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An Individual-Based Method to Measure Animal Activity Levels: A Test on Brown Bears

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Abstract

*Measuring activity levels in animals provides important information about their behavioral ecology and may be a relevant factor in management and conservation. We tested an individual-based method to discriminate active and passive behaviors on brown bears (*Ursus arctos*), using a dual-axis motion sensor mounted on Global Positioning System–Global System for Mobile Communications (GPS–GSM) collars. The method takes into account individual variation in activity levels and does not require further calibration. We validated the method through direct observations of captive bears and an extensive survey of wild bear signs in the boreal forest of central Sweden. We found good correspondence between sensor-measured and observed activity on captive bears. Analysis of wild bear signs at GPS locations and its comparison with the collar-based activity status confirmed the possibility of successfully applying the method to study brown bear activity patterns in the wild. The method provided 94.3% correct activity classification on captive bears and about 78.2% on wild bears. We tested the possibility of using this technique to measure increasing levels of activity by analyzing the correlation between the collar-derived numeric activity and the intensity of bear movement. At a broader scale (active vs. passive), the sensor-measured value provided information on the degree of activity, but no correlation was evident at a finer scale (specific behaviors). We suggest that using more sensors in different regions of a bear's body could overcome this difficulty and improve our knowledge of animal behavior in the wild, through remote monitoring of activity levels. We conclude that this method can be useful in the study of behavioral ecology of a wide range of animals, especially species that are difficult to observe or move great distances.* (WILDLIFE SOCIETY BULLETIN 34(5):1314–1319; 2006)

Key words

activity levels, brown bear, dual-axis sensor, GPS collar, radiotelemetry, Sweden, Ursus arctos*.*

Diel and seasonal activity patterns are important components of behavioral ecology, and their mechanisms are defined by a complex trade-off between the internal physiological system of the organism and its interactions with several properties of the environment (Palmer 1976). Aside from this theoretical interest, investigating activity patterns is relevant for management and conservation because of the increasing interaction between wild species and humans, which poses the need for a correct calibration in time of potentially disturbing anthropogenic activities (Gunther 1990, Thurber et al. 1994, Kligo et al. 1998, Olson et al. 1998). Nevertheless, animal activity often is hard to investigate, especially in species that are elusive, forest-dwelling, or those that move great distances.

Some studies have documented activity patterns through direct observations of focal animals (Phillips 1987, Olson et al. 1998, MacHutchon 2001, Gelatt et al. 2002). These methods can be successfully applied only in areas with little or no cover and where animals can be easily watched, but the results often are biased against nocturnal activity or activities that occur in areas with a low visibility. For these reasons many researchers have used radiotelemetry to study circadian and annual activity patterns of a wide range of mammal species, such as bears (*Ursus* spp.), wolves (*Canis lupus*), and deer (Roth 1983, Beier and McCullough 1990, Clevenger et al. 1990, Ciucci et al. 1997), through 1) the interpretation of signal fluctuations, or 2) using the information provided by motion-sensitive radiocollars.

The signal-fluctuation method is based on the assumption that animal movement can influence the transmission of radio signals (Cochran and Lord 1963). Therefore, the animal is considered active when the received signal changes repeatedly in tone or strength during a fixed time interval. This method has been widely used to investigate activity patterns (Roth 1983, Roth and Huber 1986, Bjärvall and Sandegren 1987), but Knowlton et al. (1968) considered it to be an unreliable index of activity, mainly because it requires a subjective interpretation of radio signal quality.

In motion-sensitive radiocollars, animal movement activates a sensor that changes the signal mode, usually the pulse rate. The activated pulse rate continues for a fixed time interval (reset switch mode) or until a further movement generates a new change in the pulse rate of the signal (tip switch mode). Motion-sensitive radiocollars often give more reliable indications of activity than signal fluctuations (Garshelis et al. 1982), but the time delay between movement and signal change can be a major problem, aside from the difficulty of finding a reliable criterion to define activity (Kaczensky at al. 2004).

We tested the possibility of using a dual-axis motion sensor, mounted on Global Positioning System (GPS) collars, as a new and more reliable tool to study activity patterns, with brown bears (*Ursus arctos*) as the test species.

