Myrmecophagy of Japanese black bears in the grasslands of the Ashio area, Nikko National Park, Japan

Koji Yamazaki1,3, Chinatsu Kozakai2, Shinsuke Koike2, Hideto Morimoto2, Yusuke Goto2,4, and Kengo Furubayashi2

1Zoological Laboratory, Ibaraki Nature Museum, Bando-city, Ibaraki 306-0622, Japan
2Laboratory of Forest Animal Conservation, Faculty of Agriculture, Tokyo University of Agriculture and Technology, Fuchu-city, Tokyo 183-8509, Japan

Abstract: Ants are an important food resource for most of bear species. During the summer, Japanese black bears (Ursus thibetanus japonicus) use grasslands in the ~60 km² Ashio area as an ant feeding site. We studied levels of myrmecophagy using GPS locations and activity sensor information along with direct observations of 2 bears during 2004 and 2005. We measured species composition, biomass, and nutrient contents of the ants and estimated use of ants through bear scat analysis. Both the number of ant species and biomass were higher in Ashio than in the adjacent forest areas. We recorded 15 ant species, 9 of which were fed on by the bears. Lasius flavus and L. hayashi were most abundant species and the species used by bears most often. Bears spent 7–8 hours/day feeding on ants. We estimated that they potentially ate 50,000–60,000 mg (dry weight)/day of ants, whose energy content was around 180–300 kcal/d, insufficient to meet their basal and field metabolic needs. Bears may have used ants for essential amino acids that they are unable to produce themselves. Assuming bears come to Ashio specifically for ants, these grasslands are valuable for bears at a time when vegetative food resources are limited.

Key words: activity pattern, ant, Japanese black bear, myrmecophagy, Ursus thibetanus japonicus


Japanese black bears (U. t. japonicus) are omnivorous with an herbivorous bias (Hashimoto and Takatsuki 1997). In spring, available food resources documented for bears were sprouts, new leaves, flowers of grasses (e.g., Angelica pubescens, Veratrum album, Sasa spp.) and trees (e.g., Fagus spp., Quercus crispula, Prunus spp.), which contained more protein and less fiber than in other seasons (Koike 2011). In summer, bears switched to spotty fruits (e.g., Rubus spp., Prunus spp.). Hence, Japanese black bears are unable to find abundant food resources in the summer, during which time social insects, including ants, are believed to be a valuable food for the bears (e.g., Koike 2010). Particularly in summer, bears have been documented to feed on ants in several areas (e.g., Nozaki et al. 1983, Yamazaki et al. 1996, Horiiuchi et al. 2000, Hashimoto 2002, Huygens et al. 2003). Therefore, evaluation of ants as a summer food resource for bears is important in understanding their lives. Thirteen species of ants have been recorded as consumed by Japanese black bears (Watanabe et al. 1970, Yamamoto 1973, Azuma et al. 1976, Takada 1979, Torii 1989, Yamazaki et al. 1996, Sawada et al. 2006, Torii and Takano 2006, Nanbu and Goto 2007, Hamaguchi et al. 2009).
The Ashio area, located in central Honshu, is characterized by open, grassy habitats. From May to August, bears have been observed in these grasslands and spend most of the time feeding on ants, including those which nest under rocks (Yamazaki et al. 2008). In September, bears have been observed to shift their home range into the surrounding areas characterized by deciduous broad-leaved forest stands where they fed on acorns (Kozakai et al. 2011, Yamazaki et al. unpublished data). Because it was unclear how bears used the grasslands of the Ashio area, our study objects were to: (1) determine the importance of ant foraging, (2) identify the abundance and biomass of ants in both the Ashio area and a control area, as well as identify nutrition content and energy intake from ants, and (3) determine if bears exhibited a preference for ant life-stage.

Study area
Our main study area was in the Ashio area of the Nikko–Ashio Mountains, located in Nikko National Park (near the city of Nikko in the prefecture of Tochigi) within the Watarase River Basin (36°41′N, 139°26′E, 680–2,000 m). The study area was approximately 60 km² (although the 100% minimum convex polygon of collared bears during 2003–08 was approximately 460 km²). In the past, vegetation in the Ashio area had suffered damage from pollutants produced by a forest fire in 1877 and a copper mine which operated from the 1880s to 1950s. Substantial soil erosion had also occurred. Since 1956, tree planting operations have been carried out by the Japanese government; thus, there were patches of Japanese clethra Clethra barbinervis, Japanese green alder Alnus firma, larch Larix kaempferi, locust tree Robinia pseudoacacia, and Japanese black pine Pinus thunbergii. However, those forest stands do not produce fruit used by bears. During our study, the landscape was still primarily open and grasslands were widespread.

