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Body temperature changes in wild-living badgers *Meles meles* through the winter

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In central Norway, the body temperatures of two wild-living badgers *Meles meles*, one male and one female, were recorded in the morning and evening from early November to late March using an implanted temperature-sensitive radio transmitter. The external ambient and internal sett temperatures were also recorded. Both badgers showed a general decrease in their mean daily body temperature from early November until the second half of December, followed by a general increase until the beginning of March. The reduction in body temperature for both animals was around 2-3°C. The female spent most of the winter under a building, in a crawl space where the internal temperature varied from +4°C to -11°C, being strongly influenced by the external ambient temperature. The male spent the winter in a natural sett where the temperature was rather constant (+2-5°C), and where the external ambient temperature had little influence on the internal sett temperature. However, the external ambient temperature only accounted for 11 and 12% of the observed body temperature variations in the male and female, respectively. When the length of daylight was compared with the body temperatures, it was found to account for 60 and 30% of the variations in the male and female temperatures, respectively. Thus, the data indicate that the photoperiod, at its minimum at the winter solstice, acted as the primary synchroniser of the body temperature cycle in the badgers during their winter lethargy.

Key words: body temperature, burrows, Meles meles, sett temperature, winter lethargy

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To cope with periods of unfavourable climatic conditions, many mammals (e.g. American badger *Taxidea taxus* (Harlow 1981), European badger *Meles meles* (Kruuk 1989), alpine marmot *Marmota marmota* (Arnold 1990) and racoon dog *Nyctereutes procyonoïdes* (Kauhala 1993)) use underground burrows and show both behavioural and physiological adaptations to promote their survival and increase their reproductive output. The European badger forms social groups with shared burrows ('setts') scattered around its territory, one of the setts (the 'main sett') being used for joint overwintering by group members (Roper & Christian 1992). To tackle exposure to severe winter conditions in parts of their geographical range, badgers reduce their activity (Göransson 1983), insulate sleeping chambers (Roper, Tait, Fee & Christian 1991) and build up large fat reserves in autumn (Kruuk & Parish 1983). Under seminatural conditions, they are also known to reduce their body temperature during the winter lethargy (Fowler & Racey 1988). To our knowledge, the winter body temperature of wild-living badgers has not been measured previously, although it was recorded in captive animals which were entirely exposed to natural environmental conditions in their artificial sett in Scotland (Fowler & Racey 1988). In the present paper, we describe body temperature variations in two wild-living badgers during their winter lethargy at 63°N in central Norway in relation to ambient temperature, internal sett temperature and length of daylight. The two badgers belong to one of the northernmost reproducing badger populations in Scandinavia (Bevanger & Lindström 1995).

Material and methods

Two badgers (a young female of 13.9 kg and an adult male of 14.5 kg) were caught in cage traps at a sett beneath a daily occupied engineering workshop and outside a natural sett dug in clay soil, respectively, in Trondheim (63°36'N, 10°25'E), Sør-Trøndelag, Norway, in autumn 1989 (Bevanger, Brøseth, Johansen, Knutsen, Olsen & Aarvak 1996). In winter 1989/90, the mean monthly ambient temperatures were high in all months during October-March, except for December, compared to the 30-year normal. February had unusually high temperatures, with an ambient temperature which was 7.4°C above normal and which dropped below zero on four days only (data provided by the Norwegian Meteorological Institute).

The badgers were immobilised by an intramuscular injection of ketamine hydrochloride (*cf.* Cheeseman & Mallinson 1980) and were taken to a veterinary surgeon who implanted a temperature-sensitive radio transmitter (Telonics IMB/400/L S4, 142 MHz) in their abdominal cavity, as described by Fowler & Racey (1988), to measure their body temperature (Tb). The cylindrical transmitters (33 × 97 mm weighing 90 g) comprised less than 1% of the body mass when implanted and were calibrated to an accuracy of 0.2°C. Following surgery, the badgers were given an intramuscular injection of an antibiotic (600 mg benzyl penicillin procain) and were released at their setts.

The data acquisition system comprised a standard dipole antenna (Telonics RA-2AK) and a receiver (Telonics TR-2) connected to a digital data processor (Telonics TDP-2) which measured the inter-pulse period (in milliseconds) from the S4 thermistor signal emitted by the radio transmitter. The Tb was calculated using the formula Tb = R2(PIt)/PI1, where R2 is the resistance of the precision resistor, PIt the pulse interval determined by the thermistor and PI1 the pulse interval determined by the precision resistor. The external ambient (Ta) and internal sett (Ts) temperatures were recorded using Grant model D recorders, with thermistors 0.5 m above ground level at the sett entrances and about 3 m inside the setts. Data were collected in the morning (07:00-12:00 GMT) and evening (18:00-22:00 GMT) from late October to the beginning of March, when the winter lethargy terminated.

