A preliminary evaluation of activity-sensing GPS collars for estimating daily activity patterns of Japanese black bears

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Abstract: The Japanese black bear (*Ursus thibetanus japonicus*) is a forest-dwelling species and can be very difficult to observe directly in most of its habitats. Therefore, as a research tool to evaluate activity patterns and time budgets, we fitted GPS radiocollars with activity sensors on 4 Japanese black bears, 2 males and 2 females, during 2003–06 in the Ashio Mountains, which have open habitats. Through comparison to observations from a video camera with activity sensor values, we categorized activities as either resting (inactive) or feeding with short distance movements (active). Bears were mostly diurnal, although they were increasingly active at dusk. Mean time inactive was 66%, including considerable inactive time during daylight. Time active ranged from 22–48%, depending on the bear. For one adult female, diel active time during a year she was solitary declined significantly from the previous year in which she had nursed 2 yearlings. For one sub-adult male, diel active time decreased significantly with increasing age. Although more research is needed to relate activity values to age and sex in a variety of habitats, we conclude that GPS collars with a built-in activity sensor can be an effective research tool for clarifying the living habits of Japanese black bears. If future studies can further refine relationships between sensor values and activity categories, diel energy costs for Japanese black bears may also be estimated.

Key words: activity sensor, Ashio Mountains, diel activity patterns, GPS, Japanese black bear, time budgets, *Ursus thibetanus japonicus*

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There is little published information on activity patterns of the Japanese black bear (*Ursus thibetanus japonicus*; Nozaki and Mizuno 1983, Hazumi et al. 1985). Because they inhabit steep, forested areas, it has been difficult to determine their activity patterns and time budgets. The only means of determining activity patterns has been using VHF (very high frequency) radiocollars and recording the changing signal strength via a pen recorder (Nozaki and Mizuno 1983; Hazumi et al. 1985; Yamazaki unpublished data). VHF radiocollars with a motion sensitive device that changed the beacon rate in response to movement of the bear's head have been used to study ursids: American black bear (*Ursus americanus,* Beecham and Rohlman 1994); Asiatic black bear (*Ursus thibetanus* in Taiwan, Hwang and Garshelis 2007); European brown bear (*Ursus arctos*, Kaczensky et al. 2006); Andean bear (*Tremarctos ornatus*, Paisley and Garshelis 2006). However, researchers using this method have to listen to the beacon continuously, and obtaining activity information requires much effort and luck due to the extensive range of the bears.

Recently, GPS collars with built-in activity sensors have been used to measure activity patterns of ungulates such as cattle (Turner et al. 2000), moose (*Alces alces*, Moen et al. 1996), white-tailed deer (*Odocoileus virginianus*, Coulombe et al. 2006), and red deer (*Cervus elaphus*, Adrados et al. 2003). Gervasi et al. (2006) used GPS collars to measure activity patterns for brown bear, but this method has not yet been used on Japanese black bears.

We fitted GPS collars with activity sensors on Japanese black bears to record activity information continuously and quantitatively into the data logger. We also recorded behaviors on video when possible, which allowed us to compare known behaviors with activity sensor values. We also examined activity

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patterns and time budgets of bears during the summer using these activity values.

Study area

Our study area was the catchment basin of the Watarase River (36°41′N, 139°26′E) in the Ashio Mountains, Nikko City, central Japan. Nikko National Park and the Watarase Forest Management Area of the Forestry Agency, Nikko District Forest Office, covered most of the area.

Vegetation was destroyed by a forest fire in 1887 and by sulfur dioxide from a copper mine from the 1880s to 1950s, with resulting soil erosion. Extensive tree-planting was later carried out, with concomitant vegetation recovery. Grasses characterized the study area, with patches of planted forests such as ryobu (*Clethra barbinervis*), yashabushi (*Alnus firma*), larch (*Larix kaempferi*), acacia (*Robinia pseudoacacia*), and Japanese black pine (*Pinus thunbergii*). Because of this open habitats, direct observation of Japanese black bears was easier than in other habitats.

Methods

We captured bears using hand-made barrel traps baited with honey, rainbow trout (*Oncorhynchus mykiss*), and sika deer (*Cervus nippon*). We set traps at 3–4 sites each year and checked them each morning and evening. We immobilized trapped bears with tiletamine hydrochloride and zolazepam hydrochloride (Virbac, Carros, France). After obtaining body measurements and extracting a premolar, we placed a microchip, ear tags, and GPS collar on each bear and released them at the trap site. We determined age by counting the cementum layers of the extracted premolar (Hachiya and Ohtaishi 1994).