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We developed a method to discriminate active and passive behaviors by measuring the true acceleration of the collar in 2 orthogonal directions. The method is individual-based because it accounts for individual variation in activity levels, treats each animal independently, and does not require further calibration. We validated this method using experimental data from captive and wild bears through direct observations and an extensive survey of bear signs.

The information provided by the dual-axis sensor is not a binary activity status (active–passive), but rather a numeric value, a result both of intensity and duration of collar movement. We usually consider activity as an expression of the energy an animal uses during a certain time interval, and we often classify it in binary categories, even though energy expenditure changes along a continuum. Measuring the increasing energy associated with movement would provide greater insight into behavior than simply assigning an activity status. For this reason we also analyzed the relationship between the numeric information provided by the dual-axis sensor and the intensity of bear movement to test the possibility of using this technique to measure increasing levels of activity.

Study Area

We captured 4 wild female brown bears in April 2004, in the boreal forest of Dalarna and Gävleborg counties (61°27′N, 15°21′E) in central Sweden. The area was characterized by a gently rolling terrain and dominated by an extensive forest of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). We fitted the bears with a type of collar as described below and monitored them between April and September 2004, with a schedule of 48 GPS locations per day. During this period we randomly selected 868 GPS bear locations from the data set. We examined the locations 3 days after the bear had been at the site and recorded all visible fresh signs of bear presence inside a 30-m circle centered on the location, discriminating between signs of active behavior (used anthills, tree stumps, carcasses, turned stones) and those of passive behavior (daybeds).

Methods

The Individual-Based Method

The dual-axis motion sensor in the GPS collars in our study (Vectronic Aerospace GmbH, Berlin, Germany) is an accelerometer, which separately measures the true acceleration of the collar in 2 orthogonal directions 6–8 times per second. Then it averages all the acceleration values recorded during the time interval between 2 successive activity fixes and generates a numeric value for each direction, ranging from 0 to 255. However, the acceleration value measured by the sensor can be affected by several factors not directly related to animal movement. Collar tightness, as a consequence of neck size, is the most important of these factors and can differ between bears or even for the same bear between spring and autumn. Therefore, using this dual-axis sensor as an activity indicator requires a method that takes into account these factors and the individual behavior of each animal (Moen et al. 1996).

The individual-based method we developed is founded on the hypothesis that activity levels do not change gradually. When an animal is passive (sleeping or resting), its activity should be very close to zero, whereas active behaviors (walking, eating, running) should produce relatively high levels of activity. This hypothesis generates the prediction of a bimodal frequency distribution of activity levels and suggests the possibility that the low point of the distribution marks the separation between active and passive behaviors. Testing this hypothesis was the main goal of the validation process; therefore, we expected the distribution of activity levels recorded by the sensors to be bimodal.

Data Collection

The protocols for brown bear research by the Scandinavian Brown Bear Research Project were approved by the Uppsala (Sweden) Ethical Committee on Animal Experiments (Uppsala djurförsöksetiska nämnd), permit C40/3. This approval was given on 28 March 2003 and was valid for 3 years.

We fitted 2 captive brown bears, a yearling male and an adult female, with GPS–Global System for Mobile Communications (GPS–GSM) collars equipped with the dual-axis motion sensor described above. We used a 5-minute time interval between successive activity fixes because a longer fix interval can induce lower accuracy in sampling short activity bouts (Adrados et al. 2003). We released the 2 bears in a 2-ha enclosure at Orsa Grönklitt Bear Park (Orsa, Sweden) and filmed them with a digital videocamera for 40 hours between May and June 2004. Then, we classified each 5-minute sequence as "active" when the bear spent >50% of observed time feeding, grooming, or moving, or "passive" when it was sleeping, resting, or standing immobile for >50% of the observed time. We also associated each sequence to an energy expenditure index (EEI), ranging from 0 to 6, determined from observations of the intensity and duration of bear movements. We first assigned an intensity value to each behavior of every filmed sequence (0 = resting or sleeping, 1 = grooming, 2 = sedentary feeding, 3 = not sedentary feeding, 4 = walking, 5 = running, 6 = playing or fighting) and then calculated an overall EEI, weighted for the duration of each behavior in the 5-minute sequence:

$$\mathrm{EEI} = \frac{\sum_{i=1}^{N} d_i i_i}{N},$$

where i = intensity value associated with each behavior, d = relative duration of the behavior inside a sequence, and N = number of different behaviors inside the sequence.

