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RESEARCH

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Movement and heart rate in the Scandinavian brown bear (*Ursus arctos*)

Leslie Blanchet^{1*} , Boris Fuchs¹, Ole-Gunnar Støen², Audrey Bergouignan³, Andrés Ordiz⁴, Timothy G. Laske⁵, Jon M. Arnemo^{1,6} and Alina L. Evans¹

Abstract

Background: Understanding animal movement facilitates better management and conservation. The link between movement and physiology holds clues to the basic drivers of animal behaviours. In bears, heart rate increases with the metabolic rate during the active phase. Their movement and heart rate change at seasonal and daily scales, and can also depend on environmental factors. Their behaviour is, therefore, flexible in activity patterns with high individual variations. The aim of this study was to establish the relationship between heart rate and distance travelled, and test whether this relationship was influenced by environmental (e.g., time of year and time of day) and biological (e.g., reproductive status, sex, body mass and age of the bears) factors. We analysed data of distance travelled and heart rate of 15 GPS-collared brown bears, both males and females, equipped with cardiac loggers in the south of Sweden in 2014–2017.

Results: Heart rate increased with distances travelled exceeding 50 m in an hour, but this correlation depended on the day-of-year with higher heart rate in August than in May. Bears accompanied by cubs had lower heart rate than solitary bears especially in May. When movement was minimum (< 50 m in an hour), heart rate was not related to distance travelled and was very variable, regardless of the months.

Conclusions: Our findings suggest that heart rate increases with long distances travelled, but varies with day-of-year and reproductive status, depending on the metabolic rate. Studying the change in heart rate in bears can help to evaluate their seasonal rhythms and how different factors affect them. This study illustrates the usefulness of combined bio-logging proxies, i.e., movement and heart rates in our case, in animal ecology.

Keywords: Distance travelled, GPS positions, Cardiac bio-logger, Seasonal variation, Reproductive status

Background

Wildlife activity patterns may be an adaptation to daily and seasonal variations in environmental factors [1] and are relevant for optimising management. Activity patterns of large carnivores can vary seasonally due to changes in their environment, including human activities such as hunting [1, 2]. In addition, movement and physiology are linked to an individual's activity levels. For example, one study showed that red foxes (*Vulpes vulpes*) have heart rates (HRs) and body temperatures depending

on the intensity of the activity. During running, the red fox has high HR and body temperature and during sleep, its HR is lower [3]. Furthermore, bio-logging can be used to assess how changes in physical parameters of the environment can induce changes in the behaviour of the animal at the same spatial and temporal scale [4]. Global Positioning System (GPS) relocations can be matched to HR and other physiological parameters. This allows a possible correlation between physiological change and environmental factors [5]. For example, HR of carnivores can vary with the ambient temperature. In fennec foxes (*Vulpes zerda*), HR decreases when the ambient temperature rises above 35 °C [6].

Bears are ideal study models for physiological monitoring because they possess large home ranges and have

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long life expectancy [5]. Physiology and activity of bears are recorded by bio-loggers which monitor the stress responses and determine the environmental events of the bears that provoke their physiological response based on their behaviour [7]. Bears exhibit extreme variations in their physiology in response to food availability and seasonal changes [5]. Studying the change in HR in bears can, therefore, help to evaluate their seasonal rhythms and how environment and stress, due both to intraspecific and external factors, can affect them.

In northern ecosystems, when snow arrives and the ambient temperature approaches 0 °C, Scandinavian brown bears (*Ursus arctos*) enter their dens to hibernate [8]. The inactive period of the bears lasts from late October to early spring, and bears rely on fat reserves in that season [9]. Their HR and body temperature decrease to minimise energy consumption, like in black bears (*Ursus americanus*) [10–12]. In the spring, when the ambient temperature increases and reaches the lower critical temperature of the bear, it leaves the den. Den exit occurs when body temperature has almost reached eutheria (≈ 37 °C) [8]. The first active period lasts until early July. This period is the mating season and the bear can gain or lose body mass according to food availability. The second period is the season of hyperphagia, from mid-July to den entry in October [13]. In Scandinavia, bears feed on berries during this period [9], gaining fat reserves for hibernation and the next reproductive episode [14]. During these active phases, the level of activity increases as foraging activity intensifies [15] and HR increases gradually after den emergence [8].

In the brown bear, there are individual variations in activity levels and HR at daily and seasonal scales, depending on their behavioural response [16]. There are also differences related to the sex, age, and reproductive status. For example, 1-year-old bears show less difference

in activity levels between day and night than adults [14]. Furthermore, HR variability also depends on stress levels, e.g., in relation with distance to human settlements [16]. The purpose of this study was to look at the variation in HR of Scandinavian brown bears in relation with distance travelled, age, body mass, sex and reproductive status of the bears, time of year (day-of-year number), and time of day. We hypothesised that seasonal, daily, and intraspecific factors could influence the relationship between HR and movement of the bears.

Results

Mean value for HR was 65 ± 20 (mean \pm SD) beats per minute (bpm) ($n = 36,031$ measurements for the 15 bears during 2014–2017). The generalized additive mixed model (GAMM) to explain seasonal and daily effects suggested that HR was influenced by time of year and time of day. HR increased with day-of-year, being lowest around day 120 (end of April, ≈ 50 bpm) and peaking after day 200 (mid-July, ≈ 75 bpm). HR was higher around 3 A.M. and 7 P.M. and lower around midday. The best linear mixed-effects (LME) model to explain the variation in HR suggested that HR was influenced by day-of-year, reproductive status of the bears and by their interaction (Table 1). The mean HR was significantly higher in solitary bears (66.6 ± 21 bpm) than in bears accompanied by cubs (59.6 ± 18 bpm). Solitary bears had a significant higher HR than bears with cubs especially between days 120 and 150 (May). After day 220 (August), the bears with cubs had higher HR than solitary bears (Fig. 1).

