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Title: Calcium concentration in leaf litter alters the community composition of soil invertebrates in warm-temperate forests.

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Running title: Calcium in leaf litter and soil organisms

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33 ABSTRACT

34

35 Many studies have shown the effects of aboveground plant species on soil organisms
36 due to differences in litter quality. However, the calcium concentration in soil has
37 received less attention as a controlling factor of soil invertebrate communities, despite
38 its being an essential element for many animals, especially crustaceans. Litter of
39 Japanese cedar (*Cryptomeria japonica*) plantations, which account for 19% of the
40 forested area in Japan, has a higher calcium concentration compared to other taxa such
41 as broad-leaved trees. We predicted that *C. japonica* plantations affect soil invertebrates
42 by altering calcium availability. We compared soil properties including exchangeable
43 calcium concentration and soil invertebrate communities between *C. japonica*
44 plantations and natural broad-leaved forests. Exchangeable calcium was significantly
45 higher in soil from cedar plantations than in that from broad-leaved forests. The
46 invertebrate community composition differed between the two forest types and was best
47 explained by the exchangeable calcium concentration. In particular, two major taxa of
48 soil crustaceans (Talitridae and *Ligidium japonicum*) were found only in cedar

plantations. Our results suggest that calcium concentrations in soil are altered in *C. japonica* plantations and that this affects soil invertebrate communities.

Keywords: Evergreen broad-leaved trees, *Cryptomeria japonica*, forest management, crustaceans, *Ligidium japonicum*, Talitridae

65 **Introduction**

66

67 Soil organisms can be affected by differences in aboveground vegetation (Bardgett
68 and Wardle 2010), often driven by the quality of the litter types (Swift et al. 1979; Berg
69 and McClaugherty 2003). Differences in litter quality among plant species can influence
70 the chemical properties of soil and act as determinants of the community structure of
71 soil invertebrates (Widden and Hsu 1987; Wardle et al. 2006). Because calcium is a
72 major structural component of the proteins forming animals, ambient calcium
73 concentration related to the animal densities in calcium poor environment (Alstad et al.
74 1999; Hessen et al. 2000; Ohta et al. 2014). Similarly, soil calcium concentrations can
75 have an important influence on soil invertebrate communities (Springett and Syers
76 1984). For example, the abundance of some soil invertebrates increase with the
77 available soil calcium concentration (Hotopp 2002; Reich et al. 2005; Skeldon et al.
78 2007). Global pattern of soil calcium concentration is governed by geological change,
79 acid deposition and annual precipitation (Potter and Conkling 2012; Binkley and Fisher
80 2013). For example, low rainfall areas (central North America) tend to have grater soil

81 calcium than humid Eastern United States (Potter and Conkling 2012). Calcium
82 availability and cycling in regional scale are governed by numerous factors including
83 forest vegetation dynamics, atmospheric deposition, soil mineral weathering, and losses
84 due to leaching (Likens et al. 1998; McLaughlin and Wimmer 1999; Dijkstra and Smits
85 2002). However, much research over the last half century has focused on the leaching of
86 calcium due to acid deposition (Likens et al. 1996; Driscoll et al. 2001), with much less
87 emphasis on other factors, such as changes in forest vegetation, even though the calcium
88 concentration in leaf litter varies greatly among tree species.
89 Litter of members of the Cupressaceae has a higher concentration of calcium
90 compared with other plant families (Kiilsgaard et al. 1987; Ohta et al. 2014). In this
91 study, we focused on Japanese cedar (*Cryptomeria japonica*, Cupressaceae) because its
92 leaf litter contains ~3% calcium (Xue and Luo 2002; Baba et al. 2004), more than three
93 times the amount in many other taxa, such as fir (*Abies* spp.) and many broad-leaved
94 trees (Kiilsgaard et al. 1987; Reich et al. 2005; Ohta et al. 2014). Japanese cedar
95 plantations cover 12% of the total land area and 19% of the forested area in Japan
96 (Forestry Agency 2011). Because soil organic matter in forests is derived mainly from

97 plant litter, the chemical properties of litter affect soil chemical properties (Reich et al.
98 2005). Indeed, the soil in Japanese cedar plantations has a calcium content that is three
99 to four times higher than that in evergreen broad-leaved forests in some parts of Japan
100 (Tsutsumi 1987; Ohta et al. 2014). Ohta et al. (2014) showed that the calcium
101 concentration in soil and streams, and the density and survival of dominant aquatic
102 crustaceans, were significantly higher in *C. japonica* plantations compared with
103 evergreen broad-leaved forests. However, Ohta et al. (2014) did not assess the effects of
104 forest vegetation on soil animal community through alteration of calcium availability.
105 Soil crustaceans that are frequently dominant decomposers in soil systems (O'hanlon
106 and Bolger 1999), and contain large amount of calcium in their body (Greenaway 1985).
107 Terrestrial crustaceans mainly take calcium from their food (e.g. leaf litter) and soil
108 water. Therefore, we anticipate that the calcium concentration in litter affects the
109 community structure of soil organisms in calcium-poor environment.
110 Addition of inorganic calcium often increases soil pH (Likens et al. 1996; Driscoll
111 et al. 2001; Warby et al. 2009), and therefore, higher calcium concentrations in soil due
112 to differences in forest vegetation are also likely to increase soil pH (Reich et al. 2005).