The thermistors were placed as deep inside the sett as possible from the entrance. The technique used to place the thermistor was: we welded a clamp ('ball cage') for a plastic ball (of the type used to keep fishing nets floating) that could rotate around an axle on the end of a strip steel (of the type used by plumbers to open blocked sewer pipes). We then taped the thermistor to the ball cage and 'rolled' it into the sett. A cord was fastened to the tape and when it was impossible to get the strip steel further into the sett, the cord was pulled and the thermistor released.

Results

The young female in the crawl space changed her abode during the winter. Three days after the transmitter had been implanted (6 November), she moved to another sett (S2) under a barn about 2 km from the first sett (S1) and stayed there for nearly two weeks. On 19 November, she returned to S1. During these two weeks, she was observed outside the sett on several occasions during evening recordings. She remained in S1 from 20 November until 17 February and was not observed to be active outside the sett. On 18 February, she again walked to S2 and stayed there for two days before returning to S1. After another 3 days (on 24 February) she returned to S2 and remained there until the beginning of March, being observed active outside the sett during several evening recordings.

Between the date of implantation (27 October) and 12 November, the adult male was twice observed active outside the sett, but after that he was not seen active again until 5 February. From then until the beginning of March, he was seen active outside the sett during several evening recordings. Once he stayed over night in another natural sett about 500 m from his overwintering sett. Neither badger was ever observed to be active during morning recordings.

The mean daily body temperatures of both badgers showed a general decrease of 2-3°C from early November until the second half of December, followed by a general increase until the beginning of March (Fig. 1). However, the female showed larger short-time variations in body temperature than the male. In S1, where the female spent most of the winter, the internal temperature varied from +4°C to -11°C and was strongly influenced by the external ambient temperature ($r^2 = 0.53$, $P < 0.001$, $N = 147$). In the natural sett where the male spent the winter, the external ambient temperature had little influence on the internal sett temperature ($r^2 = 0.02$, $P = 0.059$, $N = 156$), which was rather constant (+2-5°C). However, the external ambient temperature only accounted for 12 and 11% of the observed variations in the body temperatures of the female and male, respectively ($r = 0.34$, $P < 0.01$, $N = 84$; $r = 0.33$, $P < 0.01$, $N = 87$). When the length of daylight was compared with the body temperatures, it was found to account for 60 and 30% of the variations in the male and female, respectively ($r = 0.77$, $P < 0.001$, $N = 116$; $r = 0.54$, $P < 0.001$, $N = 111$).

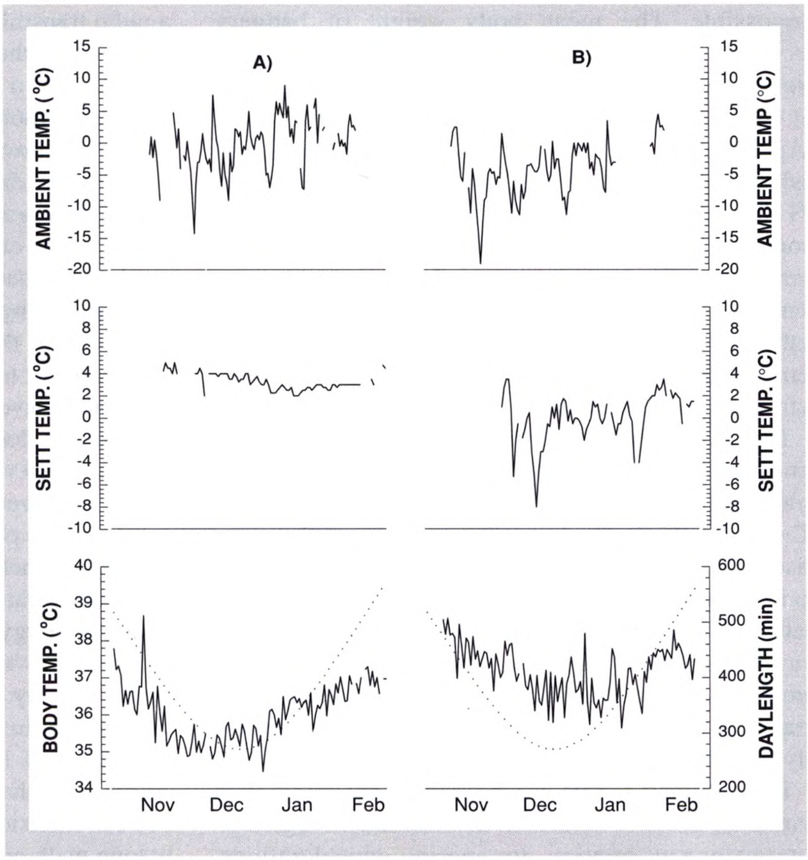

Figure 1. Variations in ambient temperature, internal sett temperature, body temperature and daylight length (dashed line) for A) an adult male badger in a natural sett, and B) a young female badger in a crawl space, in Trondheim during winter of 1989/90.

