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9 **The arthropod community of boreal Norway spruce forests responds variably to**
10 **stump harvesting**

11
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41 **Abstract**

42

43 Forest fuel harvesting increases the need to collect not just logging residues but also tree
44 stumps from harvested stands. This biomass removal has raised concern over forest
45 biodiversity. Here, the effects of stump harvesting on spiders, ants, harvestmen, ground
46 beetles and epiedaphic springtails occupying boreal Norway spruce (*Picea abies*) forest
47 floor were studied two and five years after harvesting by comparing pitfall trap samples
48 from clear-cut sites with and without subsequent stump harvesting and from unharvested
49 mature forests in central Finland. At harvested sites, traps were placed both on intact and
50 exposed mineral soil surface. Open-habitat and generalist ground beetles benefitted from
51 the stump harvesting, but generally the numbers of arthropods between stump harvesting
52 treatments and different aged clear-cuts were rather similar. The intact forest floor hosted
53 more ants, springtails and harvestmen than did the exposed mineral soil. Moreover, the
54 community structure of spiders, ground beetles and springtails was affected by stump
55 harvesting, forest-floor quality (intact or exposed), and time elapsed since harvesting.
56 Based on these results we recommend minimizing the exposure of mineral soil during
57 management practices. However, more long-term studies are required to document the
58 development of fauna in the harvested areas and the ecosystem-level impacts of
59 utilization of forest biomass for energy.

60

61 Key words: Araneae; Bioenergy; Carabidae; Collembola; Formicidae; Opiliones

62

63

64 **1. Introduction**

65

66 Since the beginning of 2000s, the harvesting of logging residues, stems and stumps has
67 considerably intensified the Fennoscandian forestry (Koistinen and Äijälä, 2005;
68 Rudolphi and Gustafsson, 2005). In particular, stump harvesting has increased (Saarinen,
69 2006; Ylitalo, 2013). Until recently, stumps were removed from forests only if infected
70 by the root rot (*Heterobasidion* or *Armillaria* spp.) (Halonen, 2004; Thies and Westlind,
71 2005; Zabowski et al., 2008). Stump harvesting may have many impacts on biota similar
72 to top-soil preparation and removal of logging residues after harvesting. It improves site
73 for tree saplings, but simultaneously the procedure removes much organic matter and
74 carbon from forests, increases soil erosion and compaction, impoverishes soil nutrient
75 stocks and cycling, and removes key structures and resources from a myriad of forest
76 organisms (Walmsley and Godbold, 2010). Many impacts of stump harvesting are
77 considerably more severe than mounding or harrowing of harvested sites, as many
78 structural elements, such as dead wood, forest floor and soil physical characteristics, are
79 altered through stump removal (Siitonen, 2008; Rabinowisch-Jokinen and Vanha-
80 Majamaa, 2010; Kataja-aho et al., 2011a).

81 The intermediate disturbance hypothesis postulates that species richness will be
82 highest in areas with intermediate levels of disturbance (Connell, 1978). Such general
83 pattern might result from different responses of species associated with undisturbed and
84 highly disturbed habitats. Indeed, open-habitat associated ground beetles
85 (carabids; Coleoptera, Carabidae) benefit from clear cutting, whereas closed-forest
86 associated species decrease, but do not necessarily disappear (e.g., Koivula, 2002;
87 Koivula, 2012). However, compared to clear cutting followed by modest top-soil
88 preparation, stump harvesting is a considerably more intensive disturbance at least for
89 organisms living in the forest floor. During stump harvesting with excavators, ca. 70% or
90 occasionally up to 90% of the soil surface is exposed to mineral soil due to stump lifting
91 and machinery movements, whereas less than 40% is exposed at the clear-cut sites with
92 traditional site preparation (mounding) (Kataja-aho et al., 2011a, 2011b). Thus, stump
93 harvesting may not represent an “intermediate disturbance” but rather “an intensive

94 disturbance” for many invertebrate taxa living in forest floor and concomitantly
95 drastically alter forest biodiversity.

