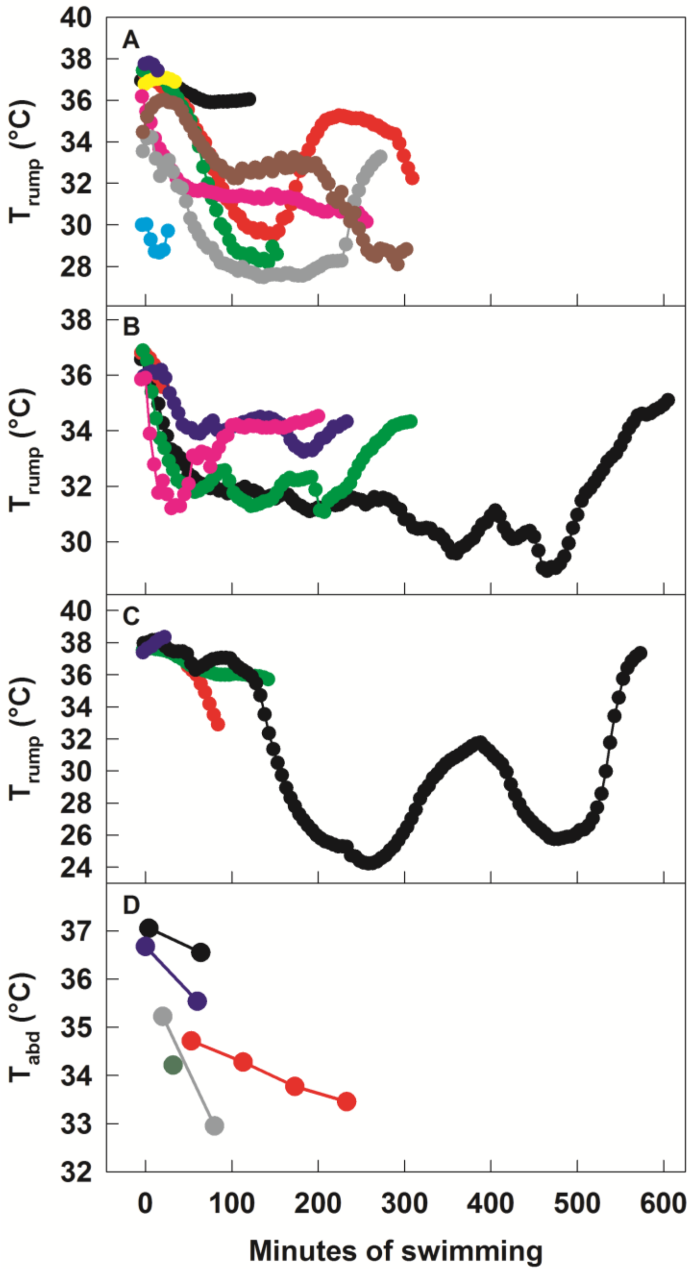


Fig. S3

Polar bear temperatures while swimming. Data recorded by loggers implanted into the rump (T_{rump}; A–C; measurements every five minutes) or abdomen (T_{abd}; D; measurements hourly). Each panel represents a single bear and each color represents a single swim that was confirmed with a combination of location and activity data.

