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1 Reforestation provides a foraging habitat for brown bears by increasing

2 cicada density in the Shiretoko World Heritage site

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10 Abstract

11	Reforestation, which converts abandoned farmland back into forestland by planting
12	woody species, can provide habitat for wildlife, including the brown bear (Ursus arctos
13	Linnaeus, 1758). In the Shiretoko World Heritage site, northern Japan, where brown bears
14	occur at high density, conifers have been planted since the 1970s to reforest abandoned
15	farmland. In this area, brown bears were first observed digging for cicada nymphs (Lyristes
16	bihamatus Motschulsky, 1861) from 2000. Our preliminary observations suggested the
17	emergence of digging behavior might be associated with reforestation. We examined
18	whether reforestation provided a foraging habitat for brown bears. We found that digging
19	occurred only within the restored conifer forests, but not within the natural forest. The
20	densities of cicada nymphs in the restored forests were higher than in the natural forest.
21	These results indicate that the reforestation of abandoned farmland provides a foraging
22	habitat for brown bears by increasing the availability of cicada nymphs in the Shiretoko
23	World Heritage site.
24	KEY WORDS cicada nymph, Lyristes bihamatus, digging, Hokkaido, large carnivore,

25 plantation, restoration, brown bear, *Ursus arctos*

26 Introduction

27	Forests, which occupy one third of terrestrial ecosystems, harbor the highest
28	biodiversity in the world (Millenium Ecosystem Assessment 2005). From the 1700s to the
29	1990s, approximately 20 % of forests were converted to farmland, and consequently a wide
30	range of forest habitat was lost around the world (Goldewijk 2001). Since the 1900s, large
31	areas of farmland have also been abandoned in developed countries because of declines in
32	human population in agricultural areas as a result of aging populations and migration to
33	urban areas (Ramankutty and Foley 1999). Reforestation, which is a major ecological
34	restoration action in forest ecosystems, aims to convert abandoned farmland to forestland by
35	planting woody species (Chazdon 2008; Aerts and Honnay 2011). The goals of reforestation
36	are not only re-establishment of forest cover, but also the enhancement of forest ecosystem
37	functions such as carbon sequestration, biodiversity conservation and wildlife habitat (Block
38	et al. 2001; Le et al. 2012; Cunningham et al. 2015; Derhé et al. 2016). Because reforestation
39	cannot fully restore the original forest ecosystem, it does not necessarily succeed in
40	recovering forest ecosystem functions. Therefore, it is important for the evaluation of

41 reforestation success to understand the ecological functions of the restored forest (Le et al.
42 2012).

43 The direction and magnitude of reforestation's influence on wildlife, differs among 44 species and taxonomic groups depending on their ecology such as habitat requirements (Law 45 et al. 2017; Whytock et al. 2018; Fuentes-Montemayor et al. 2020). Thus, it is important for 46 deepening the understanding of a function of reforestation as wildlife habitat to clarify the response per each species and taxonomic groups. 47 The brown bear (Ursus arctos Linnaeus, 1758), which is one of the most widespread 48 49 and largest carnivores in terrestrial ecosystems, plays important ecological roles as an apex 50 predator and long-distance seed disperser, and transport of marine-derived nutrients

51 (Reimchen 2000; Helfield and Naiman 2006; Ripple et al. 2014; Steyaert et al. 2019). Brown

52 bears sensitively respond to anthropogenic habitat changes due to forestry (e.g. afforestation

and deforestation), cultivation and industrial development (Cristescu et al. 2015; Frank et al.

54 2015; Sorensen et al. 2015; Penteriani et al. 2018). In fact, woodland conversion to cropland

55 leads to an increased attraction of bears to human settlements for crop raiding, and