Data Analyses

We used the overall acceleration in the 2 orthogonal directions (total activity level) as the test variable and grouped its range (0–510) into 51 activity classes of 10 units to reduce the variability of the system. Then we plotted the

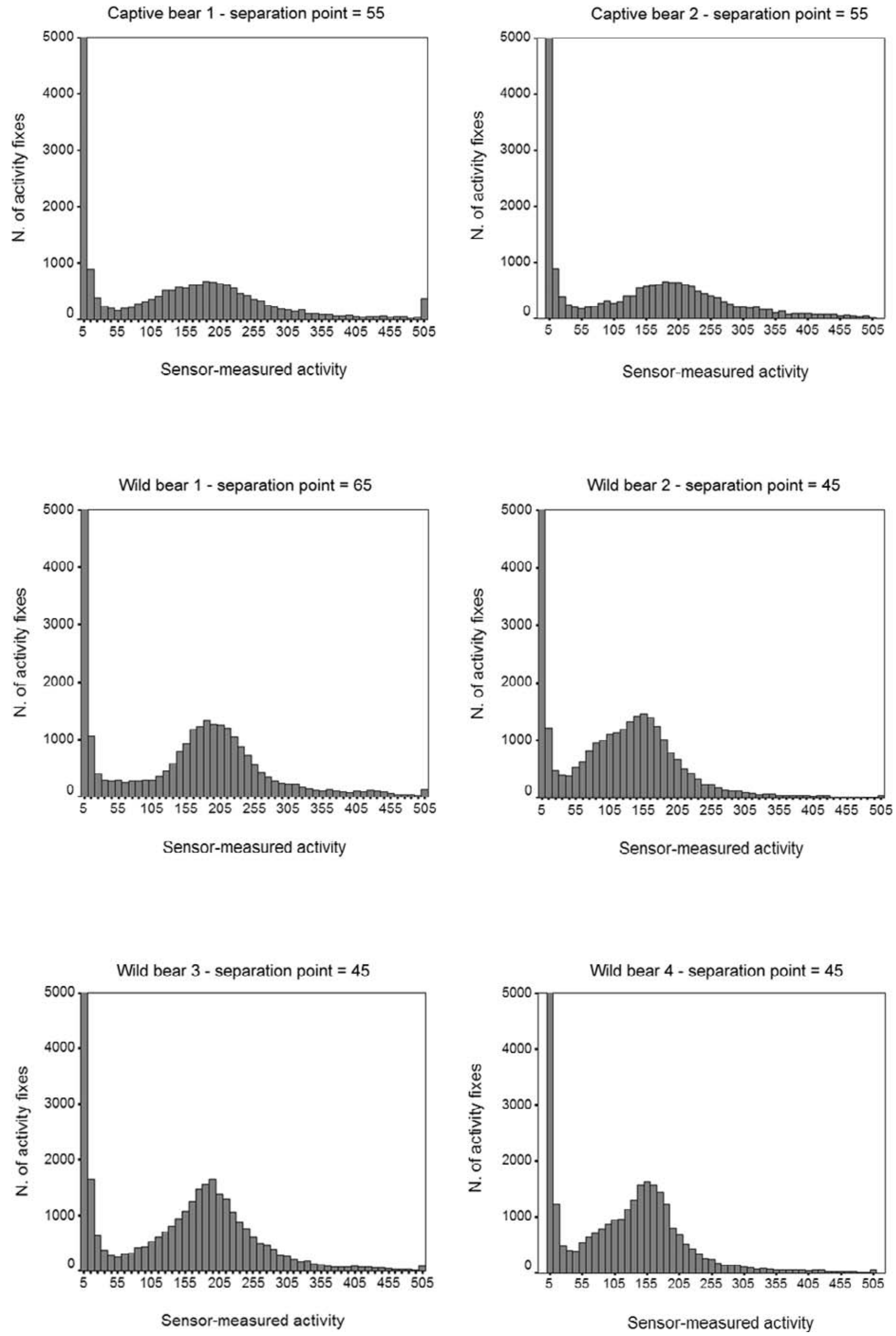

Figure 1. Frequency distribution of activity classes in captive and wild brown bears fitted with Global Positioning System–Global System for Mobile Communications collars and a dual-axis motion sensor between Apr and Sep 2004 in central Sweden.

frequency distribution of all the activity classes for each bear to determine whether it was bimodal, and defined the separation point as the mean value of the activity class with the lowest frequency in the range between the 2 modes of the distribution. Activity values lower than the separation point were considered passive, whereas values higher or equal to the separation point were considered active.