We used GPS3300S (2003 and 2004 models: Lotek Wireless Inc., Newmarket, Ontario, Canada), setting fix intervals from 5 minutes to 2 hours. All collars contained an activity sensor and had a radio activated drop-off. The collar unit and battery pack weighed 550 g.

Activity sensors contained a dual-axis motion sensor that recorded animal movements and was equally sensitive to 'up–down' (vertical = Y-act) and 'side–side' (horizontal = X-act) movements (with 7.5°, as set by the manufacturer) of the head and neck. Activity data were stored in memory every 5 minutes (maximum event count = 255). We summed the X- and Y-act at 5-minute intervals as the sensor value (X-act + Y-act count/5 min: max 510 counts/5 min), following Turner et al. (2000). To minimize the effects of collar movement on activity count accuracy (Moen et al. 1996), we placed GPS collars on the neck of each bear as tightly as possible.

After release, bears were radiotracked using the VHF signal, and direct observations attempted. When we found bears, we recorded their behavior with a Nikon Field Scope ED X60 and Nikon Field Image System MX CCD camera (Nikon, Tokyo, Japan), and a DCR-TRV30 digital video camera (Sony, Tokyo, Japan) in 2003, and a Canon 80–400 mm ED lens and a Canon XL-1 digital video camera (Canon, Tokyo, Japan) from 2004 onward.

We selected and plotted GPS fix points in areas where visibility was high. Then we compared the recorded bear behaviors and the sensor values at that time for every 5 minutes. We used ArcView GIS 3.2a (ESRI; Redlands, California, USA) and HRE Version 0.9 (Rodgers and Carr 1998) for GPS fix plotting and home range estimation of 100% and 95% minimum convex polygon (MCP).

We obtained times for sunrise and sunset in nearby Utsunomiya city from the National Astronomical Observatory of Japan and used them to classify diurnal and nocturnal periods. We compared mean sensor values between resting and feeding behaviors for each individual, as well as within activity categories between individual bears using Mann-Whiney *U*-tests. Differences were considered significant at $P < 0.05$. All statistical analyses were performed in JSTAT 9.2 for Windows (http://www.vector.co.jp/soft/win95/business/se030917.html).

Results

Captured bears and video recording

We fitted GPS collars on 2 adult female (FB74, FB70) and 2 male (MB64, AM01) Japanese black bears during 2003–06 (Table 1). FB74 was not observed with cubs during any direct observations. FB70 was seen with 2 yearlings in 2004 and was not observed with offspring in 2005. FB70 was very thin in 2004; however, she gained 21 kg in 2005. In 2006, FB70 gave birth to 2 cubs and had again lost weight (15 kg). MB64 was an adult male and AM01 was a subadult male.

Although the Ashio Mountains are an open environment, we found it difficult to find collared bears due to patches of forest stands, frequent rain, and dense fog during the summers. We video-

Table 1. GPS-collared Japanese black bears in the Ashio Mountains of central Japan, 2003–06.

Year	Bear ID	Sex	Age (yr)	Body weight (kg)	Period analyzed[a]
2003	FB74	Female	7	47.5 (Jul)	27 Jul–19 Aug
2004	MB64	Male	8	68.0 (May)	14 May–25 Jun
	FB70	Female	8	41.0 (Jun)	10–24 Jun
2005	FB70	Female	9	62.0 (Jun)	14 Jun–22 Sep
	AM01	Male	1	24.5 (Jul)	25 Jul–13 Sep[b]
2006	AM01	Male	2	36.0 (Jun)	15 Jun–14 Aug
	FB70	Female	10	47.0 (Jun)	25 Jun–20 Sep

[a]GPS collars worked longer, but we only used data from the Ashio area.
[b]10 days (13–15 and 27–31 Aug, 2–3 Sep) of data were excluded, because bear was retrapped during those days.

recorded behaviors of FB74 and FB70 (different collars were deployed on each female) for a total of 410 minutes and 429 minutes, respectively, but we were unable to record MB64 and AM01 continuously for more than 5 minutes. Video sessions longer than 5 continuous minutes, which we judged suitable for comparison to activity sensor logs, totaled 43 (215 min) for FB74 and 44 (220 min) for FB70 (Table 2). During the video recordings, distance between video camera and bears was 100–250 m. The telephoto lens on the video recorder enabled us to observe bear behaviors from these distances.