96 Local invertebrate species richness may increase after clear cutting as forest
97 generalists persist and many open-habitat species colonize the sites (Niemelä, 1997).
98 Forest habitats change remarkably during clear cutting, which may be reflected e.g. in
99 species richness of hunting and web-building spiders (Araneae) that are dependent on
100 particular structural elements of forest (Larrivéé et al., 2005) and carabid beetles that
101 respond to logging and within-site variation according to their associations with tree-
102 canopy closure and soil moisture (Niemelä et al., 1988; Niemelä and Halme, 1992). In
103 addition, mounds of *Formica* wood ants are generally smaller and host fewer individuals
104 in clear-cuts than in standing forests (Sorvari and Hakkarainen, 2005). This may have
105 consequences on forest ecosystem functioning since ants, particularly red wood ants
106 (*Formica rufa* group), are considered keystone species of European and Asian boreal and
107 mountain forests because of their contribution to ecosystem carbon and nutrient pools and
108 fluxes (e.g., Rosengren et al., 1979; Laine and Niemelä, 1980; Risch et al., 2005; Finér et
109 al., 2013).

110 Nittérus et al. (2007) found that the removal of logging residues from clear-cuts
111 results in an increase of generalist carabid beetles and a decline in carabids associated
112 with closed tree canopy 5–7 years after the operations compared to sites where slash is
113 left on the ground. Hence, large-scale biofuel harvesting might cause a shift in species
114 dominance and changes in community composition of forest-floor arthropods. On the
115 other hand, many euedaphic decomposers are well buffered against the initial impacts
116 caused by clear cutting and site preparation and, although microbial biomass may
117 decrease in regenerated areas, changes may not necessarily occur at higher trophic levels
118 of food webs (Siira-Pietikäinen et al., 2001; Siira-Pietikäinen et al., 2002).

119 Spiders, ants and carabid beetles are important predators in boreal forest floor
120 (Roberts, 1985; Hölldobler and Wilson, 1990). They feed on detritivores, herbivores and
121 other carnivores, thus being top predators of forest-floor food webs (Roberts, 1996;
122 Townsend et al., 2004; Miyashita and Niwa, 2006). Spiders and ants also act as a link
123 between the below- and above-ground biota as they feed on fauna from both sources
124 (Hölldobler and Wilson, 1990; Miyashita et al., 2003). The present study focuses on

125 spiders, harvestmen, ants and carabid beetles because as top predators they are
126 particularly prone to disturbances. Spiders and carabids also rapidly respond to changes
127 in their habitat (Pearce and Venier, 2006; Koivula, 2011, 2012) and are easy to sample in
128 sufficient numbers for statistical analyses (Nilsson et al., 2001). In addition, epiedaphic
129 springtails (large collembolans) are an abundant prey in forest floor food webs (Siira-
130 Pietikäinen et al., 2002).

131 The aim of the present study was to examine the difference in numbers, species
132 richness and community structure of ground-dwelling arthropods (spiders, harvestmen,
133 ants, collembolans and carabid beetles) in clear-cuts with stump harvesting, clear-cuts
134 with stump retention, and mature unharvested forests. Data in the present study consist of
135 pitfall trap catches that reflect species-specific “activity densities” rather than true relative
136 abundances (e.g. Greenslade, 1964). These catches are hereinafter referred to as
137 “abundance” (unless specified otherwise) for convenience. The following questions are
138 examined using data collected at replicated sites harvested in different times:

- 139 i) Are there differences in abundance and community structure of ground-
140 dwelling arthropods between stump harvesting and stump retention sites?
- 141 ii) Does the quality of forest-floor habitat in clear-cuts (here, exposed mineral
142 soil or intact forest floor) affect these taxa?
- 143 iii) Are there differences in abundance or community structure of ground-
144 dwelling arthropods in clear-cuts at different successional stages?

145

146 **2. Materials and methods**

147

148 *2.1 Study sites and experimental design*

149 The study was carried out in central Finland (61°48'N, 24°47'E) in boreal Norway spruce
150 (*Picea abies* (L.) Karst.) dominated forest stands (sites) growing on Myrtillus (MT) or
151 Oxalis-Myrtillus (OMT) site types (Cajander, 1926). The field layer of MT forest is
152 characteristically dominated by *Vaccinium myrtillus*, *V. vitis-idaea* and *Linnaea borealis*,
153 whereas that of OMT forest is dominated by *V. myrtillus*, *L. borealis*, *Oxalis acetosella*,
154 *Maianthemum bifolium* and *Convallaria majalis* (Hotanen et al., 2008). The soil in the
155 study area was podzolised moraine with a 3-4 cm thick organic layer; mean annual
156 temperature was 4.9°C and annual precipitation was 646 mm in 2007. The ground was

157 completely snow covered for approximately three months during the winter 2007
158 (Finnish Meteorological Institute, 2008).