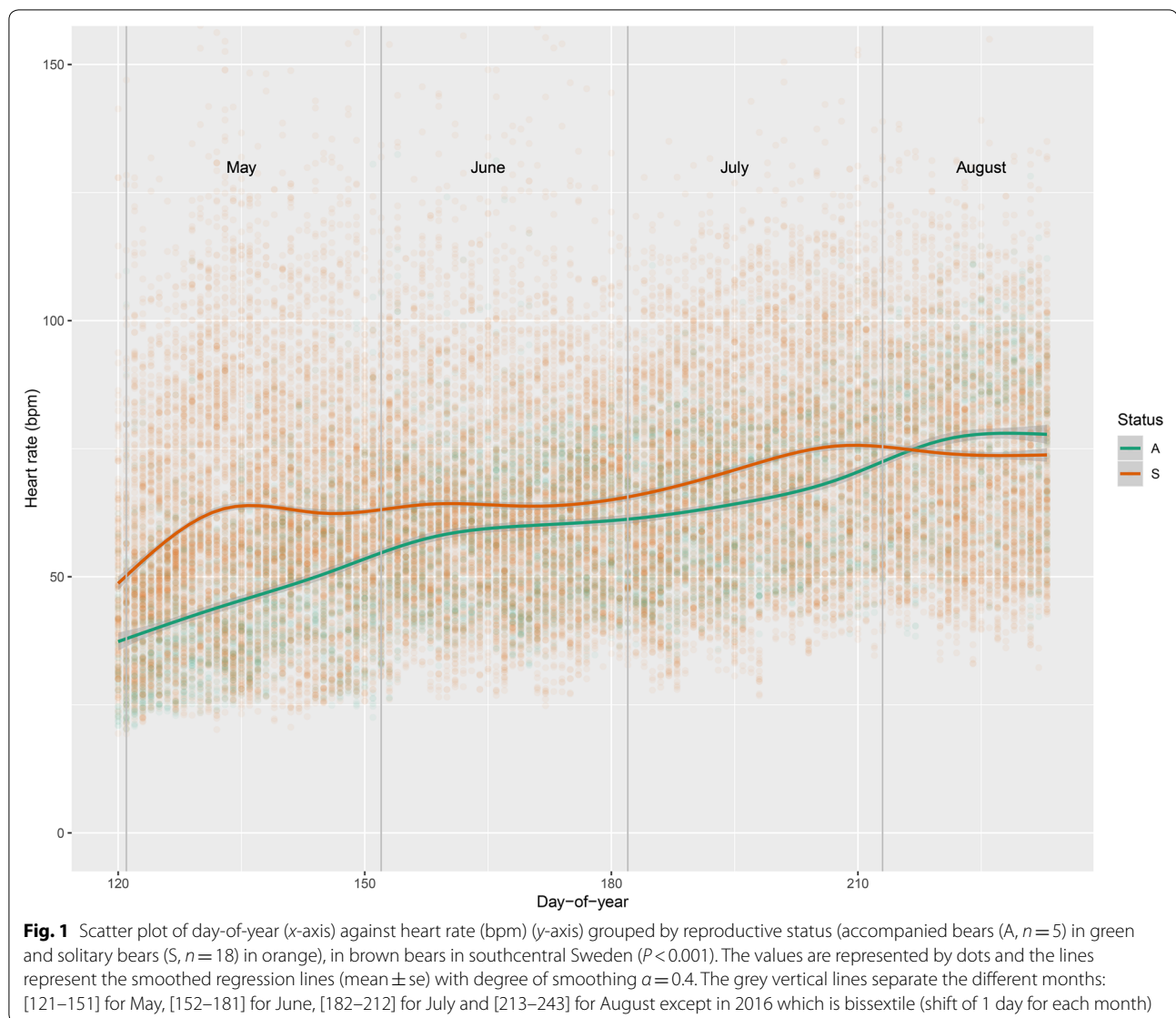
The distribution of the logarithmic distance travelled of bears ($n = 18$) was bimodal (Fig. 2). The two patches were separated by a distance of 50 m (3.9 in log), corresponding to short and long distances.

The relationship between HR and distance travelled was less correlated during short distances (< 50 m in an

Table 1 LME model with factors affecting HR of brown bears in southcentral Sweden

| Groups | Name | Std. dev. | | |
|-------------------------------------------------|-------------|------------|---------|--------|
| Random effects | | | | |
| YID | (Intercept) | 10.24 | | |
| Residual | | 16.78 | | |
| Number of observations: 36,031, groups: YID, 23 | | | | |
| | Value | Std. error | t-value | P |
| Fixed effects | | | | |
| (Intercept) | − 3.01 | 4.75 | − 0.63 | 0.53 |
| yday | 0.35 | 0.01 | 48.93 | <0.001 |
| StatusS | 56.85 | 5.36 | 10.59 | <0.001 |
| yday:StatusS | − 0.28 | 0.01 | − 34.89 | <0.001 |

YID (bear identity + year) is included in random effect. Status S corresponds to the solitary bears. yday corresponds to day-of-year numbers