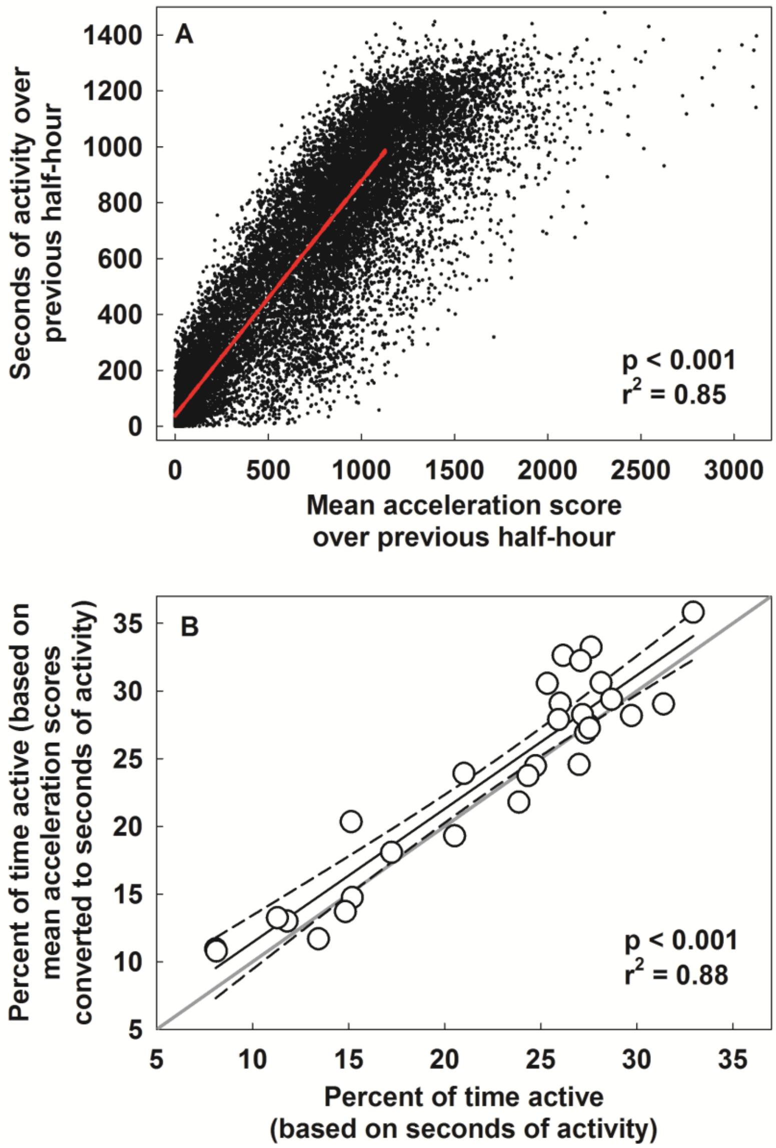


Fig. S4

Relationship between data collected simultaneously by two different collar-mounted accelerometers on seven polar bears. (A) Data are pooled across all bears. Statistics describe the linear regression (solid red line; 95% confidence interval is narrow and cannot be distinguished from the line itself) which extends from x values of 0 to 1128 (the cutoff identified by segmented regression). (B) The x-axis represents a monthly mean derived from number of seconds of activity per half-hour, and the y-axis represents a monthly mean derived from acceleration scores converted to number of seconds of activity per half-hour. The relationship x=y is also shown (gray line). Statistics describe the linear regression (solid black line; 95% confidence interval shown by dashed black lines).

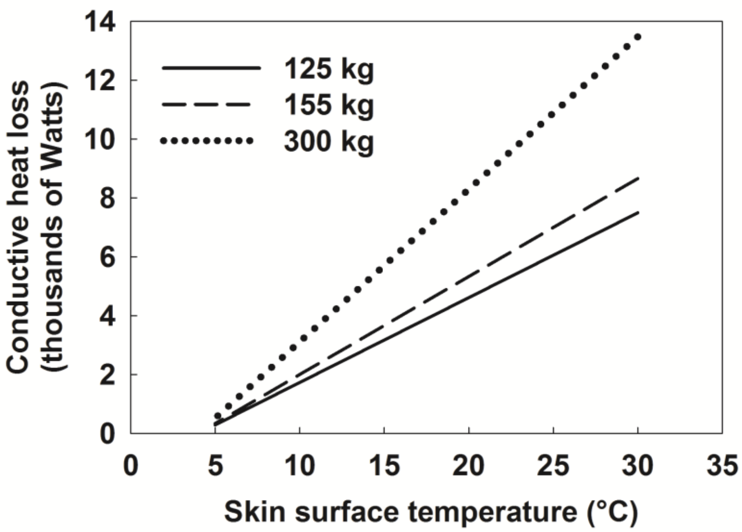


Fig.S5

Estimated heat loss of swimming polar bears. Heat loss is influenced by bear body mass (different lines) and skin surface temperature.

Table S1.

Statistics of Welch t-tests comparing data collected from polar bears on shore and on sea ice. Where present, data from 2008 and 2009 were combined. The variable of time spent active is derived from both seconds of activity per half-hour, and from acceleration scores converted to seconds of activity per half-hour.

Variable	Month	Mean ± SE Shore	Mean ± SE Ice	*p*	t	df
Time spent active	July	11.8	24.6 ± 0.9	NA	NA	NA
	August	21.4 ± 5.3	20.0 ± 1.9	0.80	0.26	7.50
	September	17.8 ± 2.1	14.6 ± 1.1	0.21	1.33	13.54
	October	19.2 ± 2.7	19.3 ± 1.8	0.99	-0.01	12.71
Movement rate	July	0.12	0.31 ± 0.02	NA	NA	NA
	August	0.16 ± 0.02	0.32 ± 0.01	<0.01	7.55	9.85
	September	0.11 ± 0.02	0.33 ± 0.03	<0.01	-6.34	19.14
	October	0.14 ± 0.04	0.40 ± 0.05	<0.01	-4.35	17.99
Abdominal temperature	August	37.0 ± 0.2	36.8 ± 0.1	0.42	-0.88	4.50
	September	36.8 ± 0.2	36.6 ± 0.1	0.48	-0.74	6.24
	October	37.1 ± 0.2	36.8 ± 0.1	0.21	-1.44	5.13

Table S2.