113 Alteration of soil pH also causes changes in the abundance of soil invertebrates (Hågvar
114 1990; Myrold 1990; Kaneko and Kofuji 2000). Therefore, plantations of *C. japonica*
115 may affect the community structure of soil invertebrates via increased soil pH.
116 We examined the effect of Japanese cedar (*C. japonica*) plantations on the
117 community structure of soil invertebrates, particularly the density of crustaceans. We
118 conducted field surveys in six plots that differed in surrounding forest vegetation. We
119 predicted (1) that the calcium concentration and soil pH would be higher in *C. japonica*
120 plantations compared to evergreen broad-leaved forests, and (2) that crustacean density
121 would be higher in *C. japonica* plantations than in evergreen broad-leaved forests.
122
123 **Methods**
124
125 *Study area*
126
127 We conducted field surveys in the Wakayama Experimental Forest of Hokkaido
128 University (33°40'N, 135°40'E; 428 ha; annual mean temperature: 15.2ºC) on the

129 Southern Kii Peninsula of Japan. The geological structure in this region consists of
130 sandstone and mudstone formed during the middle Tertiary (Tateishi 1976). Because of
131 the highly acidic soil and high annual rainfall (~4000 mm), the area is extremely poor in
132 calcium (Kihira et al. 2005). The forest soils are extremely thin, nearly exposing the
133 bedrock. Japanese cedar was planted in much of the area beginning in the 1960s, and
134 remnant natural evergreen broad-leaved forests are patchy.
135 We established a sampling plot (50 × 50 m) in each of six different catchments of
136 the Wakayama Experimental Forest. The plots were located on relatively flat forest
137 floors and separated by 0.2–1.5 km. Three of the six catchments were mostly covered
138 by evergreen broad-leaved forests 'evergreen', and the other three were covered by
139 Japanese cedar plantations 'cedar'. Forests in the 'evergreen' plots were dominated by
140 *Quercus acuta*, *Quercus myrsinifolia*, *Quercus sessilifolia*, *Neolitsea aciculata*, *Eurya*
141 *japonica*, and *Machilus thunbergii* (Ohta et al. 2014). The *C. japonica* trees in the
142 'cedar' plots were planted 30–82 years prior to this study. Calcium concentration in the
143 litter of *C. japonica* (3.4%) is about three times higher than in the evergreen
144 broad-leaved species (0.8–1.5%) at this study site (Ohta et al. 2014). Carbon, nitrogen,

145 phosphorus, and magnesium concentrations do not differ significantly among the
146 species, whereas potassium is about three times lower in *C. japonica* compared to the
147 broad-leaved species (Ohta et al. 2014).
148
149 *Sampling*
150
151 On 24 July 2012, we collected five samples at each plot from the litter and soil layers
152 using core samplers (soil layer: 50 mm in diameter and 50 mm in height, litter layer:
153 113 mm in diameter and 40 mm in height) to measure soil chemical properties and mass
154 of the litter layer. To determine the soil crustacean density, we established five sampling
155 quadrats separated by over 10 m in each plot. We collected crustaceans within the
156 sampling quadrats (25 × 25-cm) to a depth of 3 cm (including litter and surface soil
157 layers) on 17 May and 21 September 2013. Soil crustaceans were separated from soil by
158 hand-sorting and placed in 99% ethanol. To examine the community structure of
159 ground-dwelling macroinvertebrates, we established two subplots (20 × 20 m) in each
160 plot. We collected ground-dwelling invertebrates using five pitfall traps (8 cm in

161 diameter and 6 cm in depth) per subplot. We placed the pitfall traps in each subplot ~2
162 m apart on 17 May, 19 July, 19 October, and 18 November 2013, and collected them 3
163 days later. We counted and identified all invertebrates found in the traps at least to the
164 ordinal level following Aoki (1999) and Ueno et al. (1985).
165
166 *Sample processing*
167
168 To measure soil nitrate and exchangeable calcium, we shook (160 rev min^{-1}) a 0.5 g
169 (air-dried mass) subsample of each soil sample in 100 ml of 1 M KCl solution for 1 h,
170 filtered the sample through filter paper (No. 5C; Advantec, Tokyo, Japan), and then
171 stored the suspension at –30ºC until analysis. We analyzed the soil extracts for calcium
172 and nitrate concentration per unit air-dried mass using an inductively coupled plasma
173 (ICP) atomic emission spectrometer (ICPE-9000; Shimadzu, Kyoto, Japan) and the
174 absorptiometric method (Sakata 2000). We placed a 5-g (air-dried mass) subsample of
175 each soil sample in 25 ml 1 M KCL and measured the pH using a pH meter (TOA-DKK,
176 HM-30V; TOA Electronics, Tokyo, Japan). We dried soil subsamples in a drying oven