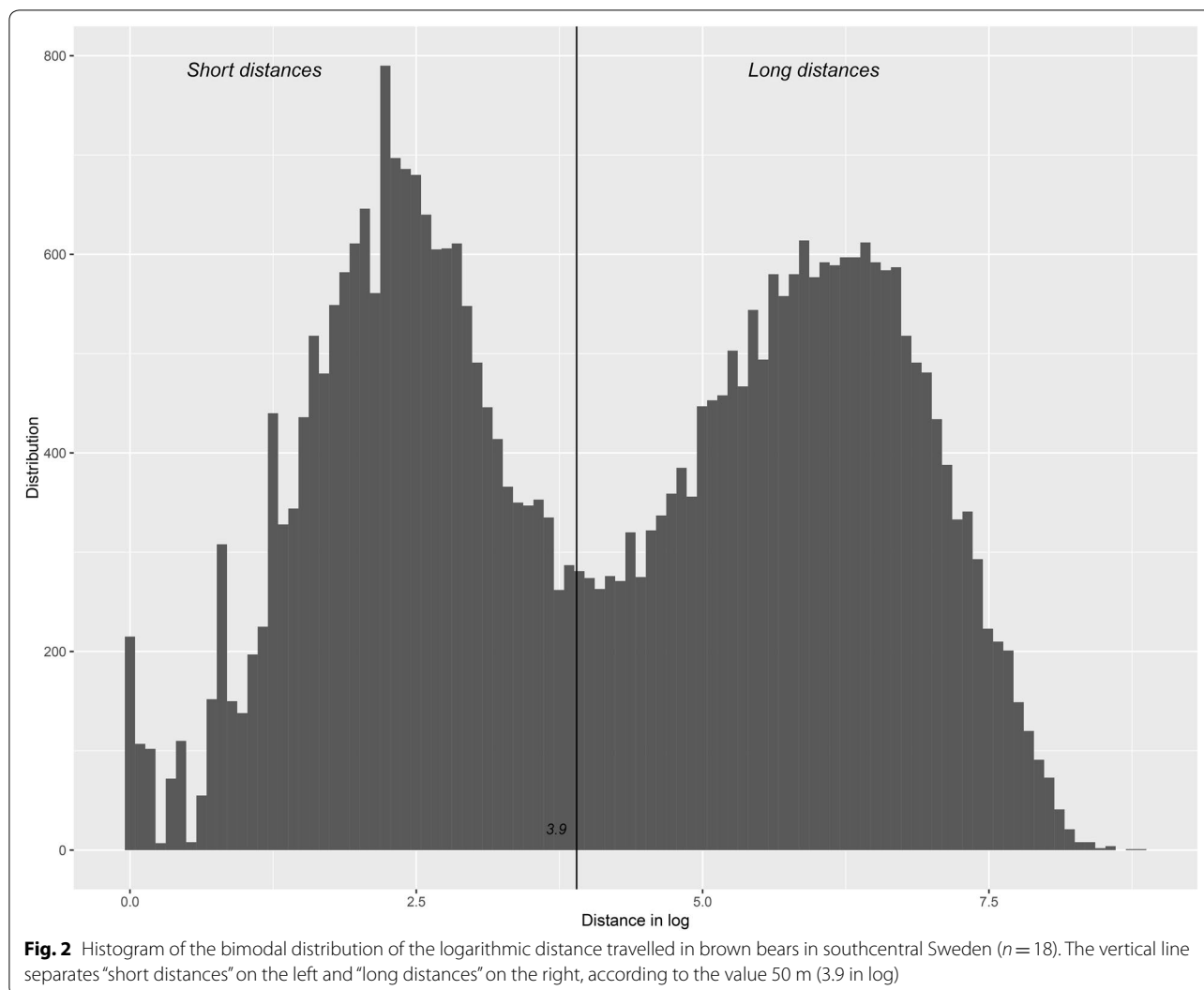


hour; Pearson, $r=0.10$, $t=13.72$, $P < 0.001$) than during long distances (> 50 m in an hour; Pearson, $r=0.29$, $t=41.87$, $P < 0.001$). The GAMM suggested that HR increased with long distances but not with short distances (Fig. 3). HR also increased with the days during long and short distances (Fig. 4). For the daily effect, HR was higher around 3 A.M. and 8 P.M. than around midday during long distances. During short distances, this difference was less substantial (Fig. 5).

The best LME model suggested that distance travelled, day-of-year and their interaction can influence HR during long and short distances. All other tested models had delta AIC (Akaike Information Criteria) higher than 4 and were not further considered (Table 2).

During long distances, HR was influenced by distance travelled, day-of-year and by their interaction (Table 3). The relationship between HR and long distances travelled depended on time of year being similar in June, July and August but different in May. In May, HR increased more than during other months in distances travelled longer than 2000 m in an hour (Fig. 6). During short distances travelled, HR was influenced by day-of-year but not by distance travelled or by the interaction between distance and day-of-year (Table 4). The relationship between HR and short distances travelled was similar between May, June, July and August (Fig. 7).

The ANOVA test which compared the best models that only included fitted values with the models that added YID as random effect showed that individual and annual differences among bears were important in explaining the