56	consequently increases their human-caused mortality (Hata et al. 2017; Penteriani et al.
57	2018). In forest ecosystems, clearcuts temporarily change in resource availability for bears
58	via increasing light environment and biomass of coarse woody debris, and influence their
59	habitat selection (Nielsen et al. 2004a, 2004b; Frank et al. 2015). For example, in west-
60	central Alberta, Canada, grizzly bears select clearcut sites, which provide some foraging
61	resources such as ants, herbaceous plants and berries, during summer (Nielsen et al. 2004a,
62	2004b). On the other hand, it is unknown how brown bears respond to reforestation, which
63	significantly alters the habitat from farmland to forest.
64	In the Shiretoko World Heritage site (hereafter; SWH), Hokkaido, northern Japan, a
65	reforestation project started in the 1970s was led by the local government and residents to
66	recover forest landscape from abandoned farmland. In the reforested sites of the SWH,
67	brown bears have been observed digging for cicada nymphs (Lyristes bihamatus
68	Motschulsky, 1861) during the summer season since 2000 (Tomita and Hiura 2020). Tomita
69	and Hiura (2020) showed some preliminary observations that this behavior was frequently
70	found in reforested larch plantations (Larix kaempferi (Lamb.) Carrière), and that the density

71	of cicada nymphs in the plantations was over 30-fold higher than in natural forests. These
72	preliminary results suggest that reforestation has increased the availability of cicadas for
73	brown bears. However, there is no quantitative data on this behavior, information such as the
74	frequency of this digging behavior between the restored forests and natural forest has yet to
75	be studied. Because cicada emergence density usually fluctuates between years (Sato and
76	Sato 2015), to elucidate if reforestation has provided a foraging habitat for bears, we should
77	examine whether cicada emergence density in the plantations is higher than in natural forests
78	across years.
79	We compared the frequency of this digging behavior and the density of cicada nymphs
79 80	We compared the frequency of this digging behavior and the density of cicada nymphs between the natural forest and plantations. Based on our previous findings (Tomita and Hiura
79 80 81	We compared the frequency of this digging behavior and the density of cicada nymphs between the natural forest and plantations. Based on our previous findings (Tomita and Hiura 2020), we made the following predictions: (1) brown bears digging for cicada nymphs occurs
 79 80 81 82 	We compared the frequency of this digging behavior and the density of cicada nymphs between the natural forest and plantations. Based on our previous findings (Tomita and Hiura 2020), we made the following predictions: (1) brown bears digging for cicada nymphs occurs more frequent in the restored plantations than in the natural forests, (2) the density of cicada
 79 80 81 82 83 	We compared the frequency of this digging behavior and the density of cicada nymphs between the natural forest and plantations. Based on our previous findings (Tomita and Hiura 2020), we made the following predictions: (1) brown bears digging for cicada nymphs occurs more frequent in the restored plantations than in the natural forests, (2) the density of cicada nymphs is higher in the plantations than in the natural forests, (3) there is a positive

85 Material and Methods

86 Study site

87	This study was conducted in the Horobetsu-Iwaobetsu area (44°09=N, 145°02=E)
88	located in the western parts of the SWH (Fig. 1). The elevation ranges from 120 to 220 m.
89	The annual mean temperature at the study site is 6.2 °C. and monthly mean temperature
90	ranged from -10.4 °C in February to 15.1 °C in August (1981-2010). The annual mean
91	precipitation is 1,149 mm (1981-2010). UNESCO certified this area as a World Natural
92	Heritage site because it represents one of the richest northern temperate ecosystems in the
93	world (<u>http://whc.unesco.org/en/list/1193</u>). In the study area, approximately 40% of the
94	conifer-broadleaved mixed forests were converted to farmland for grazing by cattle during
95	the post-war period from the 1940s to the 1960s (Shoyama 2008). Agricultural crops such
96	as corn and sugar beet were rarely cultivated in this area. During the period of high economic
97	growth in Japan, from the late 1960s to the 1970s, all the farmland was abandoned because
98	farmers immigrated to urban areas. Since 1977, reforestation of the abandoned farmland has
99	been conducted by the local government and residents through a national trust movement.