Discussion

The observed body temperature reduction of 2-3°C during winter lethargy of wild-living badgers supports the general results found by Fowler & Racey (1988) under seminatural conditions in Scotland. The only individual deviating from this pattern was a pregnant adult female in the Scottish study, who reduced her body temperature by 8-9°C prior to implantation of the blastocysts. There was no indication that the young female in Trondheim gave birth to cubs while she was being studied.

Harlow (1981) estimated a metabolic saving for the American badger of 17 g fat/day with a reduction in body temperature of 1.7°C. Transferred to the European badger, a reduction of 2-3°C is a significant contribution to energy saving during winter lethargy; a rough estimate would give 30 g fat/per day for 150 days, which is about 4,500 g. Thus, if the badger did not reduce the body temperature it would suffer a weight loss of about 9 kg, which is clearly impossible. The mean body weight of badgers recorded in the study area in autumn (October/ November) was 13,047 g (N = 8) and 13,251 g (N = 6) for females and males, respectively. In spring (April/May), the mean body weight had been reduced to 7,810 g (N = 5) for females and 8,590 g (N = 18) for males (Bevanger et al. 1996). A proportionately higher weight loss for females, 40% compared to 35% in males, probably arises because females are nursing without access to food during the lethargy period. Consequently, a reduction in body temperature is essential if the animal is to survive the winter at these latitudes.

The hypothesis has been put forward that the length of the winter is the crucial factor for the geographical distribution of the badger in Scandinavia (Lindström 1989, Bevanger & Lindström 1995). The distribution boundary, where the cost of inaccessible food caused by snow cover and frozen ground must balance the potential for fat storage and possibilities for physiological recovery, can to some extent be predicted. Without a lethargy period, the present geographical distribution of the species would presumably have been displaced southwards.

The observed frequency of badger setts associated with man-made structures in the Trondheim region is interesting in relation to energy considerations (Bevanger et al. 1996, Brøseth, Bevanger & Knutsen 1997a). Of 62 setts identified in a badger research area in the city of Trondheim, 40 were established in connection with man-made structures, i.e. mainly below buildings (Bevanger et al. 1996). The reasons for the extensive use of man-made structures as setts by badgers could be that the animals save energy by utilising buildings and crawl spaces if they fulfil sett requirements, or that there is a lack of possibilities for natural sett establishment in the area. Moreover, as badgers have been numerous in central Norway for about 20 years only (Bevanger 1990) the development of complex sett structures like those found e.g. in England (Neal & Roper 1991) may still take some time.

A rationale behind the present study was to identify possible differences in energy saving between natural and man-made sett constructions as overwintering places for badgers. The findings, a stable internal temperature in the natural sett unaffected by the ambient temperature and a temperature in the crawl space sett that is significantly influenced by the outside temperature, indicate that natural setts are more optimal. The fact that another female, implanted with a radio transmitter without a thermistor, stayed in the same sett as the male during the winter, indicates that this sett was a good overwintering place. The apparently less stable pattern of sett use during the lethargy period shown by the young female, who alternated between different setts and was active in their vicinity on several occasions, could be another indication of the crawl space sett being suboptimal compared to the natural sett. Her sett was located beneath an engineering workshop, and the people working there during the day heard movements beneath the floor more or less all winter. The activity of the workers could have had a disturbing effect on animals beneath the floor as well and may have contributed to the increased variation in body temperature.

The observed variation in body temperature indicates that the photoperiod, at its minimum at the winter solstice, acted as the primary synchroniser of the body temperature cycle in the badgers during their winter lethargy. Moreover, the ambient temperature and snow cover obviously have a modulating effect on the activity of the animals (Fowler & Racey 1988, this study). In central Norway, the first snowfall in the winter of 1989/90 came on 21 November, coinciding with the last day the female was observed to be active outside the sett. The male took a particularly long walk on 11 February, being observed at 23:00 GMT more than 2 km from the sett. The ambient temperature had risen from -2.5°C on 10 February to +3°C on 11 February. However, the roads were still completely covered by snow and ice.

Badgers mainly feed on invertebrate prey which they find in and on the ground at these latitudes (Skoog 1970, Lindström 1989, Brøseth, Knutsen & Bevanger 1997b). Hence, in central Scandinavia, badgers have no access to food during the period of snow cover and frozen ground, i.e. October/ November to March/April. Thus, to be able to live at these high latitudes, they spend the unfavourable time of the year in insulated underground burrows and have developed behavioural adaptations like joint hibernation (Brøseth et al. 1997a) and physiological adaptations like body temperature reduction to cope with the food shortage.

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