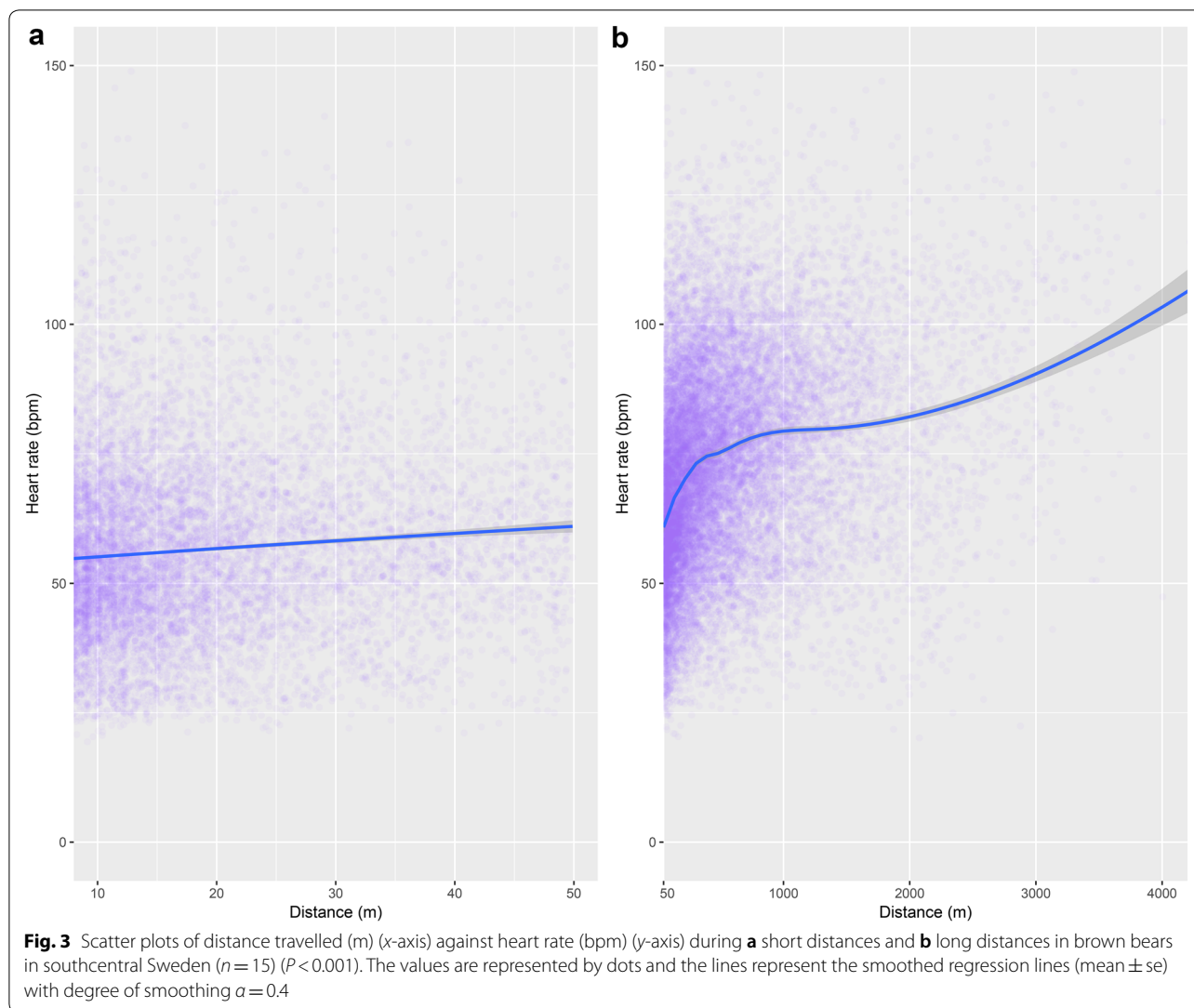


variation in HR (Table 1) and in the relationship between HR and distance travelled (Tables 3, 4).

Discussion

Here, we show that HR in brown bears in southcentral Sweden was not always related to distance travelled. During long distances (>50 m in an hour), the correlation between HR and distance travelled differed between months but remained high, coinciding with the seasonal variation found in HR, regardless of the distance travelled in the first part of our result: higher HR was recorded in August, and HR was higher for solitary bears than for bears accompanied by cubs, especially in May. Nevertheless, during short distances, the correlation between HR and distance travelled was low and did not change between months. Therefore, HR can show large variations during short movements.

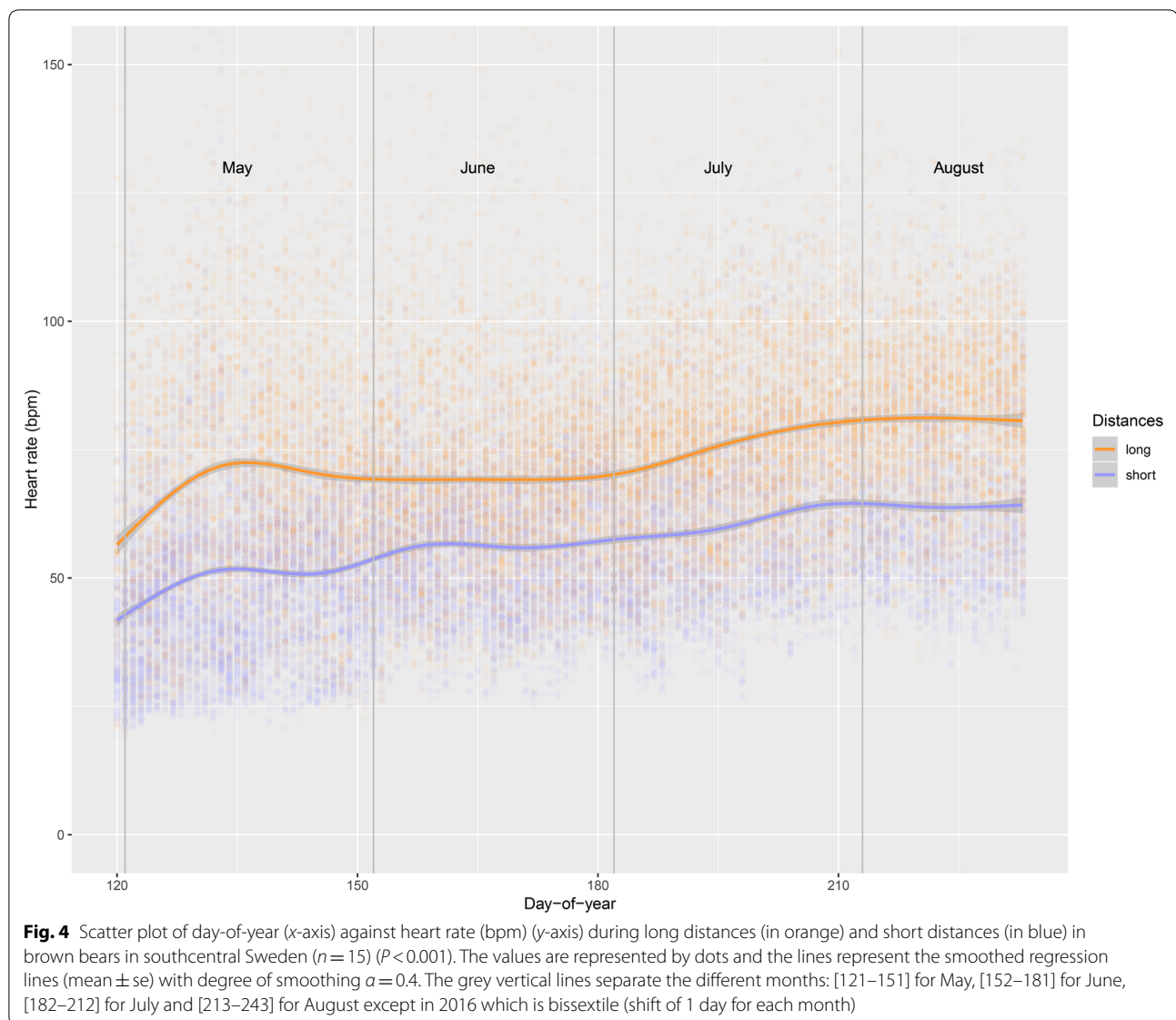
These findings have three main implications. First, HR was influenced by day-of-year and by reproductive status of the bears. Physiological condition of the bears is represented by HR, which is linked to the metabolic rate being a proxy of the rate of energy expenditure and oxygen consumption [17, 18]. HR indicates energy consumption and varies with activities such as sleeping, lying, sitting and slow or fast walking like in polar bears (*Ursus maritimus*) [19]. HR is, therefore, related to activity and does not decrease during summer months [8]. The metabolic rate and HR are, therefore, high during the hyperphagic period. Bears are constrained by fluctuation in berry availability and intake rate, capacity of digestion and metabolic efficiency for gaining body mass in summer [20]. They have a high energy requirement and forage food items with a high sugar and protein content [21]. In May, HR is lower than in summer, likely because bears have a low energy budget during this month [22], or