100	Coniferous trees such as Japanese larch, Sakhalin spruce (Picea glehnii (F.Schmidt) Mast)
101	and Sakhalin fir (Abies sachalinensis (F.Schmidt) Mast), have been planted on the
102	abandoned farmland for the purpose of reforestation. Most of the larch and fir plantations
103	were established during the 1970s, whereas the spruce plantations were established during
104	the early 1990s. The restored plantations accounted for 18 % of the total forest area
105	(Shoyama 2008), with Sakhalin spruce, Japanese larch and Sakhalin fir plantations account
106	for 13 %, 4 %, and 1 %, respectively. The natural forests are conifer-broadleaved mixed
107	forests, mainly consisting of Sakhalin fir and Mongolian oak (Quercus crispula Blume) and
108	maple (Acer mono Maxim.), and account for 82 % of the forest area in the study site. The
109	stand characteristics for each forest type are shown in Table 1. On the abandoned farmland,
110	pasture grass such as Miscanthus sinensis Andersson and Anthoxanthum odoratum L. are
111	dominant and soft mast species such as Rubus spp., which are a common food for bears in
112	summer, rarely grow (Ministry of the Environment, the Government of Japan 2017).
113	The SWH has one of the highest densities of brown bears in the world (Shimozuru et

al. 2020a). In the study area, food items of the brown bears change across the seasons,

115	depending on resource availability. Herbaceous plants are consumed in spring, and
116	herbaceous plants, ants and cicada nymphs in summer, from June to August. Q. crispula
117	acorns, Vitis coignetiae (Pulliat) berries, and anadromous salmons (Oncorhynchus
118	gorbuscha Walbaum, 1792) are consumed in autumn, from September to November
119	(Ohdachi and Aoi 1987; Matsubayashi et al. 2014; Tomita and Hiura 2020). Home range size
120	of adult female bears is estimated at 26.5 km ² in the study area (Kohira et al. 2009). Bear
121	viewing is a major tourism activity in this region which generates an estimate 3 million
122	dollars in revenue (Kubo and Shoji 2014). At the study site in 2018, 11 individual bears were
123	observed digging for cicada nymphs, consisting of 2 sub adults and 2 solitary female adults,
124	and 3 females with cub(s) (Tomita and Hiura 2020). Individual identification and age classes
125	were determined based on color, marks, body size, and family structure of bears. Two native
126	cicada species, L. bihamatus and Yezoterpnosia nigricosta (Motschulsky, 1866), only occur
127	in forest of the SWH and emerge during late summer and spring to early summer,
128	respectively. No cicada nymphs occur on the farmland because the nymphs feed from tree
129	roots. In the study site, brown bear preys on the final instar nymphs of L. bihamatus, but not

Y. nigricosta (Tomita and Hiura 2020). Hence, this study focuses on the final instar nymph
of *L. bihamatus* as a prey of bears; the term "cicada" represents *L. bihamatus*.

132 Field Survey

133 We conducted field surveys in two successive years. From late August to September 2018 and 2019, 100 m² survey plots were set on the following forest types: larch plantations 134 135 (n = 15), fir plantations (n = 12), spruce plantations (n = 15), and natural forests (n = 30). Since bears dig for cicada nymphs until the end of July when the final instar nymphs fully 136 137 emerge (Tomita and Hiura 2020), this survey's duration is appropriate for the evaluation of 138 this behavior and cicada emergence density. The locations of the survey plots are shown in 139 Fig. 1. We set more plots in the natural forest because it made up the highest proportion of 140 all forest types. The availability of cicada nymphs was determined by the density of cicada 141 exuviae collected from all trees (diameter breast height, DBH > 2 cm) within the plots, since 142 brown bears forage on only the nymphs in their final instar (Tomita and Hiura 2020). Cicada 143 exuviae attached to trees were collected from trunks and branches under 3 m from the ground, 144 as most exuviae on trees can be observed under this height. We also collected the exuviae on

145	the ground within 1 m from the trunk of a tree, because most exuviae falling from the tree
146	were found within 1 m of the trunk. Since final instar cicada nymphs usually attach to the
147	tree trunk when they emerge, the exuviae density in a survey plot can be regarded as the total
148	emergence density from a given plot. Although exuviae could move a short distance due to
149	the wind, the plot size (i.e. 100 m^2) is large enough to cover for passive movement of the
150	exuviae after emergence. Digging marks were regarded as evidence of brown bears foraging
151	on cicada nymphs. According to our preliminary observations using 8 camera traps set in
152	larch plantations where brown bears dug the previous year, brown bears usually dig for
153	cicada nymphs near tree trunks. Thus, we evaluated the digging frequency per plot as the
154	proportion of trees which had the digging traces within 50 cm diameter from the base of a
155	tree, to all trees (DBH > 2 cm) in the plot.