159 Twenty-five study sites were selected for our study. The same sites had previously
160 been used to study decomposer communities (Kataja-aho et al., 2011a). At the time of the
161 present study, ten of these sites had been clear-cut five years before (“5 years old sites”),
162 and ten sites had been clear-cut two years before (“2 years old sites”) the present study.
163 Following clear cutting, ca. 70% of the logging residues had been removed from all sites,
164 and stumps had been removed from half of them (five in both harvesting years) using an
165 excavator equipped with a stump-removal bucket. Soil had been prepared by mounding at
166 all sites with an excavator by inverting a scoop of soil on top of the ground nearby. The
167 study design involved five replicates of each combination of stump treatment (harvested
168 or retained) and age (harvesting done 2 or 5 years earlier). All harvested sites had
169 subsequently been planted with nursery-produced 1.5 years old Norway spruce seedlings.
170 All the management and regeneration practices had been done according to the prevailing
171 guidelines for Finnish forestry (Metsätalouden kehittämiskeskus Tapio, 2006). The area
172 of clear-cut sites varied between 0.5 and 4.5 hectares. In addition to the clear-cut sites,
173 five unharvested mature Norway spruce sites (hereinafter referred to as “mature forests”)
174 were selected to derive reference data for the effects of clear cutting.

175 At each site, a ca. 30 m × 30 m (900 m²) study plot for vegetation and arthropod
176 samplings (see below) was chosen by avoiding moist and rocky patches. The distance
177 from the plot to the nearest stand edge was at least 30 meters to avoid severe edge impact.
178 The proportions of intact soil and the soil exposed to mineral surface were estimated for
179 each plot (Kataja-aho et al., 2011a). Soil surface consisting of mixed mineral and organic
180 soil layers was classified as disturbed mineral soil surface.

181

182 *2.2 Sampling and sample treatments*

183 Arthropods were collected using pitfall traps made of 2-dl plastic cups set flush with soil
184 surface, and covered with 10 cm × 10 cm plastic sheets placed a few cm above the soil
185 surface to prevent rain and litter from entering the traps. The traps were half-filled with
186 50% ethylene glycol to kill and preserve arthropods falling into the traps. Eight traps
187 were set at each site; at harvested sites, four traps were placed on surface that had

188 originally been exposed to mineral soil and four on intact soil surface. The traps were
189 placed in two parallel rows ca. 5 m apart (i.e. 2×4 traps; Fig. 1). The type of surface for
190 each trap was randomized in a pair-wise manner. At each mature-forest site, all eight
191 traps were placed into intact soil. Altogether 200 pitfall traps per sampling period were
192 used in the study.

193

194 Fig. 1.

195

196 Data were collected over three 10-days periods in 2007. The first sampling period
197 was from 28th of May to 7th of June (“spring”), the second was from 9th to 19th of July
198 (“summer”) and the third was from 10th until 20th of September (“autumn”).

199 Spiders, harvestmen, carabid beetles, ants and collembolans were counted, and
200 groups other than harvestmen were identified to species. Due to labor restrictions, spiders,
201 harvestmen and ants were identified only from six traps per study plot; three from
202 mineral soil surface and three from untreated soil surface. Similarly, six out of eight
203 pitfall traps were taken into account when collecting and analyzing these three groups
204 from the mature forests. All eight traps per site were investigated for carabid beetles and
205 collembolans.

206 Vegetation surveys were done at each study plot on 10th of July 2007 by
207 identifying plants to species and estimating their percent covers from ten $0.5 \text{ m} \times 0.5 \text{ m}$
208 subplots; five of these were on mineral soil surface and five were on intact soil surface
209 (Kataja-aho et al., 2011a). Here, only the covers of ground- and field-layer vegetation
210 were used as explanatory variables for the abundance and species richness of studied
211 animal groups.