We also simulated the effect of choosing a different separation point and created 50 more activity classifications. In each of them we chose a different activity class to separate passive and active behaviors. We then compared the observational data collected on captive bears and field data collected for wild bears with those provided by the dual-axis motion sensor, to test their correspondence and validate the individual-based method. The validation process was based on 3 null hypotheses, which we tested using χ^2 tests:

H_1 There is no correspondence between the collar-based activity classification and the direct observations of captive bears.

H_2 The characteristics of fresh signs at bear locations are independent of the activity classification provided by the collar.

Table 1. Correspondence between collar-measured and observed activity of 2 captive brown bears fitted with Global Positioning System–Global System for Mobile Communications collars and a dual-axis motion sensor between May and Jun 2004 in Orsa Grönklitt Bearpark, Sweden.

Bear	Observed activity	Collar-based activity		Correspondence (%)
		Active	Passive	
1	Active	138	7	94.9
	Passive	5	56	91.0
2	Active	141	6	95.7
	Passive	4	54	92.6
Total	Active	279	13	95.3
	Passive	9	110	91.8

H_3 The correspondence between collar-derived and observed activity on captive bears is not higher using the separation point calculated with this individual-based method than using other values of the distribution.

Finally, we tested the null hypothesis (H_4) that increasing levels of bear activity, as a result of different behaviors, do not produce increasing collar-derived activity values. We used a Spearman's correlation test to analyze the relationship between the numeric value of total activity, provided by the sensor, and the energy expenditure index, assigned to each sequence through the visual observation of bear movement. We applied the Spearman's test first to the whole data set, then only to the sequences of active behavior to analyze the correlation on a broad and fine scale.

Results

We collected about 40,000 activity fixes for each captive and wild bear during 5 months of sampling. The frequency distribution of collar-based activity classes was bimodal for captive and wild bears; therefore, we calculated the separation value for each bear (Fig. 1).

We found a significant correspondence between sensor-measured and observed activity on captive bears. The mean percentage of correct classification was 94.3% (95.3% when the bears were active, 91.8% when they were passive; Table 1) and we could reject the null hypothesis of an equal proportion of active and passive observations among the 2 collar-based categories ($\chi^2 = 298.05$, df = 1, $P < 0.001$).

During the survey of wild bear locations, we found 143 fresh daybeds. Among them, 117 were associated with a passive collar-based classification and 26 with an active classification. The distribution of fresh daybeds and that of collar-derived passive fixes corresponded ($\chi^2 = 57.91$, df = 1, $P < 0.001$). We also found 371 fresh signs of active behavior. Among them, 285 were associated with an active collar-based classification and 86 with a passive classification. The distribution of fresh signs of active behavior and that of collar-derived active fixes also corresponded ($\chi^2 = 106.74$, df = 1, $P < 0.001$). The total percentage of correct activity classification for wild bears was 78.2%. The separation point of activity class 6 (total activity level = 55), calculated with the individual-based method for 2 captive bears (Fig. 1), provided the highest percentage of correct activity classifications (Table 2).

During observations of captive bears, we assigned an EEI to 405 filmed sequences. Among them, 77 sequences (19.0%) corresponding to sleeping or resting behaviors received a value of the index ranging from 0–1 and provided a mean sensor-measured activity of 22.9 (Table 3). Values of the EEI ranging from 5 to 6 were assigned to 12 (3.0%) sequences of playing and fighting behaviors, which provided a mean activity level of 240.6 (Table 3). We found a positive relationship between the total activity level and the EEI ($r = 0.474$, $P < 0.001$). Nevertheless, the relationship was not significant when we applied the correlation test only to the sequences of active behaviors ($r = 0.026$, $P = 0.641$). In particular, we found that grooming and feeding behaviors, which received lower values of the EEI than walking behaviors, provided higher sensor-measured activity levels.