177 at 60ºC for 24 h and then analyzed 50-mg dried soil samples for carbon and nitrogen
178 concentrations per dry mass using a CN analyzer (Sumigraph NC-900; Sumika
179 Chemical Analysis Service, Osaka, Japan). We dried a 1-g fresh subsample at 60ºC for
180 48 h to calculate the soil water content as the difference in mass before and after
181 desiccation.
182
183 *Statistical analysis*
184
185 The soil properties (mass of the litter layer, water content, pH, C:N ratio,
186 exchangeable calcium, total carbon, total nitrogen, and nitrate concentration) were fit to
187 linear mixed models with forest vegetation type as a fixed factor and plot identity as a
188 random factor. The statistical significance of the effect of the fixed factor in each model
189 was evaluated by a likelihood ratio test ($\alpha = 0.05$).
190 We performed canonical correspondence analysis (CCA) to explore the
191 relationships between the soil invertebrate composition and soil properties. The
192 invertebrate data from the five pitfall traps on all four sampling dates were pooled for

193 each subplot. Before conducting the CCA ordination, the abundance data for each taxon
194 were standardized to unit variance, and the most important explanatory variables from
195 all soil properties were determined by forward stepwise selection based on Akaike's
196 information criteria and Monte Carlo permutation tests. All statistical analyses were
197 conducted with R version 2.9.2 software (R Development Core Team 2011).
198
199 **Results**
200
201 Soil exchangeable calcium concentration (likelihood ratio test: $\chi^2 = 9.13$, d.f. = 1, P
202 = 0.002) and C:N ratio (likelihood ratio test: $\chi^2 = 8.90$, d.f. = 1, $P = 0.003$) were
203 significantly higher, and nitrate concentration (likelihood ratio test: $\chi^2 = 8.53$, d.f. = 1, P
204 = 0.003) was significantly lower in 'cedar' than 'evergreen'. In particular, soil in 'cedar'
205 plots had ~2.5 times more exchangeable calcium than the 'evergreen' plots (Table 1,
206 Fig. 1). The other soil properties including the mass of litter layer that was selected
207 explainatory variable in community composition of soil invertebrates did not differ
208 significantly between the forest types although soil pH was marginally higher in 'cedar'

than ‘evergreen’ (likelihood ratio test: $\chi^2 = 3.05$, d.f. = 1, $P = 0.08$). We found two taxa of crustaceans, Talitridae (Amphipoda) and *Ligidium japonicum* (Isopoda: Ligiidae) in ‘cedar’ plots by hand-sorting, but we found no crustaceans in ‘evergreen’ plots (Fig. 2). Abundances of Talitridae and *L. japonicum* did not differ significantly among ‘cedar’ plots between the two sampling months (generalized linear models assuming Poisson distribution and likelihood ratio tests: $P > 0.05$).

Crustaceans, spiders, ants, beetles, lepidopteran larvae, and millipedes accounted for 23, 19, 9, 19, 10, and 9%, respectively, of the total invertebrates captured by pitfall traps (Table 2). Crustaceans (mainly Talitridae and *L. japonicum*) dominated the ground-dwelling invertebrate communities in ‘cedar’ plots, while they were remarkably scarce, and millipedes (Paradoxosomatidae) and beetles were relatively abundant in ‘evergreen’ plots. Talitridae and *L. japonicum* were only collected in ‘cedar’ plots using pitfall traps, and a few individuals of *Venezillo* sp. (Isopoda: Armadillidae) were collected not only in ‘cedar’ but also ‘evergreen’ plots (Table 2). Taxonomic compositions of ground invertebrates differed distinctively between ‘cedar’ and ‘evergreen’ plots (Table 2, Fig. 3). From all the soil properties, exchangeable calcium