For comparative purposes, we set up a control area in a forested area, ~14 km away, in the Katashina area along a branch of the Otaki River (36°46′N, 139°18′E, 980–2,500 m). The Katashina area (~60 km²) is vegetated by Fagaceae spp. stands and has not experienced fire or pollution; most of the area is covered by deciduous broad-leaved forests with a mixture of planted Japanese cedar (Cryptomeria japonica), hinoki cypress (Chamaecyparis obtusa), and larch. The area is a part of the annual home range for the same bear population (Yamazaki et al. unpublished data) and was used by these bears as their autumn range.

Methods
Species composition, biomass, and nutrient contents of the ants
To investigate species composition and biomass of ants, during 19–21 July 2004 we established in Ashio 2 quadrats (A: 36°42′7.20″N, 139°25′55.09″E, and F: 36°42′2.40″N, 139°25′29.70″E) in grasslands and 2 quadrats (D: 36°42′3.39″N, 139°25′42.30″E, and E: 36°42′10.29″N, 139°25′49.80″E) in larch and deciduous broad-leaved forests. In Katashina, we established 2 quadrats (B: 36°46′35.90″N, 139°18′49.89″E and C: 36°44′44.59″N, 139°18′2.59″E) in larch and deciduous broad-leaved forests. Excepting quadrat F, which was 50% smaller, all quadrats were 625 m² in size. Investigations were conducted only under sunny daytime conditions when ants were expected to be active. We did not record temperatures; however, our impressions were that they were typical of summer conditions and relatively constant. We defined biomass as the available quantity of ants at the soil surface.

When we discovered ants under stones or within rotten wood, we photographed them and later counted queens, workers, males, and pupae (including larvae) in the photos. We turned over stones and rotten wood and then quantified the escape time of ants as the time required for them to disappear from the surface (or the time required for all pupae, including larvae, to be carried away by the workers). Escape times exceeding 300 sec were recorded as 300 sec. Species we could not identify in the field were preserved in ethanol for later identification (Japanese Ant Database Group 2003).

We used an aspirator to collect queens, males, workers, and pupae for each ant species and weighed them after drying for 10 months in a refrigerator with desiccant. To estimate biomass by species and life-stage, we weighed 100 individuals each for queens, males, workers and pupae and estimated individual weights by dividing by 100. If we could not collect 100 ants, we used the actual number weighed. We then calculated total ant weight in the Ashio and Katashina areas.

We sampled 60 g of the most abundant species and analyzed for crude protein (Kjeldahl method:
nitrogen protein conversion factor was 6.25), crude fat (diethyl ether extraction method), and crude ash (ashing method; Japan Food Research Laboratories, Tokyo, Japan). Because samples contained water, we quantified nutrient content volume as percent dry mass. Percent carbohydrate was estimated as 100 minus the sum of crude protein, crude fat, and crude ash. We calculated energy content according to Auger et al. (2004) as 4.8 cal/mg crude protein, 9.5 cal/mg crude fat, and 4.2 cal/mg carbohydrate. Hence, in this study, we excluded crude ash from the calculation. Amino acids (percentage to the total volume) were measured by the amino acid analyzer method (performing acid oxidation and hydrochloric acid hydrolysis prior to measurement). High-performance liquid chromatography was employed for measuring cystine.

**Radiotracking and ant-feeding behavior of Japanese black bears**

We captured bears in barrel traps baited with honey, rainbow trout (*Oncorhynchus mykiss*), and sika deer (*Cervus nippon*) meat. We set traps at 3–4 sites each year and checked them each morning and evening. Trapped bears were immobilized with Tiletamine hydrochloride and Zolazepam hydrochloride (Virbac, Carros, France). After obtaining body measurements and extracting a premolar, we placed a microchip, a GPS collar, and ear tags 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 GPS collars (GPS3300S, 2003 and 2004 models: Lotek Wireless Inc., Newmarket, Ontario, Canada), each of which contained an activity sensor with a radioactivated drop-off. The activity sensors contained a dual-axis motion sensor that recorded animal movements and were equally sensitive to up–down (vertical = Y-act) and side–side (horizontal = X-act) movements of the head and neck. Activity data were stored in the internal memory of the collars every 5 minutes. We summed the X- and Y-acts at 5-minute intervals and differentiated activity types as inactive (0–41) or active (>42) (Yamazaki et al. 2008). Collars with battery packs weighed 550 g. We fitted GPS collars with built-in activity sensors on an adult female (FB70: 8 years old as of 2004) and a yearling male (AM01), in 2004 and 2005. FB70 was GPS-tracked in both 2004 and 2005; she was accompanied by 2 yearlings in 2004 but was solitary in 2005. We monitored FB70 for 12 days (13–24 Jun) and 7 days (29 Jun–5 Jul) in 2004 and 2005, respectively; we monitored AM01 for 7 days (27 Jul–2 Aug) in 2005. We excluded periods from analysis if we could not determine whether the collared bears were in the grasslands (e.g., due to GPS fix failures).