156 Statistical Analysis

157 Generalized linear models (GLMs) with log link, Poisson error distribution and Tukey 158 post hoc test were used to examine the differences in the digging frequencies and the 159 densities of cicada nymphs among the forest types. When the GLMs indicated a significant

160	difference (<i>p-value</i> < 0.05) of one forest type from others, we performed multiple
161	comparisons among the forest types. The GLMs were used to compare the digging frequency
162	and the density of cicada nymphs between 2018 and 2019. In GLMs for digging frequency,
163	we introduced an offset term as the log-transformed number of trees to adjust for differences
164	in the number of trees among the survey plots. To examine the effects of the density of cicada
165	nymphs on the digging frequency, we performed GLMs for each forest type. All statistical
166	analyses were conducted in R version 3.5.1 (R Core Team 2018).
167	Biomass measurement of cicada nymphs
168	In mid-June 2019, we collected 10 cicada final instar nymphs from the larch plantation.
169	In the laboratory, these nymphs were measured individual using dry mass after a 48 hour at
170	60 °C drying period. The biomass of cicada final instar nymphs per 100 m ² were calculated
171	by multiplying individual dry mass of the nymph by the density of cicada exuviae.
172	

173 **Results**

174 Across all survey plots, we collected a total of 629 and 3344 cicada exuviae in 2018 175 and 2019, respectively and recorded a total of 2176 trees with or without digging traces. 176 The GLMs found a significant effect of forest type on digging frequency and the 177 density of cicada nymphs. Surprisingly, brown bears only dug for cicada nymphs in the 178 restored plantation plots, even when the natural forest plots were mainly composed of fir 179 species (Fig. 2). Digging frequency in the larch plantations was highest in all forest types in 180 both years, but significantly differed between years (Fig. 2). The density of cicada nymphs 181 in the larch plantations did not differ from the fir plantations, which had a lower digging 182 frequency (Fig. 3). The density of cicada nymphs was lowest in the natural forest (Fig. 3). 183 The spruce plantation plots had a lower digging frequency and density of cicada nymphs 184 than other types of plantation plots (Fig. 2, 3). The densities of cicada nymphs across all 185 forest types in 2019 were significantly higher than in 2018 (p < 0.001, Fig. 3). The density 186 of cicada nymphs positively correlated to the digging frequencies in fir and spruce plantations (p < 0.001), but not in larch plantations in 2018 (p = 0.19) (Fig. 4). Individual 187

- 188 dry mass of the final instar nymphs was evaluated at 1.12 ± 0.20 g (mean \pm SD), and the
- 189 biomass density of nymphs in each forest type is shown in Table 2.

190 **Discussion**

191 The results of this study generally supported our predictions. In particular, brown 192 bears foraged on cicada nymphs only in plantations, not in natural forests (Fig. 2). This 193 clearly indicates that reforestation provided a foraging habitat for brown bears by increasing 194 the availability of cicada nymphs. To our knowledge, this is the first study showing that 195 reforestation provides a foraging habitat for brown bears. 196 Our results indicate that the difference in the digging frequency among forest types 197 can generally be explained by the density of cicada nymphs (Figs. 2, 3, 4). The digging 198 frequency showed that brown bears preferentially dug for cicada nymphs in the larch 199 plantations, although there were no differences in the density of cicada nymphs between 200 larch and fir plantations (Figs. 2, 3). Brown bears might indirectly search for the nymphs by 201 using larch trees as an aboveground landmark for detecting the location of underground 202 cicada nymphs. In the study site, larch trees do not occur in the natural forest because larches 203 are an introduced plantation species. Thus, brown bears may have learned to associate nymphs with larch trees. This potential explanation is supported by our finding that a lower 204