Observed activity patterns

We categorized activity patterns of FB74 and FB70 from video recordings as 'resting' or 'feeding with short-distance movements' (i.e., 'active'). Except one occasion (in which the bear moved a short distance but also rested, see below), all 5-minute recordings were occupied by single behavior category. In the videos, however, we could not record behaviors such as courtship, mating, moving, and running by single behavior category more than 5 minutes.

During active periods, bears spent most of their time (Table 2) turning up stones in grasslands and feeding on ants (*Lasius flavus*, *L. japonicus*, *Myrmica kotokui*), or, more rarely, on grasses (*Cirsium* spp., *Eupatorium chinense*). Selection of resting sites differed between FB74 and FB70. FB74 was observed to rest on a branch of an *Alnus firma* tree, and repeatedly alternated her resting position from prone to upward (rolling-over). In one instance, FB74 adopted a standing position while resting on a branch and the activity sensor value was recorded as high (129). FB70 was mostly observed to rest on a rock in the prone position, but once was also observed to be resting while standing (sensor value = 18). For FB70, there was also an exception to resting and feeding, short distance movements including resting (sensor value = 44), which we categorized as 'other,' and this datum was excluded from analysis.

Table 2. Activities from video data for GPS-collared Japanese black bears in the Ashio Mountains, central Japan, 2003–06.

	Intervals	
Activity	Bear FB74	Bear FB70
Ant feeding	6	35
Resting	37	8
Other	0	1
Number of 5 min videos	43	44
Total time	310 min (10 Aug 2003)	429 min (17–20, 22–24 Jun 2004)

Sensor values and activities

Mean sensor values for FB74 were 9.4 (SD = 21.5, range = 0–129, $n = 37$) for resting and 106.2 (SD = 47.2, range = 65–188, $n = 6$) for active, and for FB70 were 2.9 (SD = 6.2, range = 0–18, $n = 8$) for resting and 142.5 for active (SD = 47.6, range = 53–216, $n = 35$). Sensor values while resting differed from those while feeding (Fig. 1; $P < 0.0001$).

To determine a cut-off value between the 2 behavior categories, we combined data for both bears (FB74 and FB70) because they did not differ in sensor values while active (Mann-Whitney U-test, $P = 0.1101$) or inactive ($P = 0.0771$). Combined sensor values while inactive varied from 0 to 129 ($\bar{x} = 8.3$, SD = 19.8, $n = 45$), and while active from 53 to 216 ($\bar{x} = 137.2$, SD = 48.7, $n = 41$). We applied the cut-off value estimation method of Coulombe et al. (2006) for the combined data of FB74 and FB70. In this method, all possible sensor values (0–510 counts/5 min) were evaluated as possible cut-off points where true activity was known; the cut-off point is taken as that value that minimizes overall error. Sensor values from 30 to 52 had equally high probability of correctly classified behaviors (inactive = 97.8% and active = 100%;

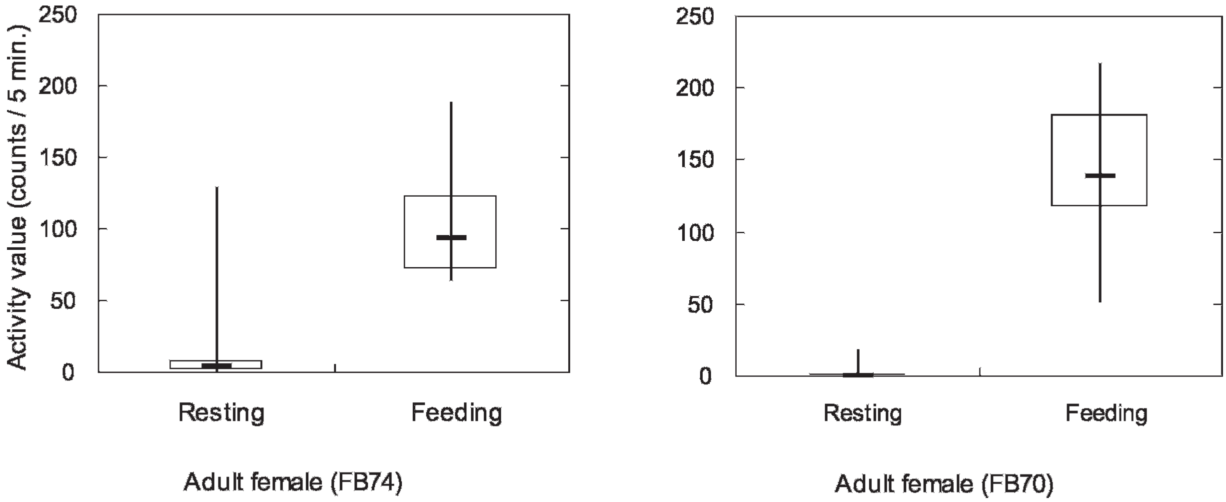

Fig. 1. Sensor values and observed activity of 2 GPS-collared Japanese black bears in the Ashio Mountains, central Japan, 2003–06. The box indicates the median, 25%, and 75% quartiles; the whiskers show the smallest and largest values.