212

213 *2.3 Statistical analyses*

214 For the statistical analyses the data from all three sampling periods were pooled. The
215 numbers and species richness of arthropods were analyzed using a split-plot ANOVA to
216 evaluate the effects of stump harvesting, time elapsed since harvesting operations (age of
217 the site), and the quality of soil surface (intact soil or exposed mineral soil). The split-plot
218 ANOVA was used because the samples for each surface-quality type within a given site

219 were not independent replicates for stump harvesting or site age. Hence, the surface acted
220 as a within-subjects factor and was plotted with the treatment and the age of the site (the
221 between-subjects factors) in the analyses. Variation in the arthropod community structure
222 was analyzed using non-metric multidimensional scaling (NMDS) with a Bray-Curtis
223 distance matrix and multi-response permutation procedures (MRPP) (Zimmermann, 1985)
224 in PC-ORD 5.33 software. The abundance and species richness of arthropods in the traps
225 of intact soil surface were compared between mature forests and clear-cuts using the age
226 of the site as the only explanatory variable (two or five years since clear cutting, or
227 mature uncut forest). These data were analyzed with a univariate ANOVA, and possible
228 significant effects were evaluated using Tukey's post hoc tests. Mechanistic causes for
229 possible differences between treatments were explored by calculating Spearman rank
230 correlations between vegetation cover and abundance or species-richness of arthropods.
231 The ANOVA and correlation analyses were done using IBM SPSS Statistics software,
232 version 22.

233

234 **Results**

235

236 *3.1 Effects of stump harvesting on macroarthropods*

237 Altogether more than 42,000 individuals and 170 arthropod species were captured,
238 counted and identified (Table 1). The numbers of captured spiders, ants, harvestmen and
239 collembolans between the stump harvesting and stump retention sites were rather similar
240 (Fig. 2, Table 2). The abundance and species richness of carabid beetles were higher at
241 the stump harvesting sites compared to the stump retention sites (Table 2, Figures 2 and
242 3). The stump retention sites harbored more spider species than the stump harvesting sites
243 (Table 2, Fig. 3).

244

245 Table 1

246 Fig. 2.

247 Fig. 3.

248

249 *3.2. Effects of soil surface quality on macroarthropods*

250 More harvestmen and ants were captured from the intact forest floor than from the
251 exposed mineral soil. In the five year old stands the intact forest floor harbored more
252 spiders than did the exposed mineral soil (Table 2, Fig. 2). At the two year old sites
253 collembolans were more abundant on the intact forest floor than on the exposed mineral
254 soil (Table 2, Fig.2). Ants were more speciose on the intact forest floor compared to the
255 exposed mineral soil (Table 2, Fig. 3). Generally, the covers of ground- and field-layer
256 vegetation only occasionally and inconsistently correlated with the abundance or species
257 richness of the studied invertebrates (Supplementary material, Table 1).

258

259 3.3. *Effects of stand age on macroarthropods*

260 Age of the clear-cut site had negligible effects on the abundances of the studied
261 animal groups. Mature forests did not significantly differ from the clear-cuts in terms of
262 the abundance of carabid beetles, ants or collembolans (Table 3, Fig. 2). Harvestmen
263 were more abundant in the mature forests compared to the clear-cuts (Table 3, Fig. 2).
264 Spiders were significantly and positively affected by clear-cutting. In addition, the older
265 clear-cuts harbored more spider species than did the younger clear-cuts (Tables 2 and 3,
266 Figures 2 and 3). The species richness of collembolans was higher at the two-years old
267 sites compared to the five-years old sites (Tables 2 and 3, Figures 2 and 3). The species
268 richness of carabids or ants did not differ significantly between the mature forests and the
269 clear-cuts (Table 3, Fig. 3).