206 (Fig. 4A). Another possible explanation is that brown bears have fewer chances of 207 encountering fir plantations than larch plantations, because the total area of larch plantations 208 is larger than that of fir plantations in the study site. 209 Within the same forest type, digging frequencies were positively affected by the 210 density of cicada nymphs (Fig. 4B-F). This indicates that brown bears can accurately detect 211 the location of the cicada nymphs within a certain distance, perhaps using their remarkable 212 olfactory senses (Gittleman 1991; Rosell et al. 2011). Other fossorial mammals can use the 213 smell of volatile signals from unseen belowground resources to detect food (Sörensen et al. 214 2019; Stephens et al. 2020). Thus, bears may identify locations where there are high densities 215 of cicada nymphs by smelling the volatile signals. We note that it is unclear yet whether 216 cicada nymphs emit volatile signals to the surface. 217 If bears rely on olfaction while searching for cicada nymphs, the relationship between

density of cicada nymphs did not affect digging frequency in larch plantations during 2018

- 218 digging frequency and cicada density should be significantly positive in the larch plantations.
- 219 The possible reason is that the searching tactics of bears are different among individuals;

220	some bears rely on spatial learning, associating cicada with larches, while others use
221	olfactory cues. Behavioral differences among individuals are common in bears (Leclerc et
222	al. 2016; Lesmerises and St-Laurent 2017). Data based on the digging behavior of
223	individuals is required to deepen our understanding of how bears search for cicada nymphs.
224	Across all forest types, the density of cicada nymphs in 2019 were significantly higher
225	than that of 2018 (Fig.2), suggesting that emergence density of L. bihamatus varies among
226	years. Emergence densities of annual cicada vary among years because of the age structure
227	in the nymphal stage (Sato and Sato 2015), so this inter-annual difference is probably a
228	general pattern for cicada species. Importantly, the emergence densities of cicadas in the
229	restored forests were significantly higher than in the natural forest, despite the different
230	density of cicadas over the study period. Given that the plantations are located proximate to
231	the natural forests in the study site (see Fig.1) and dispersal distance in adult cicadas is
232	estimated at about 100-250 m (Andrade et al. 2020), adult cicadas can easily come and go
233	between the plantations and the natural forest. Since emergence schedule in cicada is usually
234	homogeneous within same population (e.g. periodical cicadas (Dybas and Lloyd 1974)),

periodicity of cicada emergence doesn't differ between the plantations and natural forests.
These strongly indicate that the restored forests play a role as foraging habitat for brown
bears across years.

238 We speculate that the reason for high densities of cicada nymphs in the conifer 239 plantations is because adult cicadas intensively oviposit on coniferous species. The spatial 240 distribution of cicada nymphs is determined by the oviposition preference of adult cicadas 241 because the nymphs cannot move a long distance in the soil (Oberdörster and Grant 2006). 242 A study showed that oviposition density of the periodical cicada (Magicicada sp.) increased 243 with increasing canopy openness (Yang 2006). Although the canopy openness of larch 244 plantations was higher than natural forests, fir and spruce plantations were similar to the 245 natural forests (Table 1), suggesting that variations in light among forest types was 246 insufficient for explaining the difference in cicada density. Another possible factor is the host 247 tree architecture (Mattingly and Flory 2011). Several annual cicada species in Japan lay their 248 eggs on dead branches attached to living trees (e.g. Cryptotympana facialis (F. Walker, 1858), 249 Moriyama et al. (2016)). In the study site, oviposition scars by L. bihamatus were frequently

250	observed on dead branches of the living larch trees (K. Tomita personal observation),
251	suggesting that this species also deposits its eggs on the dead branches of living trees. Since
252	conifer plantations usually have a larger number of attached dead branches than natural
253	forests (Yoshida and Hijii 2006), the former would have a higher availability of oviposition
254	sites for cicadas than the latter.
255	Our previous study showed that the proportion of cicada nymphs in bear scats was
256	estimated at 14.3% (Tomita and Hiura 2020). Given that brown bears forage on cicada
257	nymphs only in the restored plantations (Fig.2), the plantation could contribute to the bears'
258	summer diet to some extent, even though it only accounts for 18% of the total forest area.
259	Insects such as ants (Formicidae) and the army cutworm moth (Euxoa auxiliaris Grote,
260	1873) are some of the most important summer foods for brown bears around the world
261	(Mattson et al. 1991 <i>a</i> , 1991 <i>b</i> ; Elgmork and Kaasa 1992; Sato et al. 2005; Bojarska and Selva
262	2012). Mattson et al. (1991b) estimated the proportion of army cutworm moths in bear scats
263	during summer was at 42-77% in alpine areas of the Yellowstone National Park, North
264	America. The proportions of ants, the most common insect prey for bears across their