because they are in the transition out of hibernation. The link between energy expenditure and HR can be different in this transition phase due to different physiological states. Their HR is low during hibernation and increases gradually after den emergence [8]. This can be associated with underlying physiology that reflects energy and activity levels as there is an increase in food availability over the spring [15]. HR is higher in solitary bears than bears accompanied by cubs in May, but this difference is less obvious in June and July. Accompanied bears have higher HR than solitary bears in August. The bears accompanied by cubs are under pressure in spring, having a trade-off between protecting cubs and foraging. During the spring, bears with cubs decrease their movement to avoid infanticide by males [23]. Males kill unrelated offspring because females exhibit extended maternal care [24] and do not mate during this period [25]. However, after losing a litter during mating season, females enter

estrus again in the following days [26]. Males may then reproduce by killing a female's cubs-of-the-year instead of waiting until the off-spring separate at the age of 1.5–2.5 years [27]. Furthermore, the maintenance of circadian rhythms in bears with cubs is also possible for accumulation of enough fat to survive in hibernation [9] and to feed the cubs throughout the hibernation period. This can explain the high HR in accompanied bears during the hyperphagic period. HR varies over the day, being lower around midday corresponding to the resting period [14]. During sleep, HR of bears is lower than during active phase [28].

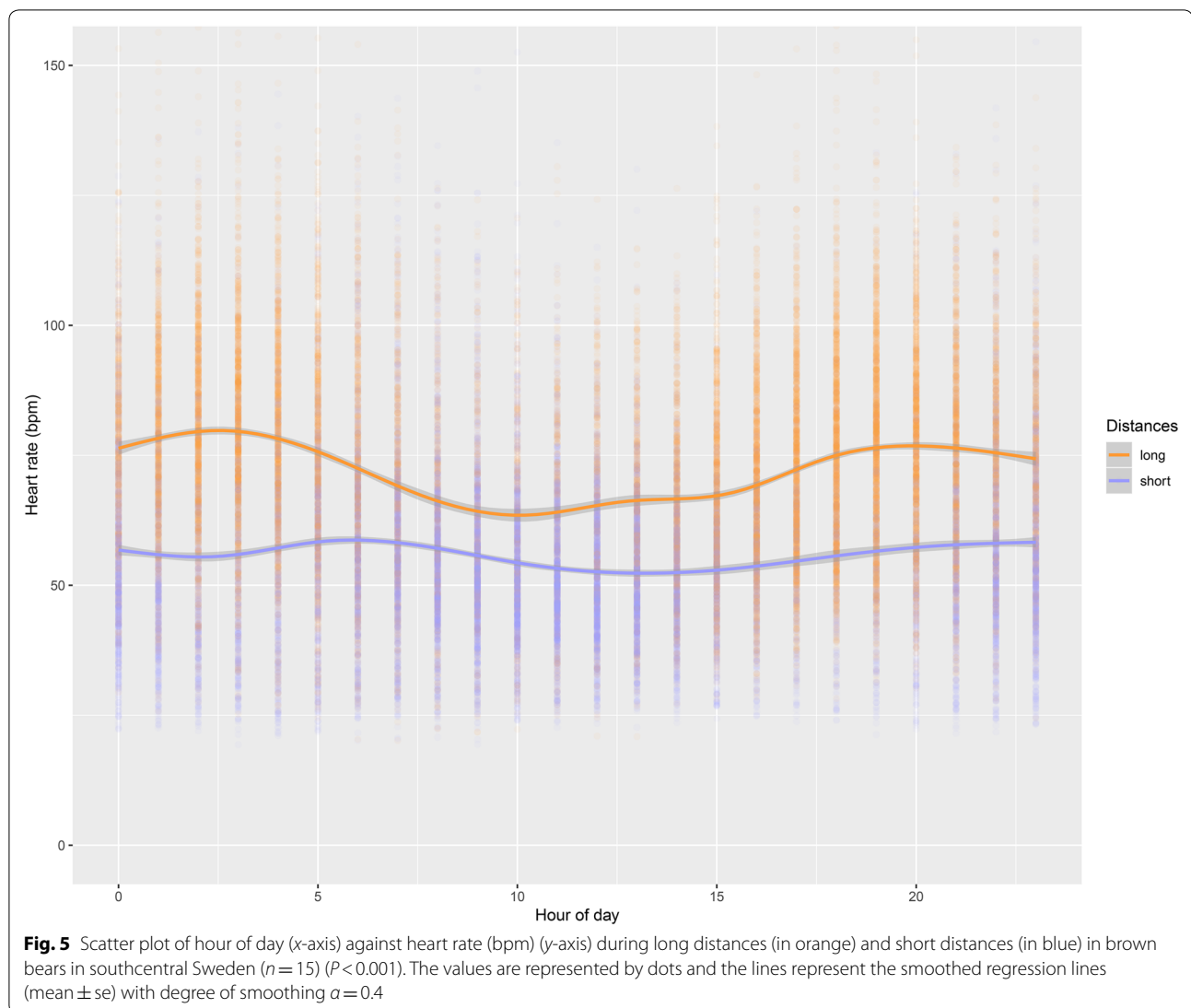
Secondly, we identified a correlation between HR and long distances travelled which changed according to day-of-year. When the bears travelled long distances, HR was less variable and the relationship between HR and distance travelled was more correlated. In polar bears, the cardiac frequency is also less variable and closely related



to speed and metabolic rate during fast walking [28]. The faster the speed, the higher the HR. However, in May, the correlation increased rapidly when distances were longer than 2000 m in an hour. Ungulates (moose or reindeer) are the most important prey during this period [29]. Thereby, HR can increase more significantly if they pursue ungulates over long distances. The spring is also the mating season; it is, thus, reasonable that HR of bears are higher in May, when they roam over large areas to find other mating bears [24]. We can, therefore, conclude that HR is related to long distances travelled and depends of the activity of the bears and of their metabolic rate.