Discussion

The individual-based method to determine activity levels performed well and was reliable in identifying the activity status of captive brown bears, with 94.3% correct classification of active versus passive behaviors. Our results are consistent with previous studies on dual-axis motion sensors. Moen et al. (1996) tested a dual-axis sensor on captive moose (*Alces alces*) and obtained 76% correspondence between observed and sensor-measured activity. Adrados et al. (2003) stressed the need for an individual calibration and tested a different individual-based method on red deer (*Cervus elaphus*), with 88% correct activity classification.

The characteristics of wild bear signs were consistent with the classification provided by the activity sensor, even though the percentage of correspondence was lower for wild bears than for captive bears. We suppose that this difference was not directly related to the efficiency of the individual-based method, but mainly caused by the higher probability of misclassifying the activity status of a bear through the interpretation of its signs in the wild rather than by observing its behavior directly. In fact, some bear behaviors, like grooming, walking, or grazing, leave poor signs and they are, therefore, difficult to detect. They can even be misinterpreted if the bear returns to the same site or a different bear visits the site, leaving signs of a different behavior. In fact, we did not find any sign of bear presence in 37% of our surveys, even though GPS locations are expected to provide an accuracy within a few meters. This percentage increased to 46% during late summer and autumn, when Scandinavian brown bears spend most of the time foraging on berries. Therefore, we concluded that the results obtained through the observation of captive bears were a more accurate measure of the reliability of the individual-based method. Nevertheless, the survey of GPS locations confirmed the possibility of successfully applying the method to study activity patterns of brown bears in the wild because it provided robust results also in uncontrolled conditions, which was the last step of the validation process.

We could not reject the null hypothesis of no correlation

Table 2. Percentage of correct activity classification for 2 captive brown bears fitted with Global Positioning System–Global System for Mobile Communications collars and a dual-axis motion sensor in Apr 2004 in Orsa Grönklitt Bearpark, Sweden, when different separation points were chosen. Class 6 provides the expected number of correct activity classifications in the χ^2 test.

Activity class	Correct classification (*N*)	Wrong classification (*N*)	Correct classification (%)	χ^2	*P*
3 (20–29)	356	49	88.1	25.51	<0.001
4 (30–39)	368	37	90.9	7.48	0.006
5 (40–49)	371	34	91.6	4.43	0.035
6 (50–59)	382	23	94.3		
7 (60–69)	369	36	91.1	6.37	0.012
8 (70–79)	360	45	89.1	17.71	<0.001
9 (80–89)	354	51	87.4	27.42	<0.001

Table 3. Energy expenditure index (EEI) and sensor-measured activity of 2 captive brown bears fitted with Global Positioning System–Global System for Mobile Communications collars and a dual-axis motion sensor in Apr 2004 in Orsa Grönklitt Bearpark, Sweden.

EEI	*n*	%	Mean activity
0–1	77	19.0	22.9
1–2	87	21.5	173.0
2–3	86	21.2	144.4
3–4	85	21.0	156.2
4–5	58	14.3	161.3
5–6	12	3.0	240.6

between collar-derived activity and intensity of bear movement. At a first level, our results confirmed that this technique can provide information on the degree of activity in brown bears, measuring the amount of energy associated with body movement. Nevertheless, this information is not reliable on a finer level: small variations in the activity level could not be used to distinguish between different active behaviors. We can determine if the bear is passive or active, but no reliable information is available on the actual amount of energy used by the animal during a particular behavior.

We believe that the position of the sensor on the collar is the main reason for this fine-scale inefficiency. Being placed around the animal's neck, the dual-axis motion sensor can be affected only by head movements, but no information was collected from the whole body, in particular from the legs. This creates a bias toward certain behaviors and makes the information about the total activity level incomplete. Supporting this idea, relatively high activity values were provided by grooming and grazing behaviors, which are relatively low in energy expenditure but entail constant head movement. On the other hand, walking behaviors, which mainly involve leg movements, provided relatively low sensor-measured activity even though they are more energy consuming.