265	distributional range, in Sweden, North America, Slovenia and Japan was reported at 16%,
266	<5%, 25% and 18%, respectively (Swenson et al. 1999; Mattson 2001; Große et al. 2003;
267	Sato et al. 2005). These suggest that the dependency of brown bears on cicada nymphs in
268	this area seems to be to the same extent as ants in other regions, though not as significant as
269	army cutworm moths in Yellowstone National Park.
270	The dry biomass of the final instar nymphs of cicada in the larch plantation was
271	estimated at 22.62 and 97.51 g/100 m^2 in 2018 and 2019, respectively (Table 2). In Sweden,
272	Slovenia and Japan, the dry biomass of ants was estimated at 96, 1.35 and 0.59 g/100 m^2 ,
273	respectively (Swenson et al. 1999; Große et al. 2003; Yamazaki et al. 2012). This indicates
274	that the biomass density of the nymphs in the plantations is more or equal than that of ants,
275	which is a major summer food for bears. Nevertheless, this does not mean that the total
276	biomass of cicada nymphs in the whole forest is higher than that of ants or other food sources,
277	because a large biomass of cicada nymphs only occurs in the restored plantations, accounting
278	for a small proportion (ca. 18%) of the study site. Further data on the foraging ecology, such
279	as the nutrients provided by the nymphs and energetic cost of the digging behavior, are



288 Concluding Remarks

The primary goal of the reforestation program in the SWH to recover the forest landscape from abandoned farmland has already been achieved (Shoyama 2008), but its ecological functions remain largely unknown (but see Fujii et al. (2017)). Our findings shed light on an ecological function of the restored forests for brown bears via providing a food resource (i.e. cicadas). In the SWH, brown bears play important roles in ecological and economical services, such as the transporting of salmon-derived nutrients and nature tourism

295	(Koshino et al. 2013; Kubo and Shoji 2014). However, bear appearances along the roads
296	have often occurred in the study site (Shimozuru et al. 2020b), and this is a potential cause
297	for increasing human-bear conflicts like "bear jams" (Herrero et al. 2005). Because large
298	areas of the restored plantations located near the roads are frequently used by tourists (Fig.1),
299	bears would need to approach the roads to forage on cicada nymphs. In fact, wildlife
300	managers often observed bears digging for the nymphs within the plantations adjacent roads
301	(Shiretoko Nature Foundation personal communication). Perhaps, the plantations might not
302	only provide a foraging habitat for bears, but also intensify human-bear conflict by attracting
303	bears towards the roads. Of course, it is also possible that human-habituated bears mainly
304	dig for the nymphs in the plantations. Testing this hypothesis requires more data on space
305	use by bears.
306	We found that brown bears foraged on cicada nymphs only in the monoculture

We found that brown bears foraged on cicada nymphs only in the monoculture plantations, but not the natural forests with higher tree diversity. Nevertheless, it doesn't mean that monocultures are an overall more valuable habitat for bears than natural forests because tree diversity assumes to enhance the ecological value of forests as wildlife habitat

310	(Stephens and Wagner 2007). Recently, there is growing evidence indicating that
311	monoculture plantations are more valuable as wildlife habitat than previously thought
312	(Brockerhoff et al. 2008; Sakamaki and Enari 2012). Given this evidence, including our
313	finding, monocultures might be regarded as distinct habitat compared with mixed forests,
314	not as less valuable habitat for wildlife. Especially, larch, one of the typical pioneer tree
315	species, can rapidly recover forest canopy. Moreover, due to high light availability on the
316	forest floor of larch plantations, biomass of herbaceous species on the plantation have same
317	extent as natural forests and deciduous broadleaved trees can easily invade into the plantation
318	(Kitaoka and Koike 2004; Takafumi and Hiura 2009). Larch plantations with high
319	availability of cicadas are the potential foraging habitat for predators consuming cicadas (e.g.
320	birds (Pons 2020), mammals (Lovari et al. 1994; Way 2008; Tomita and Hiura 2020)).
321	Therefore, larch may be a candidate species for tentative reforestation on abandoned land
322	although it should consider that in the Hokkaido island, larch is now an alien species but had
323	distributed during the last glacial period (Ooi et al. 1997). When selecting tree species for
324	reforestation, we need to consider the ecological functions of the species, not only following

325 an assumption that the value of restored forests increases as tree diversity increases.