270

271 Table 2

272 Table 3

273

274 3.4 *Community structure of macroarthropods*

275

276 3.4.1 *Spiders*

277 The community structure of spiders differed between the stump harvesting and
278 stump retention sites and between the two- and five-years old clear-cuts and between the
279 soil-surface categories (Table 4, Fig. 4). The lycosid genus *Pardosa* was the most
280 abundant genus of spiders (58% of all spiders), and *P. riparia* and *P. pullata* were the

281 most abundant species in this genus (Supplementary material, table 5). Approx. 97% of
282 the individuals in the genus *Pardosa* were caught from the clear-cuts and less than 3%
283 were sampled in the mature forests during the first sampling period. However, no
284 significant differences were found in the abundance of *P. riparia* or *P. pullata* between
285 the stump treatments or site ages. *Pardosa riparia* was more abundant on the intact forest
286 floor compared to the mineral soil surfaces ($F_{(1,16)} = 13.449$; $p = 0.002$, Supplementary
287 material, table 5). Whereas *P. pullata* was more abundant on the mineral soil surface
288 compared to intact forest floor ($F_{(1,16)} = 14.325$; $p = 0.002$, Supplementary material, table
289 5). Also the family Gnaphosidae was almost exclusively captured in the clear-cuts (98%
290 of the specimens); the most abundant species was *Gnaphosa bicolor*. One *Pardosa*
291 species, *P. lugubris*, was found also in mature forests (18% of the specimens) and the
292 abundant linyphiid *Tenuiphantes alacris* was caught mainly in mature forests (90% of the
293 specimens). As a whole, the family Linyphiidae was captured both in the mature forests
294 (35% of the specimens) and in clear-cuts (65%).

295

296 3.4.2 Ants

297 The community structure of ants was not analyzed with NMDS because the group
298 largely consisted of just one dominant species group, *Formica rufa*, which accounted for
299 more than 90% of the captured ant individuals (Supplementary material, table 2). The
300 abundance of *F. rufa* did not significantly differ between the stump treatments, site ages
301 or soil-surface quality categories.

302

303 3.4.3 Carabid beetles

304 The community structure of carabids differed between the stump treatments and
305 site-age categories (Table 4, Fig. 4). The five most abundant species were *Pterostichus*
306 *oblongopunctatus*, *P. versicolor*, *P. niger*, *Cicindela campestris* and *Bembidion lampros*.
307 *Pterostichus oblongopunctatus* and *P. niger* were found at all sites, but they were most
308 abundant in the mature forests (Supplementary material, table 4). *Pterostichus versicolor*,
309 *B. lampros* and *C. campestris* were not found in the mature forests, and the latter was
310 solely caught in the two-years old clear-cuts and mainly from the mineral soil surface
311 during the spring sampling period.

312

313 3.4.4 Collembolans

314 The community structure of collembolans did not differ significantly between the
315 stump-harvesting treatments but was different between the site-age and soil-surface
316 categories (Table 4, Fig. 4). Three most abundant collembolans over the whole study
317 period were *Orchesella flavescens*, *Lepidocyrtus lignorum* and *Pogonognathellus*
318 *flavescens* (Supplementary material, table 3). *Orchesella flavescens* was more common in
319 two-years old compared to the five-years old clear-cuts ($F_{(1,16)} = 22.29$; $p < 0.001$) and on
320 the intact forest floor than on the mineral soil surface ($F_{(1,16)} = 25.11$; $p < 0.001$,
321 Supplementary material, table 3). More *L. lignorum* and *P. flavescens* were caught in the
322 five-years old than in the two-years old clear-cuts ($F_{(1,16)} = 7.46$; $p = 0.015$; $F_{(1,16)} = 27.48$;
323 $p < 0.001$, respectively).

324

325 Fig. 4.

326 Table 4.

327

328 4. Discussion

329

330 Stump harvesting exposes mineral soil on larger areas and mixes the soil layers deeper
331 than commonly used site preparation (Kataja-aho et al., 2011a). Thus, stump harvesting
332 not only removes stumps but also changes the quality and structure of soil surface.
333 Furthermore, stump harvesting changes the decomposer community and enhances the
334 decomposition of organic matter and nitrogen mineralization (Kataja-aho et al., 2012),
335 and it also increases the diversity of plant community during the first few years following
336 the procedure (Saksa, 2013). The present results also showed that the community
337 structure of spiders, carabid beetles and collembolans was affected by stump harvesting,
338 forest floor quality and time elapsed since harvesting. However, stump harvesting
339 affected negatively only the numbers of spider species. The results also indicated that
340 some arthropod groups – most notably ants, collembolans and harvestmen – respond only
341 weakly to stump harvesting but are more abundant in intact forest floor. Hence, the

342 indirect effects of stump harvesting on macroarthropods, due to changes in the quality of
343 soil surface seem to be clear.