225 concentration and mass of the litter layer explained the most variation among the 12
226 subplots in invertebrate community composition as determined through the forward
227 selection process of CCA. The first and second axes explained 17.17 and 14.04%,
228 respectively, of the variation in community composition (Monte Carlo permutation test:
229 $P < 0.05$). The CCA ordination showed that community composition in the 'cedar' plots
230 was distinctively different from that in the 'evergreen' plots along the first CCA axis,
231 which corresponded to the gradient of exchangeable calcium concentration, and the
232 'cedar' plots had much lower variation than the 'evergreen' plots (Fig. 3).
233 Compositional difference within 'evergreen' was distinctively indicated by second axis,
234 which weakly correlated with mass of litter layer (Fig. 3). Talitridae and *L. japonicum*
235 had large negative values on the first axis, and their high abundance characterized the
236 'cedar' community.
237
238 **Discussion**
239
240 Our results show that forest vegetation might affect the community structure of soil

241 invertebrates by altering calcium availability. Our field survey showed that soil
242 exchangeable calcium was ~2.5 times higher and soil pH was not significantly higher in
243 *C. japonica* plantations compared with that in evergreen broad-leaved forests (these
244 partly supported prediction 1). The major taxa of soil crustaceans (Talitridae and *L.*
245 *japonicum*) were found only in *C. japonica* plantations, whereas only a few individuals
246 of a minor crustacean species (*Venezillo* sp.) occurred in broad-leaved forests
247 (supporting prediction 2). The community structure of soil invertebrates varied with
248 forest vegetation types, and calcium in the soil layer was the most important
249 environmental variable explaining the variation in community composition (supporting
250 prediction 2). Furthermore, both intra- and inter-plot variation in the soil invertebrate
251 community structure in *C. japonica* plantations were lower than in natural broad-leaved
252 forests, suggesting that the homogeneous environment created by the monoculture
253 plantation caused a large decrease in micro- and local-scale β-diversity of soil
254 invertebrates. This might be caused by uniform increase in the abundance of Talitridae
255 and *L. japonicum* in *C. japonica* plantations and difference in the mass of litter layer
256 within 'evergreen' plots (Table 1, Fig. 3).

257 The difference in calcium concentration in leaf litter produces significant
258 differences in soil calcium (Morrison 1985; Kloeppel and Abrams 1995). In fact, Ohta
259 et al. (2014) showed that the calcium concentration in *C. japonica* litter was about three
260 times higher than that of dominant evergreen broad-leaved trees in Wakayama
261 Experimental Forest. We found that total calcium in the litter layer and
262 water-extractable calcium in the soil at 'cedar' sites were three to four times higher than
263 at 'evergreen' sites. These results support our finding that calcium supplied by *C.*
264 *japonica* litter increased the calcium concentration in the soil of our study plots.
265 Field manipulations at the Hubbard Brook Experimental Forest in the northeastern
266 United States indicated that adding $CaSiO_3$ to a catchment area increased calcium
267 concentrations in soil (Juice et al. 2006; Minocha et al. 2010; Nezat et al. 2010) and
268 altered the community structure of terrestrial snails, which have high demand for
269 calcium (Skeldon et al. 2007). Hotopp (2002) showed that the abundance of sugar
270 maple, a calciphilic species (Likens and Bormann 1970), was positively correlated with
271 terrestrial snail density. As in snails, crustaceans must ingest a lot of calcium
272 (Greenaway 1985). Because terrestrial crustaceans lose 20% of their body calcium

273 through exuviae (Ziegler et al. 2007), they need adequate calcium to calcify their
274 exoskeleton rapidly after exuviation. Terrestrial crustaceans in soil get calcium from
275 soil water and litter (Greenaway 1985; Glötzner and Ziegler 2000). Therefore, the
276 'cedar' plots, which have high calcium levels in their litter and soil layers, are well
277 suited for the survival of crustaceans (Figs. 1, 2). Indeed, both natural and artificial *C.*
278 *japonica* forests in central Japan have high densities of crustaceans (Ikeda at al. 2005).
279 Calcium addition to acidic soil increases soil pH (Groffman et al. 2006; Groffman
280 and Fink 2011). However, our result showed the soil pH was not significantly higher in
281 *C. japonica* plantations that increase the calcium concentration of the soils (Table 1).
282 Although previous studies showed soil pH may also affect the structure of invertebrate
283 communities by altering forest vegetation (e.g. Kaneko and Kofuji 2000), forward
284 selection of the CCA analysis selected exchangeable soil calcium concentration and not
285 pH in our result. Calcium concentration may have a greater impact on the community
286 structure of soil invertebrates in our study site.
287 The litter of other members of Cupressaceae, such as *Chamaecyparis* and
288 *Sequoiadendron*, also have high calcium content comparable to that of *C. japonica*

