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Brown Bear Digging for Cicada Nymphs: a novel interaction in a forest ecosystem

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The brown bear (*Ursus arctos*) is one of the most widespread large carnivores in the northern hemisphere. Their diets are highly diverse and depend on resource availabilities across regions and seasons (Bojarska and Selva 2012). Brown bears often consume starchy plant roots and insects by digging into the soil (Mattson et al. 1991; Tardiff and Stanford 1998). In the Shiretoko World Heritage, Hokkaido, northern Japan (44° N, 145° E), where the density of brown bears is high (Kohira et al. 2009), these animals have recently been observed digging for cicada nymphs (*Lyristes bihamatus*) during summer (Fig.1a, b). This behavior has not been previously reported, even though some other mammalian species forage for cicada nymphs (Hahus and Smith 1990). In this article, we show some preliminary results of our field survey on this novel interaction between brown bear and cicada. We then discuss the reasons why brown bears forage on cicada nymphs and the possible ecological consequences of their digging in the forest ecosystem.

Wildlife managers first observed brown bears digging for cicada nymphs in 2000 in the study area. In fact, cicada nymphs have not been reported in scats of brown bears collected in the summer of mid-1980s in the study area (Fig.2; Yamanaka and Aoi 1988). This earlier study along with ours allows us to determine whether the proportion of cicadas and other foods in the diet has changed during the past 30 years. In 2018, we evaluated the composition of brown bear scats collected in the same season and region as the earlier study.

By comparing scat compositions between the mid-1980s and the 2018, we determined the changes in brown bears diets in the study area during the past 30 years. The proportion of cicada nymphs was estimated 14.3%, suggesting that brown bears consume cicada nymphs at a certain rate in summer. Final instar nymphs are highly nutritious and finish their development until emergence in shallow soil during summer, and so bears can easily dig for them (Hayashi and Saisho 2011). Although herbaceous plants comprised the highest proportion in scats in both periods, we found that the proportion of herbaceous plants in scats in 2018 is half that recorded in mid-1980s (Fig.2).

Evidence of brown bear digging was frequently observed in the larch (*Larix kaempferi*) plantations, whereas we could not find evidence of digging in the Sakhalin spruce (*Picea glehnii*) plantations and the natural mixed forests. In August 2017, when final instar cicada nymphs completed emergence, we created 10 survey plots of 100 m^2 area in each forest type and counted the number of exuviae of *L. bihamatus* nymphs as a proxy of their abundance in each plot. The largest number of the *L. bihamatus* exuviae occurred in the larch plantations (mean ± SE / 100m^2 = 153.9 ± 15.6). The number of *L. bihamatus* exuviae in the Sakhalin spruce plantations and the natural mixed forests was 8.7 ± 3.0 and 4.5 ± 2.3, respectively. These data indicate that brown bears can most efficiently forage on cicada nymphs by searching intensively in the larch plantation where the nymphs aggregate at high density.

We set up 8 camera traps in the larch plantations where brown bears dug the previous year to evaluate how many brown bears dug for cicada nymphs, by counting the minimum number of brown bears based on useful features for individual identification (e.g., color, body size, and family structure). As a result, we captured 112 videos wherein bears were recorded to be digging and detected a minimum number of 11 individuals; 3 adult bears were females with cub(s), 2 were solitary adult female bears, and 2 were subadult bears. (See Videos S1 and S2 for two examples.)

Why have brown bears begun foraging on cicada nymphs since 2000? One possible reason may be that overgrazing by sika deer (*Cervus nippon yesoensis*) has altered the diet of brown bears by reducing the available herbaceous plants for bears. An index of population density of sika deer by spotlight surveys has revealed a remarkable increase from 1 deer/km in the late 1980s to 20 deer/km in the early 2000s in the study area (Kaji et al. 2006). Because herbaceous plant species preferred by sika deer were partially in common with the species upon which brown bears foraged in summer during the 1980s (Kaji 1988), the availability of herbaceous plants for bears during summer may have decreased in the study area. This is also supported by the results of our scat analysis (Fig. 2). Therefore, brown bears may have foraged on cicada nymphs as an alternative food resource to herbaceous plants.

Our camera-traps revealed that 3 female brown bears with cub(s) dug for cicada nymphs in the study area. Possibly, the digging behavior of brown bears will propagate through the bear population via social learning from mother bear to cub, because bears likely acquire foraging behavior through learning from their mothers during at least the first year of their life (Gilbert 1999; Hopkins III 2013). Moreover, because home ranges of female brown bears tend to be fixed in proximity to that of their mother's (Zedrossor et al. 2007), female bears acquiring the digging behavior will remain in the same population. Thus, in the future, the number of brown bears that dig for cicada nymphs will probably increase via social learning in the study area.

Bioturbation by digging mammals is a well-studied example of ecosystem engineering that alters habitat structure for other species and soil nutrient dynamics (Tardiff and Stanford 1998; Meysman et al. 2006; Mallen-Cooper et al. 2019). We observed the area of a dug patch was often over 100 m^2, and there were at least several dozens of the patches. Furthermore, individual bear apparently dug up a large amount of soil according to observation by our camera traps. Thus, bioturbation by brown bear digging may have significant engineering effects in the forest ecosystem. Additionally, in the study area brown bears may have exerted these effects since 2000 when they started digging for cicada nymphs. In other words, the novel interaction between native species may have generated novel bioturbation in the forest ecosystem.