We overlaid GPS fixes (ArcView GIS 3.2a; ESRI; Redlands, California, USA) on a vegetation map produced in 1998 (Ministry of Environment, Japan) using HRE Version 0.9 (Rodgers and Carr 1998) for home range estimation of 100% minimum convex polygon (MCP).

We classified bear behaviors as either active or inactive and overlaid those categorized as active during daytime on the vegetation map. We selected active points located in grassland habitats. Because the GPS fix intervals and activity sensor data intervals were both 5 minutes, we defined “feeding activity” by 5 minute-periods. We defined diurnal activity as between sunrise and sunset.

After release, bears were radiotracked using VHF signals, and direct observations were also attempted. When we visually located bears, we recorded their behavior with a Canon 80–400 mm ED lens and a Canon XL-1 digital video camera (Canon, Tokyo, Japan). To minimize disturbance, we maintained >100 m distance from bears. We quantified ant feeding behavior by counting the number of objects (e.g., stone, rotting wood) bears turned over during each 5 minute interval, as well as ant licking time per stone. We only recorded licking behavior immediately after stones were overturned. We estimated ant biomass consumed by bears as the mean mass of ants counted during the quadrat survey adjusted by the number of objects turned over by the bears. Our calculations thus assumed that bears consumed all ants on the surface of or beneath the stones, and that bears spent all of their time while in grassland habitats feeding on ants. Therefore, this was the maximum estimated weight of ants fed on by bears.

**Scat analysis**

After bears moved from feeding sites, we investigated sites on the ground. We collected and froze all scats presumed to have been deposited by GPS-collared bears. After weighing and thawing, scats were rinsed with water using sieves of mesh sizes 0.5, 1.0, and 2.0 mm. After drying and re-weighing the contents of each scat, we sampled 0.5 to 2.0 g, depending on the total dry weight. We identified ants to species and recorded the number of individual
ants by counting the heads in each sample. Total number of ants/scat was estimated based on the ratio of the sampled weight to the entire content weight. This method did not allow us to estimate biomass of pupae (and was biased if ants were crushed). Finally, we estimated frequency occurrence of the total number of ant species in scats, as well as the frequency of scats with each ant species.

Results

Species and biomass of ants

We documented 7 ant species in Ashio and 3 ant species in Katashina (Table 1). Because *Aphaenogaster tipuna* specimens were crushed, we substituted the values of *A. famelica*. In the Ashio area, we recorded an additional 5 species of ants (*Camponotus japonicus, Lasius hayashi, Formica japonica, L. umbratus,* and *Tetramorium tsushimae*) outside of quadrats.

In Ashio, we estimated dry ant biomass (including adults and pupae) at the soil surface as *Lasius flavus* (2.4945 mg/m²), *L. hayashi* (1.3336 mg/m²), and *Myrmica kotokui* (0.9866 mg/m²). In the Katashina area, *M. kotokui* was the most abundant species (1.6891 mg/m²; Table 2). Because identification of larvae through digital photos was difficult, we combined larvae with pupae. Total ant biomass in Ashio (5.8720 mg/m²) was 3.46 times higher than in Katashina (1.6971 mg/m²). Comparing only grassland habitats (quadrats A and F), ant biomass (11.6077 mg/m²) in Ashio was 6.84 times that in Katashina.

By dry weight, proportion of ant pupae in Ashio grasslands (quadrats A and F) was 80.5% (8,751.5 mg from a total of 10,882.3 mg whole ant biomass). Using the total estimated ant biomass and estimated number of the stones, we estimated the total mass of ants/stone to be 89.9 mg (SD = 161.9, n = 121).

*L. flavus* and *L. hayashi* were the most abundant species sampled in Ashio grasslands. The number of *L. flavus* pupae carried away by worker ants following our disturbance was related to their escape time (in seconds) by the equation: escape time = 0.633937 | (number of pupae) + 104.475355, r² = 0.2839, P < 0.0001, n = 50). A similar albeit statistically insignificant relation was found for *L. hayashi*: escape time = 0.470188 | (number of pupae) + 111.865836, r² = 0.1663, P = 0.1169, n = 16: including 3 rotten wood samples.