289 (Kiilsgaard et al. 1987; D'Amore et al. 2009). This might mean change in soil system
290 through difference in calcium concentration in leaf litter is caused in other forest types.
291 Furthermore, Reich et al. (2005) showed that exchangeable calcium in soils and the
292 density of earthworms were significantly higher in forests dominated by *Acer*
293 *pseudoplatanus* and *Tilia cordata* compared to forests dominated by *Larix* and *Pinus*,
294 even though calcium concentrations were ~40% lower in the litter of *A. pseudoplatanus*
295 and *T. cordata* than in *C. japonica*. This implies that the change in soil systems is
296 caused by the alteration of forest vegetation with low calcium content relative to *C.*
297 *japonica*.
298 Soil crustaceans, such as Talitridae and *L. japonicum*, are powerful litter
299 decomposers (Zimmer 2002). Their existence influences litter decomposition rates
300 (O'Hanlon and Bolger 1999), and their abundance can lead to increased turnover rates
301 of organic matter. Furthermore, soil crustaceans affect the dynamics of organic matter
302 by incorporating organic material from the forest floor into deeper soil horizons
303 (Mattson 2012) and may also enhance microbial biomass (Escher et al. 2000). Reich et
304 al. (2005) showed that plantations of tree species with high calcium concentrations in

305 their litter cause an increase in exchangeable soil calcium and earthworm densities.
306 Therefore, especially in calcium-poor environments, transformation of forest vegetation
307 might change the densities of key decomposers such as crustaceans and earthworms,
308 thereby affecting the decomposition rates of soil organic matter and nutrient dynamics.
309
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464 Table 1 Soil properties (mean ± SE) at each plot. Significant differences between cedar
465 plantations (cedar) and evergreen broad-leaved forests (evergreen) are denoted in the
466 last column: $^{**}P < 0.01$, n.s. $P > 0.05$ (likelihood ratio tests).

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Plot name	cedar1	cedar2	cedar3	evergreen1	evergreen2	evergreen3	Significant differences between 'cedar' and 'evergreen' plots
Mass of litter layer (g)	10.42 ± 0.527	11.04 ± 0.561	10.28 ± 1.560	11.70 ± 1.240	7.47 ± 0.569	7.80 ± 0.845	n.s.
Water content (g/g)	0.62 ± 0.025	0.63 ± 0.064	0.57 ± 0.057	0.53 ± 0.045	0.64 ± 0.023	0.60 ± 0.036	n.s.
pH	4.34 ± 0.166	4.81 ± 0.143	5.20 ± 0.217	4.26 ± 0.182	4.55 ± 0.226	3.58 ± 0.085	n.s. (P = 0.08)
Exchangeable calcium (mg/g)	1.81 ± 0.256	1.83 ± 0.349	2.21 ± 0.971	0.63 ± 0.183	1.06 ± 0.413	0.43 ± 0.112	**
Total carbon (mg/g)	154.03 ± 23.188	117.63 ± 33.999	174.65 ± 58.206	139.58 ± 28.232	257.24 ± 47.917	201.00 ± 30.483	n.s.
Total nitrogen (mg/g)	10.33 ± 1.823	6.76 ± 1.770	9.90 ± 3.079	9.90 ± 1.908	19.0 ± 3.641	14.15 ± 1.880	n.s.
Nitrate (mg/g)	0.39 ± 0.021	0.52 ± 0.059	0.58 ± 0.047	0.73 ± 0.099	1.01 ± 0.113	0.82 ± 0.081	**
C:N ratio	15.89 ± 1.990	17.00 ± 0.781	17.36 ± 1.140	14.27 ± 0.775	13.52 ± 0.638	14.13 ± 0.473	**

485 Table 2 Abundance (5 traps^{-1} 12 days^{-1}; mean ± SE) of ground-dwelling

486 macroinvertebrates sampled by pitfall traps. ‘cedar’ and ‘evergreen’ mean cedar

487 plantation and evergreen broad-leaved forest.