344 However, the most abundant spider species at our study sites were lycosids that
345 actively hunt for prey and are thus likely to benefit from the increased area of bare soil in
346 their habitat (Almquist, 2005). The same holds also for the family Gnaphosidae
347 (Koponen, 2013). The availability of suitable microhabitats in a forest-floor mosaic, and
348 abiotic factors such as solar radiation and soil moisture, are important for many species
349 for example among spiders and ants (Huhta, 1971; Koponen et al., 1975; Niemelä et al.,
350 1996).

351 The abundance and species richness of carabids were higher at the stump-
352 harvesting than at the stump-retention sites in the present study. Generalist and open-
353 habitat species, such as *P. oblongopunctatus*, *P. niger*, *C. campestris* and *B. lampros*,
354 benefited from stump harvesting compared to stump retention, although *P.*
355 *oblongopunctatus* and *P. niger* were most numerous in mature forests. Pihlaja et al. (2006)
356 found that forest carabids in clear-cuts prefer undisturbed patches over bare-soil patches,
357 whereas open-habitat species show the opposite association. Stump-harvesting sites
358 provide more and larger patches of micro-habitats suitable for open-habitat species
359 compared to sites that have only been logged and prepared (Kataja-aho et al., 2011a).
360 Furthermore, open-habitat species prefer relatively warm microhabitats (Thiele, 1977).
361 The daytime temperatures are higher in plots of exposed mineral soil than in plots where
362 the soil is extensively covered by field-layer vegetation and humus (Kubin and
363 Kemppainen, 1994).

364 We found that epiedaphic collembolans seemed to somewhat suffer from stump
365 harvesting due to changes in soil-surface microhabitat, which corroborates our earlier
366 observations (Kataja-aho et al., 2011b). Collembolans are common prey for spiders
367 (Marra and Edmonds, 1998) and were generally least numerous in spring when the
368 abundance of spiders was high (Table 1). On the other hand, they were abundant in the
369 autumn period when there were hardly any spiders present and their food resources, litter
370 and fungal hyphae, were plentiful (Coleman et al., 2004). Thus, the collembolan
371 community might have been affected by direct predator-prey interactions. However, other

372 – not mutually exclusive – explanations include possible internal dynamics between adult
373 and juvenile collembolans, and the phenology and overwintering success of species.

374 Clear cutting severely impacts some forest-floor arthropods, but these organisms
375 also appear to begin to recover within a few years after the disturbance event (e.g.,
376 Niemelä et al., 2007, Siira-Pietikäinen and Haimi, 2009). In the present study clear
377 cutting itself affected spiders and harvestmen; spiders benefited from clear-cutting
378 whereas there were clearly more harvestmen in the mature forests than in the clear-cuts.
379 On intact forest floor, the abundance and species richness of spiders were lower in two-
380 years old as compared to five-years old clear-cuts. Abiotic factors, such as light intensity
381 and soil moisture that are affected by the developing vegetation, have large effects on
382 spiders (Huhta, 1971; Koponen, 2005). However, we found no significant and consistent
383 correlation between plant cover and the abundance or species richness of spiders. This
384 finding does not mean that qualitative changes in plant community could not have
385 affected the spider communities through physical and/or chemical factors.

386 Forests are the main habitat for ca. 38% of threatened species in Finland (Rassi et
387 al., 2010). Changes in the age structure of forests and shortage of dead wood in managed
388 forests are among the most important reasons for 29 spider and 308 coleopteran species
389 for being red-listed (Rassi et al., 2010). In our study, none of the 170 identified species
390 were endangered, but it should be noted that 11 species were only found in mature forests,
391 of which nine were spiders and two were carabids. Correspondingly, 74 spider species
392 and 28 carabid species were only caught from clear-cuts. Species associated with closed-
393 canopy forests, and with primeval forests in particular, respond negatively to clear cutting,
394 while many other species survive in sufficiently large retention-tree groups within clear-
395 cuts (Pajunen et al. 1995; Niemelä, 1997; Matveinen-Huju et al., 2006; Oxbrough et al.,
396 2006). However, invertebrate species that are dependent on stumps for breeding, shelter
397 or foraging are lost from clear-cuts if stumps are removed and no compensatory dead
398 wood is available (Jonsell and Hansson, 2011; Andersson, 2012; Persson et al., 2013). It
399 should be noted that pitfall traps do not sample all arthropod species and species living in
400 the stumps are mainly missed. Moreover, fauna in dead wood was not studied here but
401 they should be taken into account when exploring the overall effects of stump harvesting
402 on forest biodiversity.