We sampled nutrients in *L. flavus* and *L. hayashi*, the most abundant species in Ashio, during September to October 2004 and May to June 2005 (Table 3). The samples consisted primarily of workers and pupae, but also contained some adults and larvae. Calorie content was 3.9 cal/mg for *L. flavus* (measured body weight = worker: 0.27 mg; pupa: 0.50 mg) and 5.0 cal/mg for *L. hayashi* (worker: 0.56 mg; pupa: 0.82 mg). All 18 amino acids were detected, and excepting tryptophan, values were higher for *L. hayashi* than for *L. flavus*.

Summer feeding behavior of bears

As of 9 June 2004, FB70 weighed 41 kg; she had gained 21 kg (i.e., to 62 kg) by 13 June 2005 when she was unaccompanied by cubs. Body weight for AM01 was 24.5 kg. Both FB70 and AM01 remained in Ashio after the summer tracking periods, although we were unable to determine their range use before the tracking periods.

FB70 in 2004 and AM01 in 2005 had distinct diurnal activity patterns (Fig. 1). However, in 2005, FB70 had a unique pattern of being largely inactive.

---

Table 1. Dried body weight of ants found in the Ashio and Katashina areas, central Japan, 2004.

<table>
<thead>
<tr>
<th>Ant species</th>
<th>Location</th>
<th>Queen (mg)</th>
<th>Male (mg)</th>
<th>Worker (mg)</th>
<th>Pupa (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Formica sanguinea</em></td>
<td>A</td>
<td>7.90 (3)</td>
<td>8.90 (2)</td>
<td>4.05</td>
<td>6.39</td>
</tr>
<tr>
<td><em>Lasius flavus</em></td>
<td>A</td>
<td>8.33 (10)</td>
<td>0.27c</td>
<td>0.27</td>
<td>0.50</td>
</tr>
<tr>
<td><em>Lasius hayashi</em></td>
<td>A, K</td>
<td>NA</td>
<td>NA</td>
<td>0.56</td>
<td>0.82</td>
</tr>
<tr>
<td><em>Paratrechina flavipes</em></td>
<td>A</td>
<td>NA</td>
<td>NA</td>
<td>0.17 (9)</td>
<td>0.12 (36)</td>
</tr>
<tr>
<td><em>Aphaenogaster tipuna</em></td>
<td>A</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><em>Aphaenogaster famelica</em></td>
<td>A</td>
<td>3.18 (7)</td>
<td>1.66 (1)</td>
<td>1.43</td>
<td>2.15</td>
</tr>
<tr>
<td><em>Stenamma owstoni</em></td>
<td>K</td>
<td>NA</td>
<td>NA</td>
<td>0.38 (37)</td>
<td>0.57 (38)</td>
</tr>
<tr>
<td><em>Myrmica kotokui</em></td>
<td>A, K</td>
<td>1.73 (3)</td>
<td>NA</td>
<td>1.15</td>
<td>1.76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight (mg)b</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Queen</td>
<td>7.90 (3)</td>
</tr>
<tr>
<td>Male</td>
<td>8.90 (2)</td>
</tr>
<tr>
<td>Worker</td>
<td>4.05</td>
</tr>
<tr>
<td>Pupa</td>
<td>6.39</td>
</tr>
</tbody>
</table>

a: Ashio area; k: Katashina area
b: Individual body weight was measured using 100 ants and dividing by 100; in cases where there were fewer than 100 ants, the number used for the calculation is in parentheses.
c: We substituted the value of worker for male.
day and night (Table 4). Mean active time during daytime for FB70 in 2004 was 580.0 min (SD = 120.9) and 183.6 min (SD = 80.5) in 2005, significantly lower (Mann-Whitney U-test, U = 84, P < 0.0001). The mean active time during daytime for AM01 was 675.0 min/day.

Feeding occupied a large portion of the active time during the day (Table 4; FB70 in 2004: 80.4%; AM01 in 2005: 89.1%). In 2005, feeding times for FB70 were generally short, and she spent most of those brief active times in the forest stands adjacent to grasslands. Her mean feeding time in grasslands was 20.0 min/day (10.9% of the total active time). Forests in which she spent most of her time were dominated by Japanese green alder and Japanese clethra, both of which are planted species and do not produce edible fruits for bears (although we could not get there immediately for investigation due to steep terrain, we found no feeding signs or scats). We were unable to confirm her behavior while active in these forests. GPS fix ratios during daytime were very high when fixes were also categorized as ‘active’ (FB70 in 2004: 98.0%; FB70 in 2005: 89.7%; AM01 in 2005: 90.6%). The daily daytime range size for the FB74 in 2005 was significantly smaller than that of FB74 in 2004 (Mann-Whitney U-test, U = 25, P = 0.0002) or the AM01 in 2005 (U = 3.0, P = 0.0041).