	cedar	evergreen
Gastropoda	0.67 ± 0.67	0.00 ± 0.00
Oligochaeta		
Haplotaxida	0.33 ± 0.33	0.00 ± 0.00
Diplopoda		
Polydesmida		
Paradoxosomatidae	0.00 ± 0.00	3.33 ± 1.76
Xystodesmidae		
Xystodesmus sp.	0.33 ± 0.33	0.00 ± 0.00
Julida		
Julidae		
Anaulaciulus sp.	0.00 ± 0.00	0.33 ± 0.33
Arachnida		
Araneae	4.00 ± 0.58	4.00 ± 1.00
Crustacea		
Amphipoda		
Talitridae	4.33 ± 0.88	0.00 ± 0.00
Isopoda		
Ligiidae		
Ligidium japonicum	4.67 ± 0.88	0.00 ± 0.00
Armadillidae		
Venezillo sp.	0.67 ± 0.33	0.33 ± 0.33
Insecta		
Archaeognatha		
Machilidae	0.33 ± 0.33	0.33 ± 0.33
Orthoptera		
Rhaphidophoridae	0.00 ± 0.00	0.67 ± 0.33
Lepidoptera (larva)	2.33 ± 0.88	2.00 ± 0.00
Hymenoptera		
Formicidae		
Pachycondyla chinensis	0.67 ± 0.67	0.00 ± 0.00
Aphaenogaster famelica	0.33 ± 0.33	1.00 ± 1.00
Paratrechina flavipes	0.33 ± 0.33	0.67 ± 0.67
Formica hayashi	1.00 ± 0.58	0.33 ± 0.33
Camponotus obscuripes	0.00 ± 0.00	0.67 ± 0.67
Coleoptera (larva)	0.00 ± 0.00	0.67 ± 0.67
Coleoptera (adult)		
Geotrupidae		
Phelotrupes laevistriatus	0.33 ± 0.33	0.33 ± 0.33
Phelotrupes auratus	0.33 ± 0.33	0.00 ± 0.00
Scarabaeidae		
Panelus parvulus	0.00 ± 0.00	0.33 ± 0.33
Onthophagus nitidus	0.33 ± 0.33	0.67 ± 0.67
Staphylinidae		
Bolitobius sp.	0.33 ± 0.33	0.33 ± 0.33
Staphylininae	0.00 ± 0.00	0.33 ± 0.33
Carabidae		
Carabus iwawakianus	0.00 ± 0.00	0.67 ± 0.67
Chlaenius costiger	0.67 ± 0.67	0.00 ± 0.00
Stomis prognathus	0.00 ± 0.00	0.33 ± 0.33
Pterostichus (*Rhagadus*) sp.	0.33 ± 0.33	1.33 ± 0.88
Rupa japonica	1.00 ± 0.58	0.33 ± 0.33
Synuchus picicolor	0.00 ± 0.00	0.33 ± 0.33

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489 Fig. 1 Concentration (mean ± SE) of exchangeable calcium in soil in each plot. White
490 and black bars indicate evergreen broad-leaved forests (evergreen) and cedar plantations
491 (cedar), respectively. Significant differences between vegetation types are denoted by
492 different letters (likelihood ratio tests, $P < 0.05$).
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494 Fig. 2 Abundance (mean ± SE) of Talitridae (a) and *Ligidium japonicum* (b) in each plot
495 by the hand-sorting method. White and black bars indicate evergreen broad-leaved
496 forests (evergreen) and cedar plantations (cedar), respectively.
497
498 Fig. 3 Canonical correspondence analysis (CCA) ordination of soil invertebrate
499 community composition in 12 subplots by the pitfall trap method. Explanatory variables
500 selected by forward selection are shown as arrows: Ca, exchangeable calcium
501 concentration and Litter, mass of the litter layer. White and black symbols indicate
502 subplot scores (mean ± SE) of evergreen broad-leaved forests (evergreen) and cedar
503 plantations (cedar), respectively. Invertebrate taxa are abbreviated by alphabets: G,
504 Gastropoda; H, Haplotaxida; P, Paradoxosomatidae; Xs, *Xystodesmus* sp.; As,
505 *Anaulaciulus* sp.; A, Araneae; T, Talitridae; Lj, *Ligidium japonicum*; Vs *Venezillo* sp.;
506 L, Lepidoptera (larva); Pc, *Pachycondyla chinensis*; Af, *Aphaenogaster famelica*; Pf,
507 *Paratrechina flavipes*; Fh, *Formica hayashi*; Co, *Camponotus obscuripes*; C,
508 Coleoptera (larva); Pp, *Panelus parvulus*; On, *Onthophagus nitidus*; Pl, *Phelotrupes*
509 *laevistriatus*; Pa, *Phelotrupes auratus*; Bs, *Bolitobius* sp.; St, Staphylininae; Ci,
510 *Carabus iwawakianus*; Cc, *Chlaenius costiger*; Sp, *Stomis prognathous*; Ps,

511 *Pterostichus* (*Rhagadus*) sp.; Rj, *Rupa japonica*; Syp, *Synuchus picicolor*; M,