403

404 **5. Conclusions**

405

406 We showed that, in the short term, (1) clear cutting impacts spiders and harvestmen, but
407 (2) stump removal has minor additional effects on these taxa, and (3) open-habitat and
408 generalist carabids even benefit from stump harvesting. Moreover, (4) changes in
409 microhabitats due to forestry operations affected ants, collembolans and harvestmen, as
410 more individuals or species were found in intact soil surface as compared to the exposed
411 mineral soil. Stump harvesting decreases the amount of intact forest floor, and arthropods
412 show variable responses to such changes in their habitat. Hence, from an arthropod
413 perspective, it may be premature to conclude that stump harvesting would be an intensive
414 disturbance. However, we cautiously recommend to retain as much intact forest floor as
415 possible at harvested sites and to avoid destroying large pieces of dead wood, including
416 old stumps, to secure habitat for organisms that rely on these resources in commercial
417 forests (Persson et al., 2013). When refining the guidelines and methods of stump
418 harvesting, all relevant impacts of the procedure should be a priori carefully considered:
419 the practice affects the fertility of soil (Walmsley and Godbold, 2010; Tamminen et al.,
420 2014), lichens (Hämäläinen et al., 2015), arthropod communities (this paper and e.g.,
421 Jonsell and Hansson, 2011) and soil decomposers (Kataja-aho et al., 2011a). Large-scale
422 stump harvesting is a relatively new procedure, and the time scale in the present study
423 was probably too short to demonstrate long-term impacts of stump harvesting. Thus,
424 longer-term studies are needed to fully understand ecosystem-level impacts of forest-
425 based bioenergy production, including possible extinction debt.