Fig. 2). We thus chose the median (41) as the cut-off value to differentiate among activity types, inactive (0–41) and active (>42).

Diel activity patterns

Bears were primarily diurnal, increasing their relative activity at dusk, but some bears also showed distinct activity periods at dawn (FB70 in 2004 and AM01 in 2005); others showed lesser increases in activity at dawn (FB70 in 2005 and 2006, and AM01 in 2006; Fig. 3, Table 3). MB64 was active at dawn as well as dusk; however, his diel patterns were less distinct than the other bears. Excepting MB64, inactive values varied from 77.0–91.3% during nighttime. Bears also rested often during daylight.

Diel activity time budgets

Mean inactive time varied from 747–1,118 minutes (Table 4), which occupied approximately 66% of the day for all individuals. Mean time budget for all individuals was inactive 65.7% (945 min, SD = 172.5) and active 34.3% (494 min, SD = 172.5).

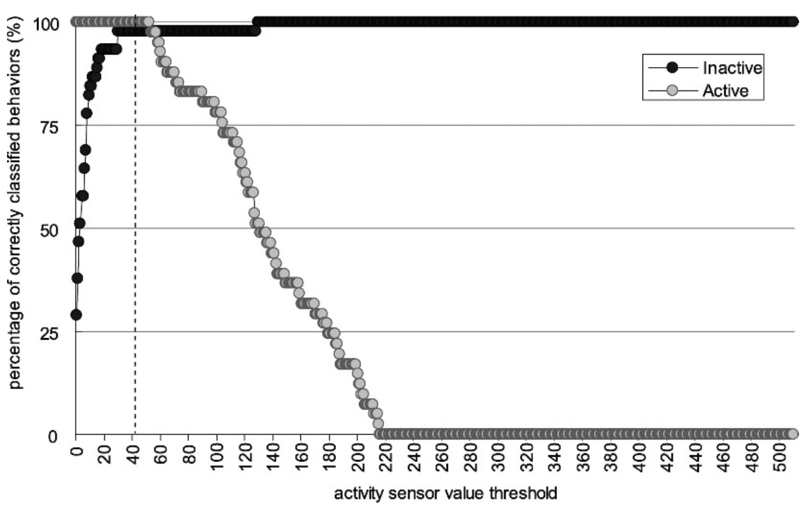

Fig. 2. Determination of the activity sensor value threshold for 2 GPS-collared Japanese black bears in Ashio Mountains, central Japan. The broken line indicates the determined cut-off value (41).