512 Machilidae; R, Rhaphidophoridae. Taxa indicated by boldface are crustaceans.

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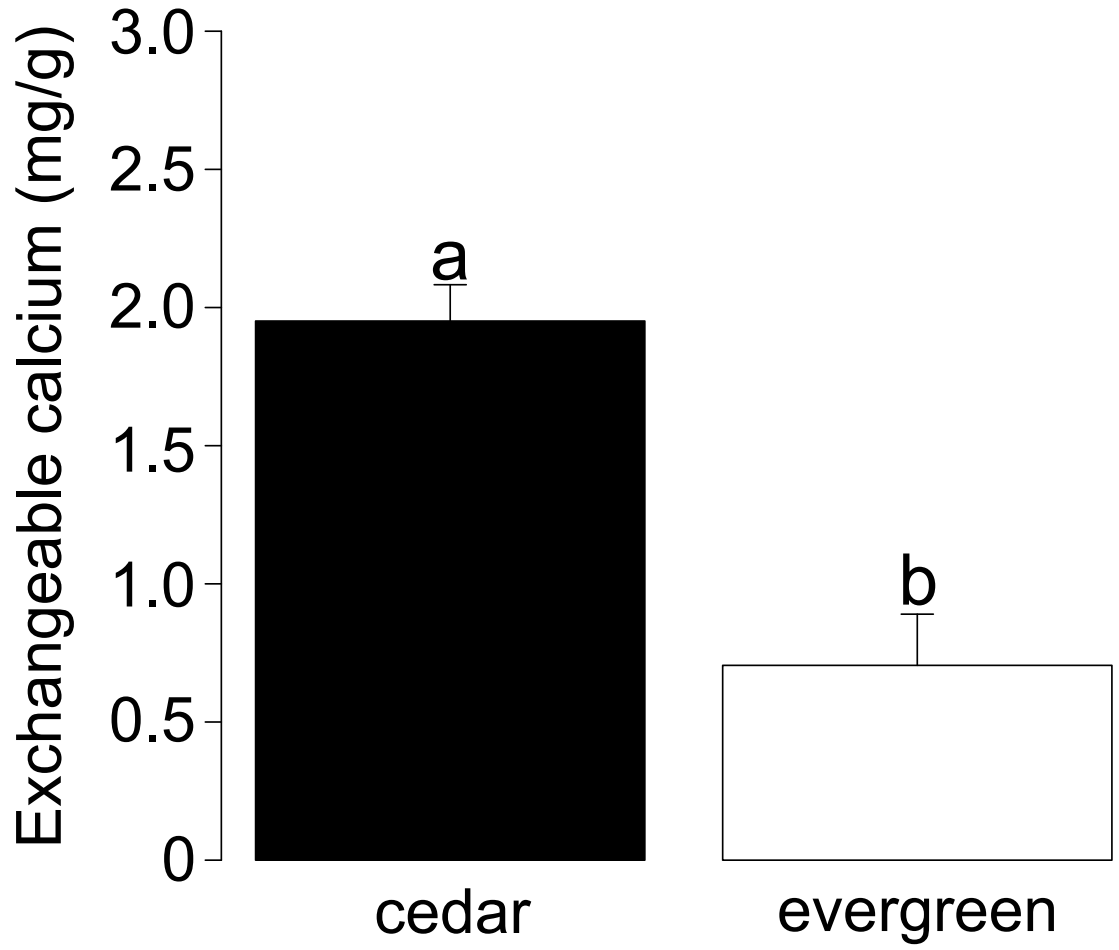
533 Ohta et al. Fig. 1



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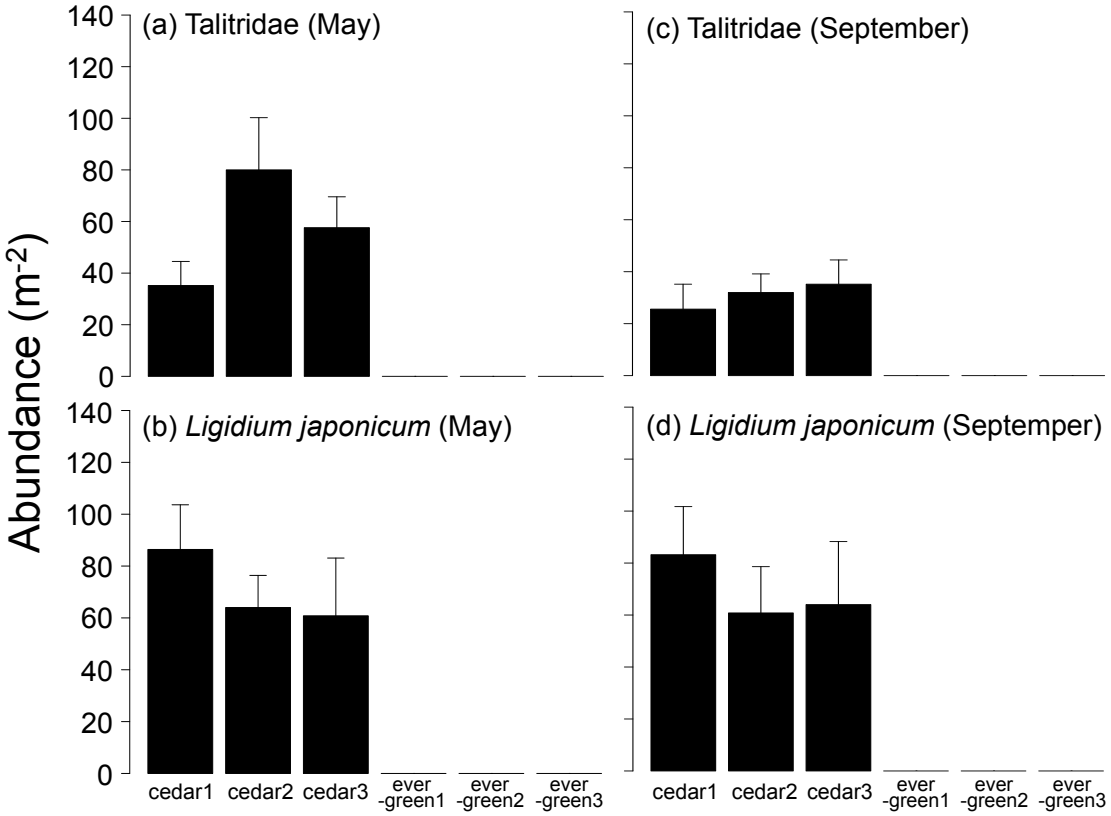
543 Ohta et al. Fig. 2