Table 2. Biomass of ants (mg/m²) measured by dry weight in quadrats sampled in the Ashio and Katashina areas of central Japan, 19–21 Jul 2004.

<table>
<thead>
<tr>
<th>Quadrats</th>
<th>Vegetation, slope, aspect</th>
<th>Ant species</th>
<th>Dry weight (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pupa</td>
<td>Queen</td>
</tr>
<tr>
<td>Ashio-A</td>
<td>grassland with rocks; very few Japanese clethra and locust tree stands slope = 32°; aspect = 147°</td>
<td>Lasius flavus</td>
<td>2.6640</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lasius hayashi</td>
<td>1.3710</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paratrechina flavipes</td>
<td>0.0098</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aphaenogaster famelica</td>
<td>0.8290</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myrmica kotokui</td>
<td>0.8955</td>
</tr>
<tr>
<td>Ashio-D</td>
<td>larch stand without undergrowth slope = 37°; aspect = 130°</td>
<td>Lasius flavus</td>
<td>0.3018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lasius hayashi</td>
<td>0.0045</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paratrechina flavipes</td>
<td>0.0182</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myrmica kotokui</td>
<td>0.9377</td>
</tr>
<tr>
<td>Ashio-E</td>
<td>broad leaf deciduous stands (mizunara oak, Japanese clethra and Erman’s birch [Betula ermanii]) without undergrowth slope = 36°; aspect = 30°</td>
<td>Lasius hayashi</td>
<td>0.3268</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aphaenogaster tipuna</td>
<td>0.5548</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myrmica kotokui</td>
<td>0.9715</td>
</tr>
<tr>
<td>Ashio-F</td>
<td>grassland with rocks slope = 38°; aspect = 220°</td>
<td>Formica sanguinea</td>
<td>2.0448</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lasius flavus</td>
<td>9.0176</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lasius hayashi</td>
<td>4.9699</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myrmica kotokui</td>
<td>0.4337</td>
</tr>
<tr>
<td>Katashina-B</td>
<td>larch stand (age 12–20 years) with a sparse patch of Sasamorpha borealis and Eupatorium chinense undergrowth slope = 10°; aspect = 295°</td>
<td>Lasius hayashi</td>
<td>0.9715</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myrmica kotokui</td>
<td>0.0009</td>
</tr>
<tr>
<td>Katashina-C</td>
<td>broad leaf deciduous stands (beech Fagus crenata and mizunara oak) with scattered patches of S. borealis undergrowth slope = 12°; aspect = 247°</td>
<td>Stenamma owstoni</td>
<td>0.0146</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myrmica kotokui</td>
<td>1.1517</td>
</tr>
</tbody>
</table>

We collected 98 scats from GPS-collared bears during 2004. Most (n = 95) consisted of only ants, although 3 (3.1%) contained no ants (i.e., unidentified plant fibers). All scats also contained a mixture of sand and gravel. Mean raw weight scats containing ants was 52.4 g (SD = 28.4, n = 95). We identified 9 ant species in scats, of which 2 (Formica candida and F. lemani) were not documented in the quadrats (Table 5). Mean number of ant species/scat was 4.7 (SD = 1.6). As in the quadrats, the most frequently encountered species were L. flavus (44.3%) and L. hayashi (41.4%). Considering only scats with ants, most frequently encountered species were L. flavus (96.8%), L. hayashi (97.9%), F. lemani (87.4%), and M. kotokui (68.4%). In total, we recorded 15 ant species (representing 8 genera) both inside and outside the quadrats and in scat, of which 9 species (from 6 genera) were fed on by bears in Ashio (Table 6).