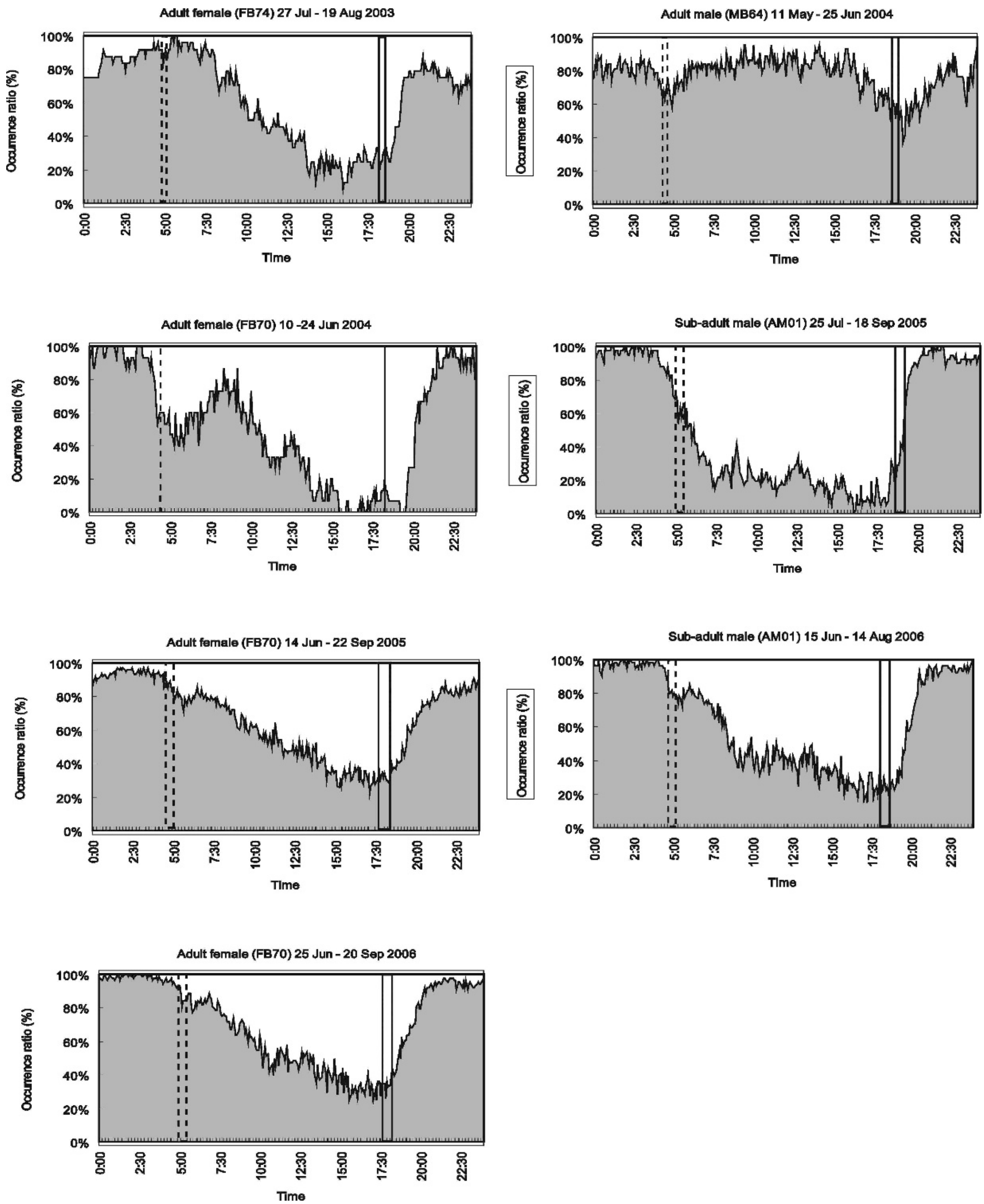

Fig. 3. Proportion of time active (as documented during 5 minutes intervals) for Japanese black bears in the Ashio Mountains of central Japan, 2003–06 (>42 = active [white], <41 = inactive [light gray]). The broken lines and solid lines indicate sunrise and sunset during the tracking period.

Table 3. Day and night activities for GPS-collared Japanese black bears during summer, Ashio Mountains, central Japan, 2003–06.

Year	Bear	Period	Inactive (%)	Number of 5-min intervals		*P*
				Inactive	Active	
2003	FB74	day	52.0	2070	1908	<0.0001
		night	77.0	2260	674	
2004	MB64	day	79.9	5945	1491	<0.0001
		night	74.2	3672	1276	
	FB70	day	35.6	935	1688	<0.0001
		night	79.5	1349	348	
2005	AM01	day	23.0	1515	5069	<0.0001
		night	88.2	4610	614	
	FB70	day	54.3	9001	7587	<0.0001
		night	82.1	10267	2233	
2006	AM01	day	46.0	4795	5631	<0.0001
		night	87.9	6280	862	
	FB70	day	54.5	7849	6542	<0.0001
		night	91.3	9995	958	

[a]χ^2 test

FB70, tracked for 3 consecutive years, was significantly less active during her solitary year (2005, $\bar{x}$ = 486 min/day) compared with her nursing year (with 2 yearlings, 2004, $\bar{x}$ = 679 min/day, Mann-Whitney *U*-test, U_1 = 267.5, U_2 = 1247.5, *P* = 0.0001). Her time active was also lower during her year nursing 2 newborn cubs in 2006 ($\bar{x}$ = 426 minutes (Mann-Whitney *U*-test, U_1 = 3178.5, U_2 = 5709.5, *P* = 0.0007) than during her solitary year. AM01 also displayed a decrease in mean time active from 693 min/day in 2005 (as a yearling) to 532 min/day in 2006 (as a 2-year old; Mann-Whitney *U*-test, U_1 = 2217.0, U_2 = 284.0, $P < 0.0000$).