As the number of brown bears that dig for cicada nymphs increases, the ecological importance of the brown bear as an ecosystem engineer will increase in the forest ecosystem. Finally, we propose a hypothesis that propagation of the digging behavior via social learning might strengthen their ecological effects of bioturbation. This hypothesis may shed light on linkage between social learning and ecosystem engineering (i.e. bioturbation). Testing this hypothesis requires data on (1) population trends of digging bears; (2) their kinship based on fecal DNA which can evaluate the relationship between kinship and diet; (3) temporal dynamics in spatial patterns of brown bear digging; and (4) engineering effects of the digging on other organisms and soil nutrient dynamics.

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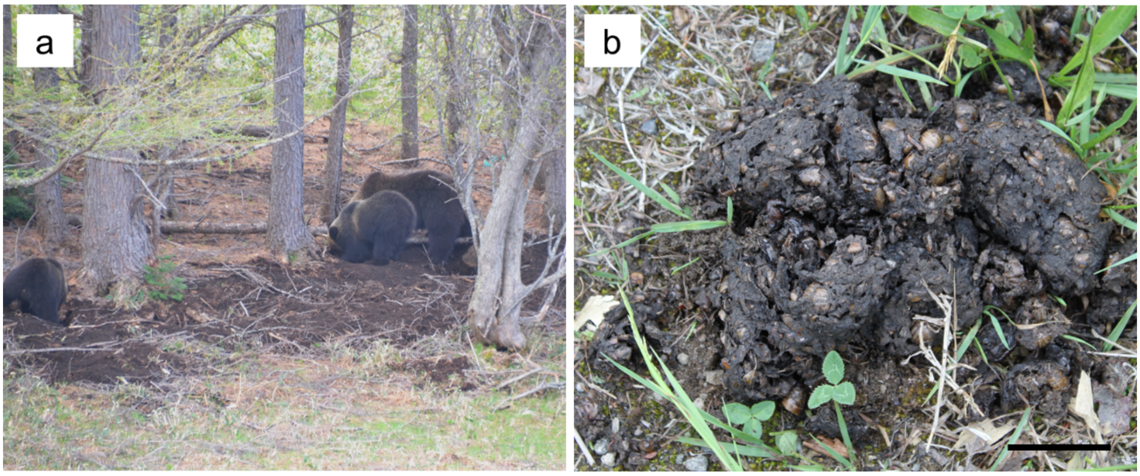
Figure legends

Figure 1: (a) Female brown bear with two cubs dig for cicada nymphs in a larch plantation. (b) Brown bear scat containing final instar *Lyristes bihamatus* nymphs. Scale bar: 50 mm (photo credit: Shiretoko Nature Foundation)

Figure 2: Scat composition of brown bears in visually estimated percent volumes for major categories, in 1985-1986 (left) and 2018 (right). Data of the scat composition in 1985-1986 from Yamanaka and Aoi (1988).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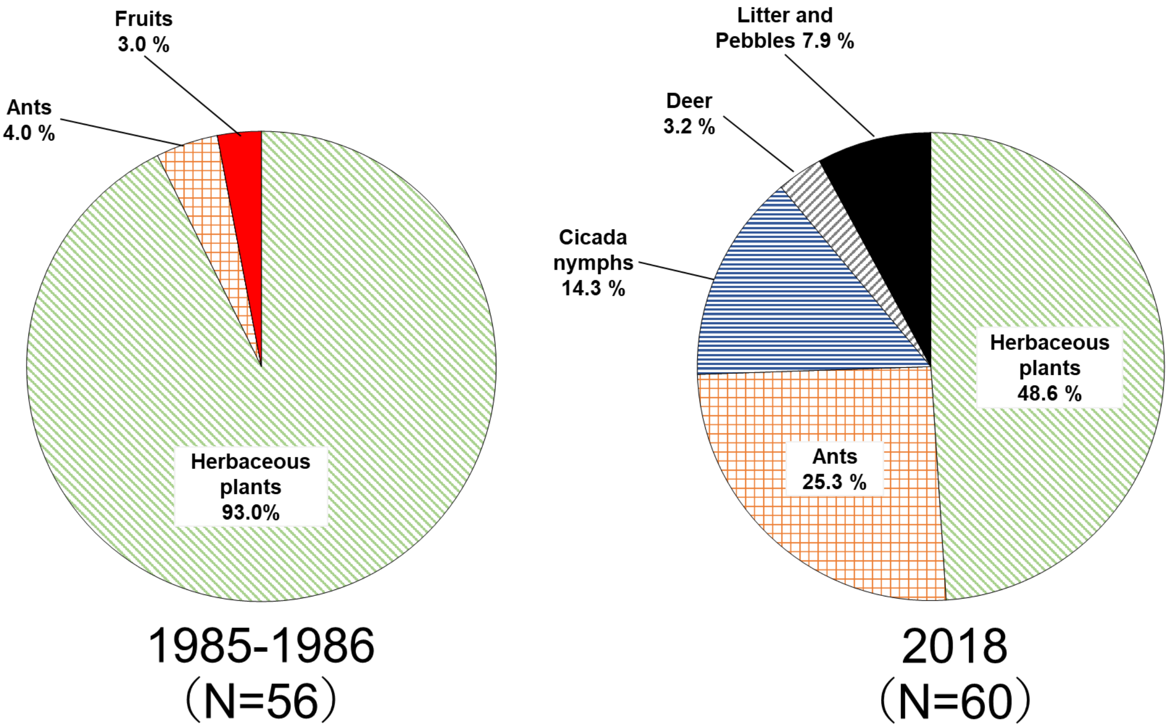

Fruits
3.0 %
Ants
4.0 %
Herbaceous
plants
93.0%
1985-1986
（N=56）
Litter and
Pebbles 7.9 %
Deer
3.2 %
Cicada
nymphs
14.3 %
Herbaceous
plants
48.6 %
Ants
25.3 %
2018
（N=60）