**Discussion**

**Ants as a food resource for Japanese black bears**

On Honshu, 13 species of ants (in 5 genera) had previously been recorded as consumed by Japanese black bears: *L. japonicus, L. flavus, C. japonicus, L. teranishii*, and *C. obscuripes* in the Okutama Mountains of Tokyo Metropolitan Government (Yamazaki et al. 1996); *F. sanguinea* in the central mountains of Nagano Prefecture (Takada 1979); *L. japonicus* in the headwater area of the Oi River in Shizuoka Prefecture (Torii 1989); *F. hayashi* and *L. japonicus* in Nanto City, Toyama Prefecture (Nanbu and Goto 2007); *C. obscuripes* in Uozu City, Toyama Prefecture (Hamaguchi et al. 2009); *C. obscuripes, F. japonica, and L. umbratus* in the Hakusan Mountains of Ishikawa Prefecture (Yamamoto 1973); *F. sanguinea* in Neo Village, Gifu Prefecture (Azuma et al. 1976); *L. japonicus* and *L. hayashi* in Miyazu City, Kyoto Prefecture (Hamaguchi et al. 2009); *C. obscuripes* in the Kyoto University Forest, in Ashu, Kyoto Prefecture (Watanabe et al. 1970); *C. obscuripes* in Nara Prefecture (Torii and Takano 2006); *L. japonicus* and *L. nipponensis* in Takano Town, Hiroshima Prefecture (Hamaguchi et al. 2009); and *Polyrhachis lamellidens, Camponotus obscuripes, Pachycondyla chinensis, and L. japonicus* in Shimane Prefecture (Sawada et al. 2006). In Ashio, we found that bears fed on 9 ant species, of which 5 (*F. candida, F. lemani,
Fig. 1. Daily activity pattern of Japanese black bears in summer 2004–05 in the Ashio area, central Japan. Black indicates inactive periods, and white indicates active periods. Adult female (FB70) in 13–24 Jun 2004, and in 29 Jun–5 July 2005; sub-adult male (AM01) in 27 Jul–2 Aug 2005; x-axis indicates hours (000–2300 hours) and y-axis indicates tracking dates.
The genera *Lasius* (previous studies; Ashio area) and *Formica* (previous studies; Ashio area) were both heavily used by bears. Previous studies have documented lower diversity of ants fed on by bears ($\bar{x} = 2.4$, SD = 1.35, $n = 12$) than in Ashio, but they were of shorter duration and less thorough than our study.

Both previous studies and our own work suggest that most ants prefer open environments such as grasslands and forest edges, and that they make their nests under stones, nearby plant roots, and in and under rotten wood (except for *F. japonica* and *C. japonicus*, which nest underground at a depth of about 1–2 m, Japanese Ants Database Group 2003). This suggests that ants nesting on the soil surface were preferred by Japanese black bears because of the ease with which they could be consumed.

**Availability of ant species in Ashio**

Unlike other Japanese black bear habitats, the Ashio area is still in the process of vegetation restoration, and thus most of the area is still primarily open grasslands. Therefore, available vegetative food items from spring to summer were limited and sparse. During April–May, we have recorded bears eating new leaves or flowers of Japanese silverberry *Elaeagnus umbellata*, willow (*Salix* spp.), Mizunara oak *Quercus crispula*, Tor-

It has long been known that bears of all sex–age categories that generally live in surrounding forest areas have used the Ashio area for ant feeding from May–August (H. Yokota and S. Haneo, wildlife photographers, Nikko-city, Japan, personal communication, 2008), lingering in Ashio for various time until *Fagaceae* spp. begin masting.

Our study confirmed that ants were more abundant in Ashio than in the adjacent forest stands that formed parts of seasonal home range of radio-marked bears. Many ant species, particularly the heavily-used *L. hayashi*, are well-suited to Ashio’s open environment and shallow soils. Redford (1987:375) classified the feeding style of bears on ants as “breaking into the nest.” However, compared with brown bears on Hokkaido that hibernate in self-dug dens (Sato 2009), Japanese black bears have much shorter claws and they mostly use natural den sites such as tree hollows, under large rocks, or pits under tree root (Yamazaki 2009). Also, we have never observed black bears excavating soil for ants in Ashio where the scattered stones on shallow soil are suitable for feeding because of the ease of finding and destroying ant nests. The Ashio grassland also might have an advantage to the bears feeding on ants that made nests under the stones in terms of solar heat effectiveness, because the temperature at the soil surface is an important factor in workers bringing pupae to the nest top (Penick and Tschinkel 2008).

During July, most nests, including *L. flavus* and *L. hayashi*, contained numerous pupae. This appeared to lengthen the time required for workers to carry them away, which provided a benefit to a bear feeding on them. In cases when pupae were particularly numerous, ant escape times exceeded 5 minutes. Given that mean feeding time of bears on ants when turning over stones was 28 seconds, bears would have ample time to feed on nests containing pupae before all escaped. Further, because pupae of most of the ant species were larger in both individual and total mass, they constituted an excellent resource for bears in terms of feeding efficiency. We could not separate nutrient contents of a pupa, but Noyce et al. (1997) reported that the nutritional value of a pupa was slightly higher than that of a worker. Auger et al. (2004) also suggested that pupae, which lack thick chitin-containing exoskeletons, are more digestible than adults. Pupae lack defensive and offensive mechanisms, and bears fed on them easily (Noyce et al. 1997, Auger et al. 2004).

However, assuming the bears come to the Ashio area at the timing of pupae appearance, the grassland of the area seems to be a superior area in terms of abundance of ants in comparison to the surrounding areas of broad-leafed forests, which are the autumn habitat for bears.