Finally, our results show a low correlation between HR and short distances travelled. The relationship between the both does not change according to day-of-year and

remains less correlated than during long distances travelled. Indeed, HR during short distances travelled is highly variable. The period of short distances travelled by the bears can correspond to their resting period. This is probably why HR is not influenced by time of day during short distances contrary to long distances. During resting, the cardiac frequency is highly variable and overlaps greatly between frequencies associated with each resting posture [28]. The short distances travelled can also be in the period when the bears are foraging and HR is high during this activity in mammals [30]. Bears can also stay stationary when they are affected by a threat, and stress induces variations in HR [10]. During short movements, the relationship between HR and distance travelled is less precise because the variation of the bears' activity is



high. We can, therefore, conclude that HR is not related to short distances travelled, being high or low depending on the activity.

The bear identities were included in the models as a random factor which takes into account the potential existence of individual variations. In turn, this may illustrate the existence of different animal personalities [16]. We found that individual differences were important in explaining HR variations. It would be relevant to not only explore more precisely these individual variations in a future study, but also explore the percent change in HR, relative to the daily or weekly average, to study more deeply the seasonal variations. Moreover, for the following of this study, it would be judicious to narrow the GPS time interval. The collars were programmed to record locations every hour, but the bears can walk around the position without going too far. We interpreted this

situation as stationary bears that travelled, at best, very short distances, but maybe they were more active, e.g., foraging on little patches of berries. Reducing the time interval between GPS positions would give us more precision about the distance travelled by the bears.

Conclusion

Our findings suggest that HR increases with distance travelled, and varies with time, reproductive status and individuals. Studying the change in HR in free-ranging wildlife helps to evaluate their seasonal rhythms and how environmental, intraspecific and human-related factors affect them. In this study, we focused on differences among bear classes, time, and distance travelled, and found that during short movements, bears could have a high or low HR, indicating that movement alone is not sufficient to study energy budget, as is sometimes

Table 2 Selection of LME models of factors influencing the relationship between HR and distance travelled

| | Models | AIC | Delta | Weight |
|-----------------|---------------------|-----------|---------|--------|
| Long distances | HR~logdist*yday | 155,612.7 | 0 | 1 |
| | HR~logdist*Age | 155,953.9 | 341.24 | 0 |
| | HR~logdist*Bodymass | 155,967.6 | 354.97 | 0 |
| | HR~logdist*Sex | 155,974.6 | 361.91 | 0 |
| | HR~logdist*Status | 155,997.5 | 384.80 | 0 |
| | HR~1 | 158,602.4 | 2989.77 | 0 |
| Short distances | HR~logdist*yday | 135,388.8 | 0 | 1 |
| | HR~logdist*Age | 136,341.5 | 952.65 | 0 |
| | HR~logdist*Bodymass | 136,351.7 | 962.91 | 0 |
| | HR~logdist*Status | 136,358.7 | 969.84 | 0 |
| | HR~logdist*Sex | 136,370.3 | 981.50 | 0 |
| | HR~1 | 136,479.9 | 1091.03 | 0 |

The selection is done on brown bears in southcentral Sweden during long and short distances. The best models are the ones with the lowest AICs having a delta < 4 and with a weight = 1. The delta is the difference between the AIC scores according to the lowest one. logdist corresponds to the logarithmic distance travelled. yday corresponds to day-of-year numbers

done [1, 31]. Failing to include additional variables may provide limited, potentially misleading, information. We suggest that this study illustrates the potential of combined bio-logging tools, e.g., GPS collars and HR loggers, in animal ecology.

Methods

Study area

The study area covered 2100 km² in Dalarna and Gävleborg counties, southcentral Sweden (61°N, 15°E). The area consists of boreal forests with lakes, bogs and coniferous (mainly Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*)), with elevations from 200 to 1000 m. This area is also covered by birch (*Betula spp.*), heather

(*Calluna vulgaris*), grasses and berry-producing shrubs [9, 32]. From 2014 to 2017, the mean ambient temperatures in spring (end of April–June 20th) and summer (June 21st–mid-August) were 11.6 °C and 16.3 °C, respectively (Dalarna county, [33]). The snow cover lasts until early May [34].

Bear's HR and movement

Bears were captured by helicopter and handled according to an established protocol [35]. All bears were previously equipped with GPS–GSM (Global System for Mobile) collars (VECTRONIC Aerospace GmbH, Berlin, Germany) with an accuracy of ±10 m [36]. The collars were programmed to obtain locations every hour. The bears were equipped with cardiac bio-loggers (Reveal[®] XT, Medtronic Inc., Minneapolis, Minnesota, USA; 9 cc; 8 mm × 19 mm × 62 mm; 15 g; 3-year recording life [5, 37], programmed with BearWare, Medtronic Inc., Minneapolis, USA). Briefly, the loggers were sterilised with ethylene oxide gas (Anaprolene AN74i 60 L, Andersen Europe, Kortrijk, Belgium) and were surgically implanted peristernally on the left side between the muscle and subcutaneous fat. The incision was closed using 2–0 monofilament glycomer (Biosyn Corporation, Carlsbad, California, USA) or PDS (Ethicon, Ohio, USA) sutures [8]. The loggers are measuring voltage differences with two 40-mm distant electrodes in a 256-Hz sampling rate. The raw electrocardiogram data are continuously processed into interbeat intervals and further into a 2-min mean HR in bpm that is saved on the logger's memory. The memory capacity is 1 year and data were retrieved using a non-invasive transcutaneous telemetry system (CareLink Model 2090 Programmer, Medtronic Inc., Minneapolis, MN, USA) during captures once per year (April to June). All animal captures and handling were approved by the Ethical Committee on Animal

Table 3 LME model with factors affecting HR during long distances (> 50 m in an hour)

| Groups | Name | Std. dev. | | |
|-------------------------------------------------|-------------|------------|---------|--------|
| Random effects | | | | |
| YID | (Intercept) | 12.46 | | |
| Residual | | 14.23 | | |
| Number of observations: 19,078, groups: YID, 23 | | | | |
| | Value | Std. error | t-value | P |
| Fixed effects | | | | |
| (Intercept) | −7.94 | 4.38 | −1.81 | 0.07 |
| logdist | 11.48 | 0.59 | 19.58 | <0.001 |
| yday | 0.26 | 0.02 | 12.94 | <0.001 |
| logdist:yday | −0.03 | 0.003 | −9.85 | <0.001 |

YID is included in random effect. logdist corresponds to the logarithmic distance travelled. yday corresponds to day-of-year numbers