We successfully validated the individual-based method on brown bears, discriminating between passive and active behaviors, and measured increasing activity levels on a broad scale. However, we believe this technique can be useful to study activity patterns of other species of large animals because of its flexibility in calibrating between passive and active modes for individuals and the increased objectivity and comparability of collected data. Our results also show the possibility of using accelerometers and multifunctional collars to study animal behavior in the wild but also reveal the limitations of this system, in its configuration of a bidirectional sensor placed in a neck collar. We suggest further research to develop a fine-scale reliable indicator of activity in order to discriminate between specific behaviors through remote monitoring of body movements. In particular, we believe this technique can be substantially improved by placing more than one motion sensor in different regions of an animal's body. This may allow researchers to know what specific body part (head, legs) an animal is moving at a certain time, providing crucial information for the interpretation of behavioral patterns and overcoming some difficulties in the study of behavioral ecology of nocturnal, wide-ranging, or elusive species.

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Literature Cited

Adrados, C., H. Verheyden-Tixier, B. Cargnelutti, D. Pépin, and G. Janeau. 2003. GPS approach to study fine-scale site use by wild red deer during active and passive behaviors. Wildlife Society Bulletin 31: 544–552.

Beier, J., and D. R. McCullough. 1990. Factors influencing white-tailed deer activity patterns and habitat use. Wildlife Monographs 109.

Bjärvall, A., and F. Sandegren. 1987. Early experiences with the first radio-marked brown bears in Sweden. International Conference on Bear Research and Management 7:9–12.

Ciucci, P., L. Boitani, F. Francisci, and G. Andreoli. 1997. Home range, activity and movements of a wolf pack in central Italy. Journal of Zoology 243:803–819.

Clevenger, A. P., F. J. Purroy, and M. R. Pelton. 1990. Movement and activity patterns of a European brown bear in the Cantabrian Mountains, Spain. International Conference on Bear Research and Management 8:205–211.

Cochran, W. W., and R. D. Lord. 1963. A radio-tracking system for wild animals. Journal of Wildlife Management 2:9–24.

Garshelis, D. L., H. B. Quigley, C. R. Villarrubia, and M. R. Pelton. 1982. Assessment of telemetric motion sensors for studies of activity. Canadian Journal of Zoology 60:1800–1805.

Gelatt, T. S., D. B. Siniff, and J. A. Estes. 2002. Activity patterns and time budgets of the declining sea otter population at Amchitka Island, Alaska. Journal of Wildlife Management 66:29–39.

Gunther, K. A. 1990. Visitor impact on grizzly bear activity in Pelican Valley, Yellowstone National Park. International Conference on Bear Research and Management 8:73–78.

Kaczensky, P., A. Wagner, and C. Walzer. 2004. Activity monitoring of a brown bear—a model approach to test field methods. Mammalian Biology 69:444–448.
Kligo, J. C., R. F. Labisky, and D. E. Fritzen. 1998. Influences of hunting on the behavior of white-tailed deer: implications for conservation of the Florida panther. Conservation Biology 12:1359–1364.
Knowlton, F. F., P. E. Martin, and J. C. Haug. 1968. A telemetric monitor for determining animal activity. Journal of Wildlife Management 32:943–948.
MacHutchon, A. G. 2001. Grizzly bear activity budget and pattern in the Firth River Valley, Yukon. Ursus 12:189–198.
Moen, R. A., J. Pastor, and Y. Cohen. 1996. Interpreting behavior from activity counters in GPS collars on moose. Alces 32:101–108.
Olson, T. L., R. C. Squibb, and B. K. Gilbert. 1998. Brown bear diurnal activity and human use: a comparison of two salmon streams. Ursus 10:547–555.
Palmer, J. D. 1976. An introduction to biological rhythms. Academic, London, United Kingdom.
Phillips, M. K. 1987. Behavior and habitat use of grizzly bears in northeastern Alaska. International Conference on Bear Research and Management 7:159–167.
Roth, H. U. 1983. Diel activity of a remnant population of European brown bears. International Conference on Bear Research and Management 5:223–229.
Roth, H. U., and D. Huber. 1986. Diel activity of brown bears in Plitvice Lakes National Park, Yugoslavia. International Conference on Bear Research and Management 6:177–181.
Thurber, J. M., R. O. Peterson, T. D. Drummer, and S. A. Thomasma. 1994. Grey wolf response to refuge boundaries and roads in Alaska. Wildlife Society Bulletin 22:61–68.

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