Discussion

Activity pattern determination

Through the use of GPS collars with built-in activity sensors, we obtained large quantities of continuous activity-sensor information along with location data. We evaluated the activity sensor through direct observation of the collared bears and categorized the activity of the bears into resting (inactive) and feeding with short distance movements (active). Unlike ungulates (Moen et al. 1996, Turner et al. 2000, Adrados et al. 2003, Coulombe et al. 2006) or brown bears (Gervasi et al. 2006), Asiatic black bears can easily climb trees (Vaisfeld and Chestin 1993); this causes some differences from previous studies of activity sensors. Because we were able to evaluate sensor values while a female (FB74) was resting on a tree, we believe our cut-off value was useful for a variety of resting site selections for Japanese black bears. We also deployed different collars on each video-recorded female (FB74 and FB70). Hence, we avoided biases that might have emerged from using only a single collar. Regardless, additional calibration is still needed.

There seemed to be an outlier during resting periods of female FB74. Although she was observed

Table 4. Summer diel time budgets for activity of GPS-collared Japanese black bears in the Ashio Mountains, central Japan, 2003–06.

Year	Bear	Inactive			Active			Days
		Mean (min)	SD	%	Mean (min)	SD	%	
2003	FB74	902	180.3	62.6	538	181.9	37.4	24
2004	MB64	1118	135.0	77.7	322	135.0	22.3	43
	FB70	761	126.8	52.9	679	126.8	47.1	15
2005	FB70	954	165.3	66.2	486	165.3	33.8	101
	AM01	747	90.3	51.9	693	90.3	48.1	41
2006	AM01	908	64.5	63.0	532	64.5	37.0	61
	FB70	1014	163.2	70.4	426	163.2	29.6	88
Average		946	172.5	65.7	494	172.5	34.3	373

at one point to stand on a branch during resting, her sensor value was unexpectedly high (129). During this 5-minute interval, Y-act was 128 while the X-act was 1. This may be a subject for further sensor calibration.

Placing collars on captive bears may also be considered. Future investigation of the sensor values relative to age and sex in a variety of habitats is also necessary. Regardless, we believe that GPS collars with built-in activity sensors are a very effective research tool for clarifying the living habits of Japanese black bears.

Summer diel activity patterns

Using our categorization of sensor values, our study bears were primarily diurnal. Diel activity patterns of Japanese black bears have never been quantitatively reported, although qualitative reports suggested that bears seemed to be diurnal if human disturbance did not exist (Nozaki and Mizuno 1983, Hazumi et al. 1985). Other studies report diurnal habits in bears: Asiatic black bear in Taiwan (Hwang and Garshelis 2007) and in China (Schaller et al. 1989); Andean bear (Paisley and Garshelis 2006); brown bear (MacHutchon et al. 1998, Klinka and Reimchen 2002); and American black bear (Beecham and Rohlman 1994, MacHutchon et al. 1998) in North America. Our result regarding the tendency of onset and cessation of activity to occur near sunrise and sunset was similar to Asiatic black bears in Taiwan (Hwang and Garshelis 2007) and Andean bears (Paisley and Garshelis 2006). However, these studies indicated that bears had distinct activity peaks at dawn and dusk (Paisley and Garshelis 2006, Hwang and Garshelis 2007). In contrast, our study bears displayed more subtle differences.

We do not know why the adult male MB64 did not show distinct diel activity patterns. One possibility is that the tracking period overlapped with the breeding season of Japanese black bears (Yamamoto et al. 1998), thus MB64 had different activity patterns than the others.

Comparing summer diel activity patterns of individuals among years

Mean time active ranged widely from 22.3–48.1% (322–693 min/day). Through direct observations of adult female FB70 (whose time active varied with her reproductive status), we noted that her yearlings frequently made extensive movements and FB70 followed them. This could be a reason why FB70 was more active with yearlings than during her solitary year. Supporting this hypothesis was our observation that the yearling male AM01 was more active as a yearling than as a 2-year old. When FB70 had 2 cubs-of-the-year, her activity level was lower than either her solitary year or her year with yearlings. The cubs were still small and she may not have needed to follow them. Kaczensky et al. (2006) reported that brown bear yearlings had higher activity level than the adults in Slovenia and Croatia.

Energy costs for each individual can also be expected to vary as a function of time budgets. If sensor values can be successfully calibrated to additional behavioral categories, (e.g. feeding, moving), evaluation of diel energy costs for Japanese black bears may also be possible.

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