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534 Table

535 Table 1 Stand characteristics across the forest types. Mean \pm SD

Forest type	Dominant tree species	Density of trees	Basal area	Canopy
(Number of plots)	(%Basal area)	(Trees 100 m ⁻²)	$(m^2 \ 100 \ m^{-2})$	openness (%)
Larch plantation	I 1 ((070/)		0.12 + 0.04	12 (0 + 2 (2
(<i>n</i> =15)	Larix kaempieri (97%)	32.07 ± 7.78	0.12 ± 0.04	12.09 ± 2.03
Fir plantation		20.15 - 10.24	0.11 + 0.04	2 41 + 0 (2
(<i>n</i> =12)	Abies sachalinensis (84%)	30.17 ± 10.34	0.11 ± 0.04	2.41 ± 0.62
Spruce plantation		27.22 + (10	0.00 + 0.02	1.02 + 0.02
(<i>n</i> =15)	Picea glehnii (95%)	27.33 ± 6.19	0.09 ± 0.03	1.83 ± 0.82
Natural forest	Abies sachalinensis (31%)		0.10 - 0.05	0.00 + 1.07
(<i>n</i> =30)	Quercus crispula (28%)	$31.5 / \pm 10.36$	0.10 ± 0.05	2.20 ± 1.06

- 537 Table 2 The density and estimated biomass of final instar nymphs of cicada Lyristes
- 538 *bihamatus* in the plot (100 m²) across forest types. Biomass of the nymphs was calculated as
- 539 multiplying mean individual dry mass of the nymph (=1.12 g) by their density. Mean \pm SD

F (4	Density of the nymphs	Density of the nymphs	Biomass of the nymphs	Biomass of the nymphs
Forest type	in 2018 (/100 m ²)	in 2019 (/100 m ²)	in 2018 (g/100 m ²)	in 2019 (g/100 m ²)
Larch plantation	20.20 ± 18.71	87.07 ± 47.72	22.62 ± 20.96	97.52 ± 53.44
Fir plantation	16.92 ± 13.71	93.50 ± 66.55	18.95 ± 15.36	104.72 ± 74.54
Spruce plantation	5.67 ± 6.22	44.40 ± 63.08	6.35 ± 6.96	49.73 ± 70.65
Natural forest	1.27 ± 1.41	8.33 ± 9.44	1.42 ± 1.58	9.33 ± 10.57

540 Figure captions

Figure 1 Location of the survey plots in vegetation map of the study site. Black lines
indicate roads. This vegetation map was created by Shiretoko Nature Foundation (Shiretoko
Nature Foundation unpublished information). This figure was created using QGIS version

544 3.14.0 (QGIS Development Team 2020).

545

546 Figure 2 The digging frequencies of brown bear Ursus arctos across all forest types in

547 2018 (dark grey) and 2019 (white). Upper case and lower letters indicate significant

548 differences among forest types in 2018 and 2019 according to post-hoc Tukey's test,

549 respectively (p < 0.05). Single asterisk indicates significant differences in the digging

frequency between 2 years by generalized linear model (p < 0.001).

551

552 Figure 3 The number of cicada Lyristes bihamatus exuviae across all forest types in 2018

553 (dark grey) and 2019 (grey). Upper case and lower letters indicate significant differences

among forest types in 2018 and 2019 according to post-hoc Tukey's test, respectively (p < p

555 0.05). Single asterisk indicates significant differences in the number of cicada exuviae

between 2 years by generalized linear model (p < 0.001).

557

558 Figure 4 Relationships between the digging frequencies of brown bear Ursus arctos and

559 the densities of cicada *Lyristes bihamatus* nymphs in the restored forests; (A) larch and (B)

560 fir, (C) spruce in 2018, (D) larch and (E) fir, (F) spruce in 2019. Dashed lines show the

561 linear model predictions with shaded areas indicating the 95% CI.