Statistics of Welch t-tests comparing data collected in 2008 and 2009, from polar bears on shore. Polar bears on sea ice were only sampled in 2009. The variable of time spent active is derived from both seconds of activity per half-hour, and from acceleration scores converted to seconds of activity per half-hour.

Variable	Month	Mean ± SE 2008	Mean ± SE 2009	*p*	t	df
Time spent active	July	NA	11.8	NA	NA	NA
	August	28.4 ± 7.5	12.2 ± 2.7	0.12	2.03	3.73
	September	18.6 ± 2.5	15.7 ± 4.5	0.60	0.58	3.33
	October	18.7 ± 3.1	22.7	NA	NA	NA
Movement rate	July	NA	0.12	NA	NA	NA
	August	0.16 ± 0.03	0.16 ± 0.02	NA	NA	NA
	September	0.10 ± 0.02	0.16 ± 0.03	0.26	-1.50	2.17
	October	0.14 ± 0.5	0.12	NA	NA	NA

Table S3.

Coefficients from ARIMA models using environmental variables to predict daily mean female polar bear activity. Activity was measured as seconds of activity in the previous half-hour, or as mean acceleration score over the previous half-hour. Sample size indicates the number of days upon which both variables were measured. Coefficients which overlapped with zero indicated no significant relationship. Variables include "Shelf" (binary: whether mean depth of water for bears on sea ice was ≤ 300 m deep), "Whale" (daily proportion of hourly locations < 500 from whaling site), and "Air temp" (daily mean of air temperature at nearby weather station).

Response	Predictor	Bear ID	Coefficient estimate (95% CI)	*n*
Seconds of activity per half-hour	Shelf	20157	1.01 (-3.16 – 5.17)	106
		20414	0.10 (-3.58 – 3.77)	96
		20446	0.05 (-1.88 – 1.97)	95
		20474	0.94 (-2.74 – 4.63)	36
		20479	-8.02 (-14.72 – -1.32)*	176
		20520	0.96 (-2.59 – 4.52)	133
		20534	2.62 (0.64 – 4.60)*	161
		20735	-2.08 (-3.91 – -0.24)*	72
		20764	-0.46 (-2.16 – 1.24)	371
		20901	0.90 (-2.58 – 4.38)	141
		21024	1.33 (-0.85 – 3.50)	324
		21032	2.19 (-2.12 – 6.50)	139
		21035	3.88 (2.30 – 5.46)*	104
		21045	-1.79 (-3.33 – -0.25)*	315
		32777	0.21 (-1.81 – 2.22)	156
Combined weighted mean coefficient (95% CI)			*0.43 (-0.16 – 1.02)*	
Acceleration score	Shelf	20414	-0.36 (-1.18 – 0.46)	66
		20446	-0.05 (-0.29 – 0.19)	61
		20735	-0.17 (-0.35 – 0.02)	56
		20741	-0.29 (-0.91 – 0.33)	56
		20764	0.03 (-0.09 – 0.14)	41
		21024	0.30 (-0.03 – 0.64)	92
		21045	-0.20 (-0.42 – 0.02)	181
		32777	0.17 (-0.17 – 0.51)	92
Combined weighted mean coefficient (95% CI)			*-0.03 (-0.11 – 0.05)*	
Acceleration score	Whale	20586	0.00 (-0.26 – 0.27)	50
		6810	-0.50 (-0.92 – -0.07)*	42
		20975†	-3.33 (-7.88 – 1.22)	27
		32282	2.69 (0.98 – 4.41)*	39
		32606	0.25 (-0.45 – 0.94)	61
		20966	0.78 (0.01 – 1.55)*	64

Combined weighted mean coefficient (95% CI)			*-0.01 (-0.20 – 0.22)*	
Seconds of activity per half-hour	Whale	20735	10.30 (-8.17 – 28.77)	72
Acceleration score	Air temp.	20414	0.14 (-0.01 – 0.30)	30
		20446	0.01 (-0.11 – 0.12)	31
		20586	0.00 (-0.02 – 0.02)	50
		20735	0.05 (-0.02 – 0.11)	33
		20966	0.00 (-0.03 – 0.02)	64
		20975†	0.05 (0.02 – 0.08)*	27
		32255	-0.08 (-0.12 – -0.04)*	36
		32282	0.02 (-0.01 – 0.04)	39
		6810	0.11 (-0.19 – -0.02)*	42
Combined weighted mean coefficient (95% CI)			*0.00 (-0.01 – 0.01)*	
Seconds of activity per half-hour	Air temp.	20414	0.53 (-0.17 – 1.23)	30
		20446	-0.21 (-0.55 – 0.13)	41
		20735	-0.17 (-0.40 – 0.05)	70
Combined weighted mean coefficient (95% CI)			*-0.14 (-0.22 – 0.04)*	

* Does not overlap with zero

†Male

Table S4.