---

**Table 6. List of ant species found (Y) in the Ashio and Katashina area, central Japan, 2004–05.**

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
<th>Inside of the quadrats</th>
<th>Outside of the quadrats</th>
<th>Fed by bears through the scat analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camponotus</td>
<td><em>C. japonicus</em></td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Formica</td>
<td><em>F. sanguinea</em></td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>F. candida</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>F. hayashi</em></td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>F. japonica</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>F. lemani</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lasius</td>
<td><em>L. umbratus</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>L. flavus</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>L. hayashi</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paratrechina</td>
<td><em>P. flavipes</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetramorium</td>
<td><em>T. tsushimae</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aphaenogaster</td>
<td><em>A. tipuna</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>A. famelica</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stenamma</td>
<td><em>S. owstoni</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myrmica</td>
<td><em>M. kotokui</em></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>8</strong></td>
<td><strong>5</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

Summer energy intake of Japanese black bears

Telemetry data showed that the yearling male (AM01) and the adult female (FB70) when accompanied by yearlings (in 2004) were diurnal and spent a majority of their active time in grassland habitats. Our direct observations confirmed that they spent a majority of their time feeding on ants by turning over stones. Dietary analyses confirmed their myrmecophagy. In our study, Japanese black bears in 2 of 3 years spent about 7–8 hours/day feeding on ants (the exception being bear FB70 in 2005), although as noted above, these values may be overestimates because we assumed active time spent while in grasslands as feeding on ants. In this estimation, the bears may have received a total of 50,000–60,000 mg/day of ants. For comparison, Ternent (1995) reported that American black bears in a Minnesota study allotted 80–100% of their June feeding time on ants.

For 2 of the 3 years we followed GPS-telemetered bears, we estimated that crude protein content of ants consumed was 16,000–28,000 mg/day, crude fat was 10,200–14,000 mg/day, and intake energy was 80–300 kcal/day. Estimates for adult female FB70 were much lower during 2005. Although nutrient requirements of Japanese black bears are not known, Nagy (1987) estimated daily caloric requirements (field metabolic rate: FMR) of eutherians as:

\[
FMR(KJ/day) = 3.35 wt(g)^{0.813} (\text{= kcal/day}) \\
= 0.8 wt(g)^{0.813}
\]

Applying this equation, FMR for FB70 was 4,501 kcal in 2004 and 6,299 kcal in 2005, and 2,961 kcal in for AM01 in 2005. In addition, McNab (1988) estimated basal metabolic rate (BMR) for eutherians as:

\[
BMR(kcal/day) = 52.7 wt(g)^{0.716}
\]

This suggested that BMR for FM70 would have been 817 kcal in 2004 and 1,098 kcal in 2005, and 565 kcal for AM01 in 2005. For these estimates, we applied body weight as measured when captured.

Assuming the FMR estimation to be accurate for Japanese black bears, our estimated energy intake from ants was considerably less than their daily caloric requirements. In fact, our estimated energy consumption from ants was even less than the estimated BMR above. Even if bears also fed on ants during nighttime, potentially doubling their energy intake from them, their energetic value would still fall far short of requirements.

Hazumi et al. (1985) studied nutrient condition of bears in our study area using concentration of femur marrow fat (FMF) and found that FMF declined beginning in April, was lowest in August, and had recovered by September, possibly as a result of acorn availability from Fagaceae species. The same phenomenon was reported in Gifu Prefecture based on kidney fat index, being lowest in July and August (Nature Conservation Division of Forest Policy Planning Department of Gifu Prefecture 1994). We also measured the body condition index of Cattet et al. (2002) of bears in our study area since 2003, and it was lowest in summer (Yamazaki et al. unpublished data). Starting in September, Fagaceae species (especially Quercus crispa) found in forests surrounding Ashio are the main food items (Kozakai et al. 2011) that allow the bears to accumulate fat reserves prior to hibernation. These seasonal changes in body condition suggest that bears use fat reserves gained in autumn not only during hibernation but also until the end of the subsequent summer because of limited food supply in spring and summer (e.g., low intake energy from ants).