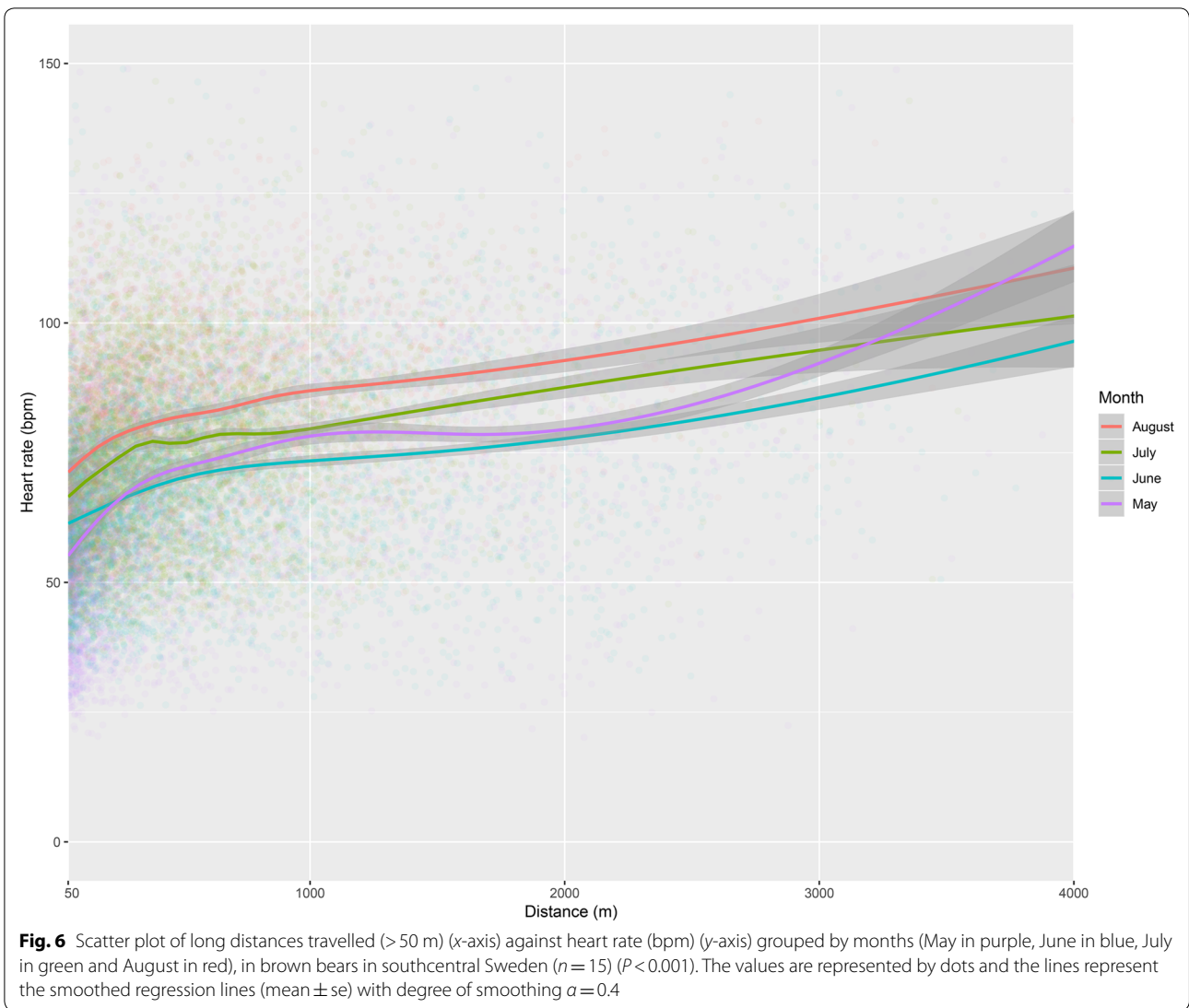
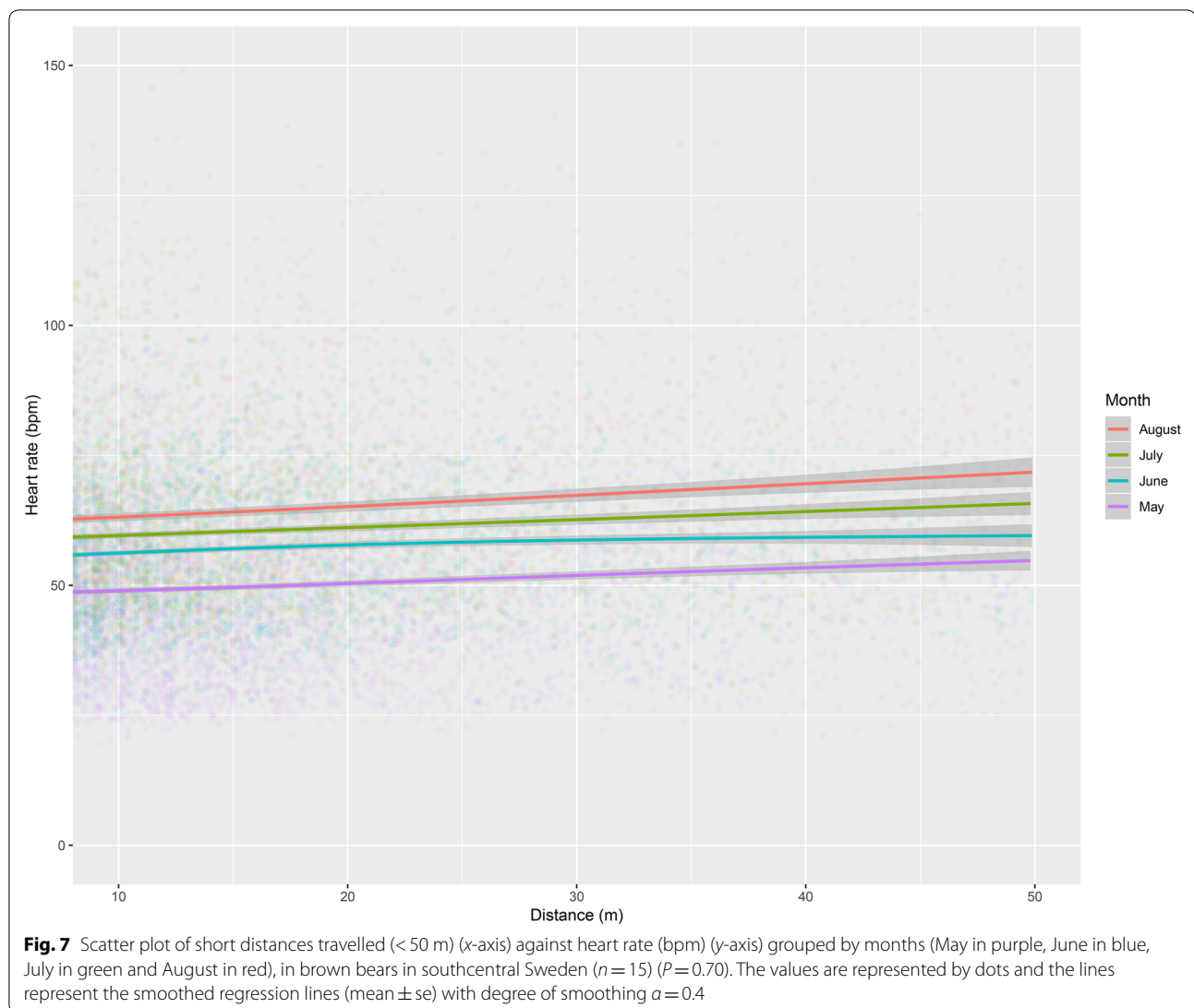