Hourly locations recorded from GPS telemetry transmitters on female polar bears on shore between August 1st and November 1st. Data from 2008 and 2009 were pooled. Expected total number of locations is the number of hours between capture and recapture of bears. Actual number of locations is fewer than expected because weather and equipment failure occasionally prevented transmitter function. For each bear, a total of the number of locations that were within 2000 m and 500 m of three sites where bowhead whale carcasses are deposited after human harvest is also presented.

		Number of hourly locations			
BearID	Year	Expected total	Actual total (% of expected)	Within 2000 m (% of actual)	Within 500 m (% of actual)
32282	2008	1103	1099 (99)	431 (39)	41 (4)
20735	2009	1677	1666 (99)	885 (53)	59 (4)
32255	2008	1030	1017 (99)	0 (0)	0 (0)
20966	2008	1700	1675 (98)	898 (54)	107 (6)
20586	2008	1386	1363 (98)	1084 (80)	931 (68)
20446	2009	945	926 (98)	14 (2)	1 (0.1)
6810	2008	1193	1144 (96)	701 (61)	649 (57)
32608	2008	1193	1041 (87)	537 (52)	50 (5)
20982	2008	1517	1104 (73)	242 (22)	28 (3)
32606	2008	402	279 (69)	155 (56)	23 (8)
20965	2008	1611	1031 (64)	159 (15)	20 (2)
20974	2008	1732	899 (52)	0 (0)	0 (0)
20414	2009	1909	930 (49)	0 (0)	0 (0)
20492	2008	1823	818 (45)	386 (47)	78 (10)
20975*	2008	1659	685 (41)	307 (45)	25 (4)

*Male

Table S5.

Correlations between hourly body temperatures and hourly activity of polar bears in the Beaufort Sea, estimated with dynamic linear models. Both body temperature variables were filtered to include only data < 4 SD from the smoothed mean. For rump temperature, data also filtered to only include measurements recorded when bears were active for > 2% of the previous half-hour.

Variables: Body temperature	Variables: Activity	Bear ID	Correlation (95% CI)	*n*
Abdominal temperature	Seconds of activity per half-hour	20414	0.24 (0.16 – 0.32)	703
		20520	0.17 (0.13 – 0.21)	2261
		20764	0.38 (0.35 – 0.41)	3595
		21045	0.46 (0.43 – 0.49)	3375
		32777	0.34 (0.31 – 0.37)	3623
	Acceleration score	20414	0.21 (0.17 – 0.25)	703
		20764	0.21 (0.15 – 0.27)	977
		21045	0.50 (0.46 – 0.54)	2181
		32777	0.25 (0.21 – 0.29)	2181
Rump temperature	Seconds of activity per half-hour	21024	0.26 (0.22 – 0.30)	2995
	Acceleration score	20586	0.26 (0.20 – 0.32)	754
		32255	0.32 (0.22 – 0.42)	473
		32282	0.40 (0.34 – 0.47)	681
		6810	0.11 (0.03 – 0.19)	642
		20741	0.03 (-0.05 – 0.11)	966

Table S6.

Body mass of polar bears. Measurements taken on the date of implantation of temperature loggers and at the date of logger retrieval (dates in 2009, except as noted).

	Implant		Retrieval	
Bear	Date	Body mass (kg)	Date	Body mass (kg)
Abdominal loggers				
20132	April 29	160	April 22*	148
20414	April 24	208	October 10	243
20520	May 09	179	April 17*	229
20529	August 11	350	April 05*	172
20562	August 04	238	October 07	211
20764	May 01	207	October 03	210
20947	August 10	434	October 11	465
21045	May 19	263	October 12	299
21150	August 10	123	October 18	189
32777	May 09	196	October 19	299
Rump loggers				
20586	August 22†	270	October 19†	323
20741	August 23†	226	October 26†	177
20898	August 16†	168	NA‡	NA‡
21024	April 25	179	October 07	225
32255	August 26†	218	October 08†	187
32282	August 25†	273	October 10†	291
6810	August 28†	234	October 17†	288

*2010

†2008

‡Logger retrieved from harvested bear

Table S7.

Sample size (number of polar bears) for three variables shown in Fig. 2.

Month (habitat)	Percent time active	Movement rate (m/s)	Proportion of movement rates > 0.33 m/s recorded when bears were inactive
April (ice)	2	2	2
May (ice)	15	15	15
June (ice)	15	15	15
July (ice)	14	15	13
July (shore)	1	1	1
August (ice)	10	9	9
August (shore)	7	5	4
September (ice)	12	13	8
September (shore)	10	11	7
October (ice)	10	11	9
October (shore)	8	9	3
November (ice)	3	3	3
December (ice)	3	3	3
January (ice)	3	3	3
February (ice)	3	3	3
March (ice)	3	3	3