Low availability of alternative foods and high incidence of ants in scats suggest that ants were valuable summer food items, but to confirm this requires future research because our estimate of the intake energy from ants was lower than estimated daily caloric requirements. Even though they included a large proportion of sand and gravel, scats averaged only about 50 g, lighter than other scats produced from vegetative food items (e.g., scats during the acorn season were often >1 kg), suggesting that mass of ants fed upon was particularly low. In an earlier study on ant feeding in Hiroshima prefecture in Western Honshu, Hamaguchi et al. (2009) reported that 1,367 workers of L. japonicus, 1,007 workers of L. nipponensis, and 4,252 of unknown pupae were found in a stomach of a yearling male black bear. We lacked data on body masses for L. japonicus and L. nipponensis, but substituting those of M. kotokui workers, which have similar body size to L. nipponensis workers, that of L. hayashi workers for L. japonicus, and that of L. hayashi pupa for the unknown worker pupae (Japanese Ants Database Group 2003), and applying estimated weights we obtained of M. kotokui and L. hayashi, the yearling male in that area consumed an estimated 5,393 mg of ants (i.e., 768 mg of L. hayashi, 1,154 mg of L. nipponensis, and 3,471 mg of unknown...
pupae). We do not know how long this bear spent feeding, but this example indicates that he would not easily have been able to consume a large biomass of ants.

Another possibility is that bears were not seeking basic nutrients, but rather were obtaining essential amino acids that they are unable to produce themselves. Unfortunately, there are no existing studies on essential amino acids for Japanese black bears. However, Eagle and Pelton (1983) suggested, in an American black bear study, that ants were a very important food item in the summer despite the small quantities because of the potential need to obtain essential amino acids and protein from ants which are difficult to obtain from other food items. Wright et al. (1999) listed 9 essential amino acids (histidine, threonine, valine, methionine, tryptophan, phenylalanine, isoleucine, leucine, and lysine) that American black bears share with humans, although they did not describe how they determined which amino acids were essential for the bears. Wright et al. (1999) also listed arginine as a non-essential amino acid in adults, but an essential amino acid in growing individuals. They found that 4 of the 9 amino acids (threonine, valine, leucine, and lysine) were highly concentrated in the plasma of both females and males, and that concentrations were higher in lactating than non-lactating females. Assuming that Japanese black bears share the same essential amino acids as American black bears, our subadult male (AM01) and the female with cubs (FB70 in 2004) might have required those essential amino acids (threonine, valine, leucine, lysine, and arginine) which were found in *L. flavus* and *L. hayashi* in relatively high values; bears might have obtained several hundred mg of each of these amino acids.

The adult female (FB70) behaved quite differently in 2005 from the previous year (when she had been accompanied by 2 yearlings) as well as from that of AM01. During June–July, her active time drastically decreased in 2005, and she spent most of her active time in the forests adjacent to the grasslands. Both her total and daytime home range sizes were smaller in 2005 than 2004 and smaller than AM01. FB70 had a large body weight difference between her nursing year in 2004 and her solitary year in 2005 (in 2006, she was with 2 newborn cubs and had lost 15 kg from 2005: Yamazaki et al. 2008). One hypothesis is that in 2005 FB70 had no cubs and thus had lower energetic demands. Bears similar to FB70, who do not need to be active in terms of their social situation, may get through summer and periods of sparse food resources by going into an aestivation-like physiological state. A similar decline in activity levels during the summer was occasionally observed in the bears inhabiting Ashio area and Okutama Mountains, Tokyo (Yamazaki et al. unpublished data). A second hypothesis is she found 1 or more sika deer carcasses in forested habitats. Bears in the Ashio area occasionally scavenge on sika deer (H. Yokota, wildlife photographer, Nikko-city, Japan, personal communication, 2006; Yamazaki unpublished data). On those occasions, the bear will stay on the carcass for some days, and her movements decrease. A third hypothesis is that mating activity (which would have occurred during the study period: Yamamoto et al. 1998) influenced the behavior of FB70 in 2005 if she were involved in courtship with a male.

How do Japanese black bears select their food, and what kind of activity patterns do they have in the summer, especially just before switching to mast in autumn? In our study, the sample size was small (2 bears) and study periods brief (7–12 days). However, we believe our results reflect the general situation for Japanese black bears and represent a breakthrough in our understanding of their summer feeding ecology.

Longer-term studies including bears of different sex, age and social status are necessary. Additionally, future studies should seek to understand the phenology of ants, bear feeding periods, and the relative abundance of other food resources in the area. Finally, future research should elucidate basal metabolic rates and essential amino acids for Japanese black bears.

**Acknowledgments**

We thank S. Haneo, H. Yokota, and I. Arimoto for field assistance, S. Chino and K. Hamaguchi for ant classification, Gunma District Forest Office—Omama Branch and Nikko District Forest Office of the Forestry Agency for permission to enter and set traps in the National Forest, and Tochigi Prefectural Imaichi Forest Management Office for permitting capturing. This study was funded by the Tokyo Foundation of Better Environment, the Foundation of River & Watershed Environment Management, and WWF Japan.

**Literature cited**


Received: 7 August 2010
Accepted: 1 September 2011
Associate Editor: M. Fitz-Earle