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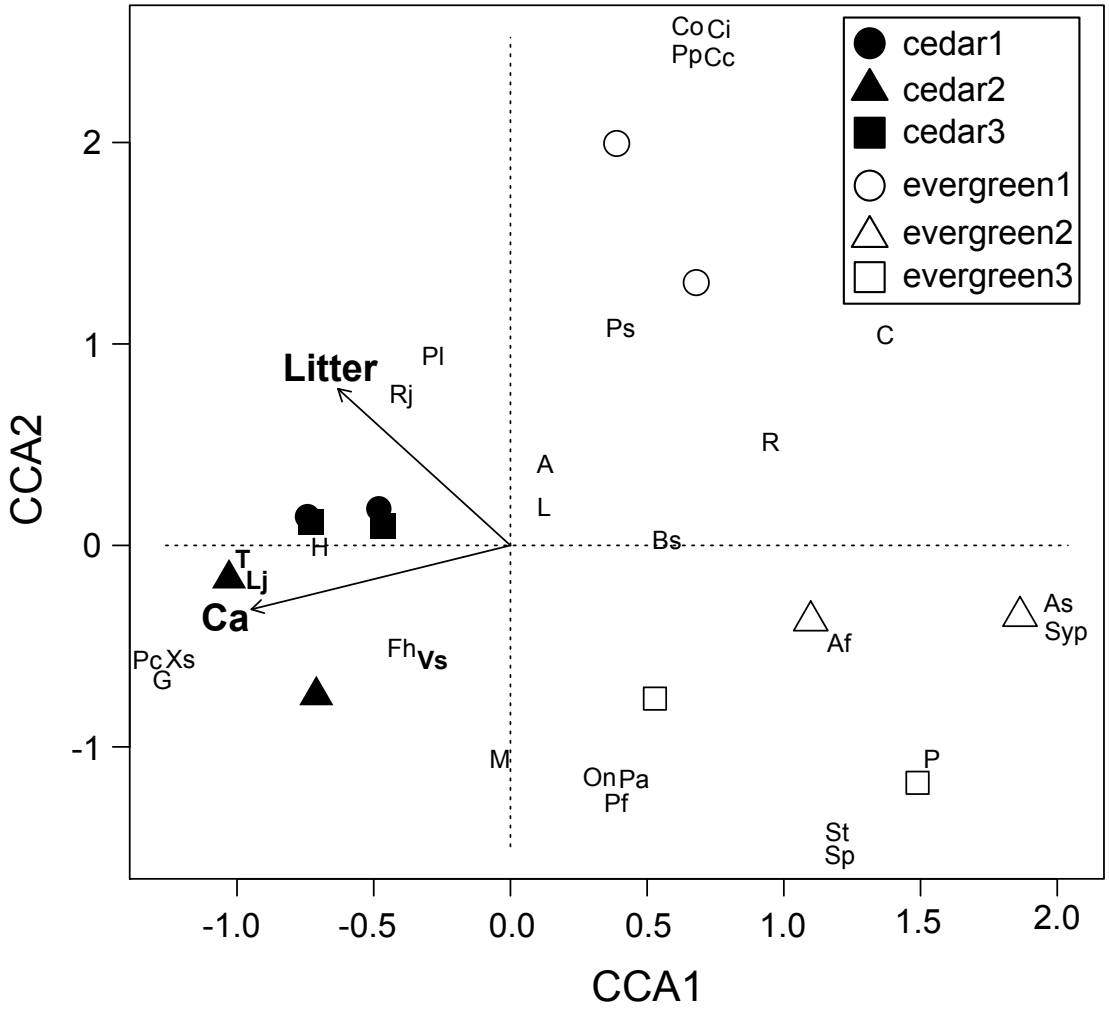
555 Ohta et al. Fig. 3



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