Table 4 LME model with factors affecting HR during short distances (< 50 m in an hour)

| Groups | Name | Std. dev. | | |
|-------------------------------------------------|-------------|------------|---------|---------|
| Random effects | | | | |
| YID | (Intercept) | 10.19 | | |
| Residual | | 13.06 | | |
| Number of observations: 16,953, groups: YID, 23 | | | | |
| | Value | Std. error | t-value | P |
| Fixed effects | | | | |
| (Intercept) | 35.54 | 2.61 | 13.63 | < 0.001 |
| logdist | 1.02 | 0.61 | 1.67 | 0.09 |
| yday | 0.11 | 0.01 | 12.39 | < 0.001 |
| logdist:yday | 0.001 | 0.003 | 0.37 | 0.70 |

YID is included in random effect. logdist corresponds to the logarithmic distance travelled. yday corresponds to day-of-year numbers

Experiments, Uppsala, Sweden (Application C18/15) and the Swedish Environmental Protection Agency.



In this study, GPS positions and HR data from the end of April to mid-August during the years 2014–2017 were included. This excludes the months of hibernation and the bear hunting season. The distances travelled between consecutive positions were calculated using adehabitatLT [38]. For each hourly locations and corresponding distance calculation, the mean HR was calculated from the 2-min heart rates of the previous hour. Data were available from 15 bears, eight males and seven females. Four females had cubs-of-the-year in 2016 and one in 2017. Body mass was weighed at capture and age (for bears not followed from birth) was determined by counting the annuli of a cross section of the premolar roots [8]. A body mass < 60 kg was considered small ($n = 8$), medium between 60 and 120 kg ($n = 11$) and large for > 120 kg ($n = 4$). An age < 5 years was considered young ($n = 11$), middle-aged between 5 and 15 years ($n = 3$) and old

when > 15 years ($n = 9$). Bears travelled long distances when the movement distance exceeded 50 m in an hour, as previously validated with 25 m in half an hour [2].

Statistical analysis

GAMM was fitted with HR as the response variable and yday (day-of-year number) and hour (time of day) as smooth terms. A combination of bear identity and year (YID, $n = 23$) was added as a random-effect smooth term. Basic LME models were fitted with HR as the response variable. Distance travelled, reproductive status (accompanied by cubs or solitary), sex (female or male), body mass (small, medium or large), age (young, middle-aged or old), hour and yday were included as potential explanatory variables. YID was added as a random effect. AIC was used for model selection [39, 40], on an

a priori formulated candidate model set. Differences in AIC scores ($\Delta < 4$) and Akaike model weights [41] were used to choose the best models. ANOVA was used to compare models with and without the random effect. Correlation coefficients (r) between HR and distance travelled were obtained by parametric Pearson tests. Distance travelled was log transformed to improve model performance and to avoid over-dispersion of the deviance. We found a bimodal distribution of the logarithmic distance travelled corresponding to short and long distances travelled by bears. We separated the data set into short and long distances travelled with 50 m as the cut-off value. All statistical analyses were done using R [42] version 3.5.1, R-studio [43] version 1.1.463 and relevant packages. All data (GPS and HR) were stored in the WRAM (Wireless Remote Animal Monitoring, [44]) database.

Abbreviations

HR: heart rate; bpm: beats per minute; GAMM: Generalised Additive Mixed Model; LME: linear mixed effects; YID: bear identity + year; GPS: Global Positioning System; GSM: Global System for Mobile; AIC: Akaike Information Criteria; WRAM: wireless remote animal monitoring.

Acknowledgements

Holger Dettki at the WRAM database in Sweden made this study, with millions of data points, feasible. Field technicians Sven Brunberg, David Ahlquist, Andrea Friebe and veterinarian Anne Randi Græsli contributed to capturing the bears and collection and storage of data. Olivier Devineau at Inland Norway University of Applied Sciences provided statistical advising. This is scientific paper no. 282 from the Scandinavian Brown Bear Research Project.

Authors' contributions

ALE, JMA, OGS, BF and TGL collected data in the field. JMA and OGS secured funding. LB and BF prepared data for analysis. LB analysed the data, and, together with BF and ALE interpreted the movement and heart rate data. BF assisted and advised on the statistical analysis. LB drafted the manuscript. All authors contributed to discussing results, preparing and revising the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used during the current study are available from Alina L. Evans on reasonable request.

Ethics approval and consent to participate

All brown bear captures and handling were approved by the Ethical Committee on Animal Experiments, Uppsala, Sweden (Application C18/15) and the Swedish Environmental Protection Agency in compliance with Swedish laws and regulations.

Consent for publication

Not applicable.

Competing interests

Timothy G. Laske is an employee of Medtronic Inc. The devices utilised are not available for sale for veterinary or wildlife applications.

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