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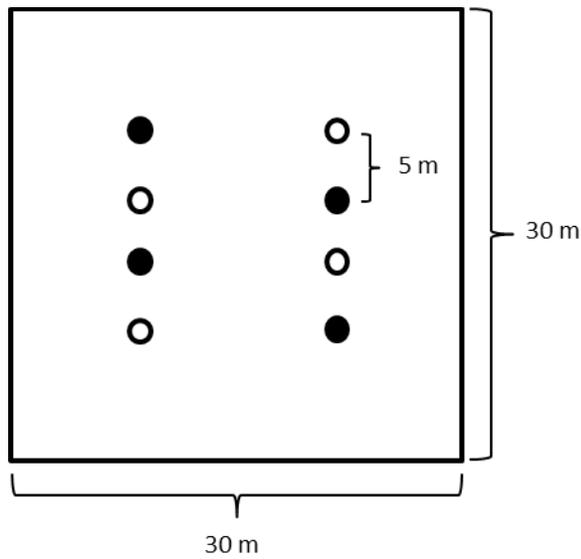
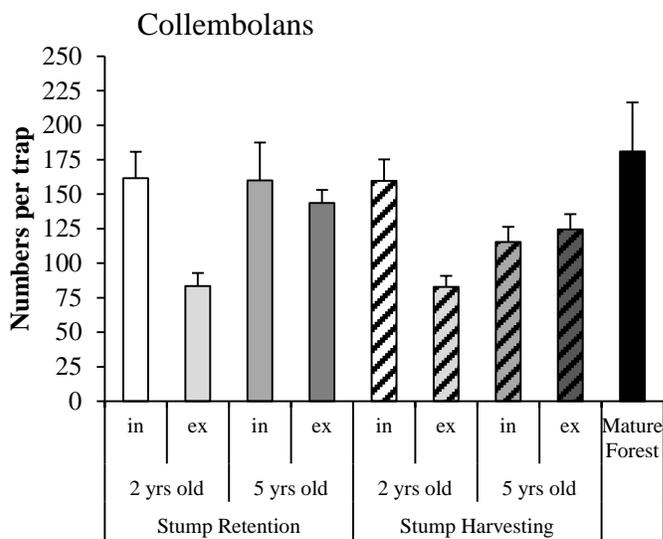
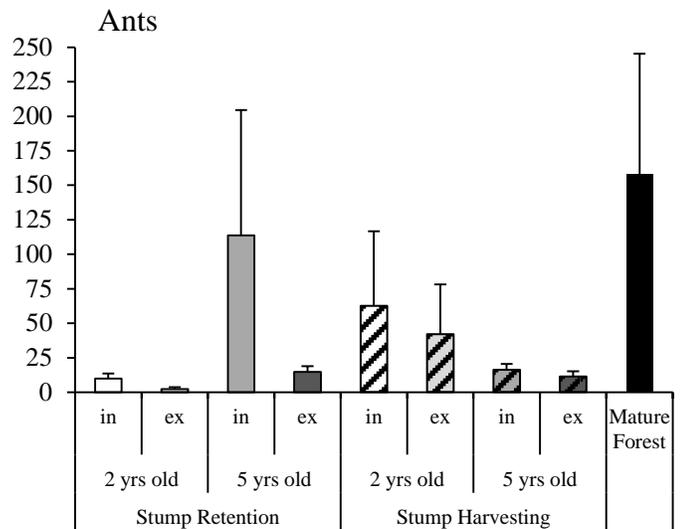
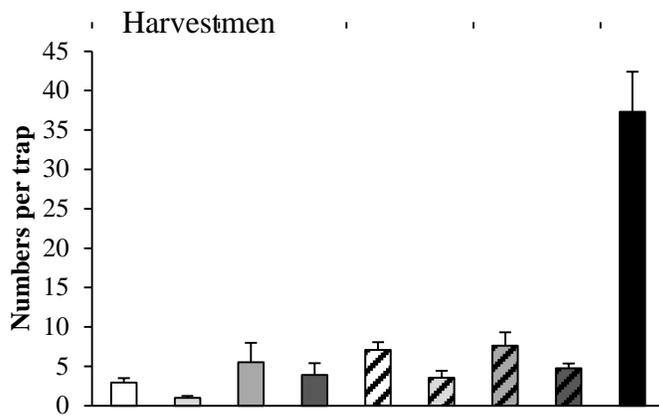
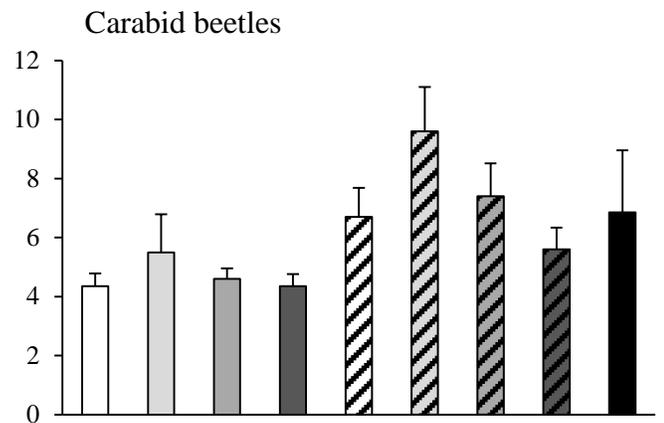
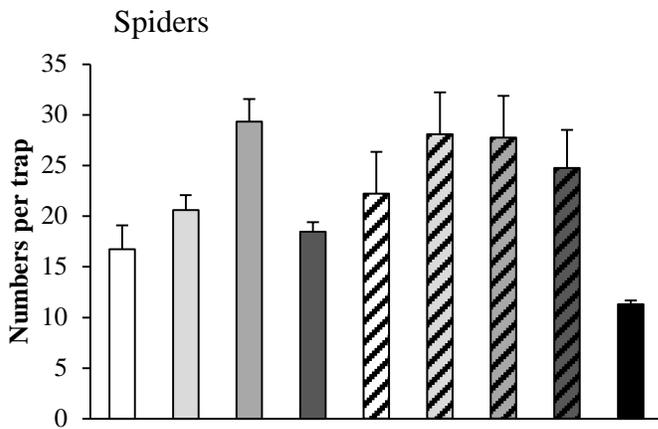
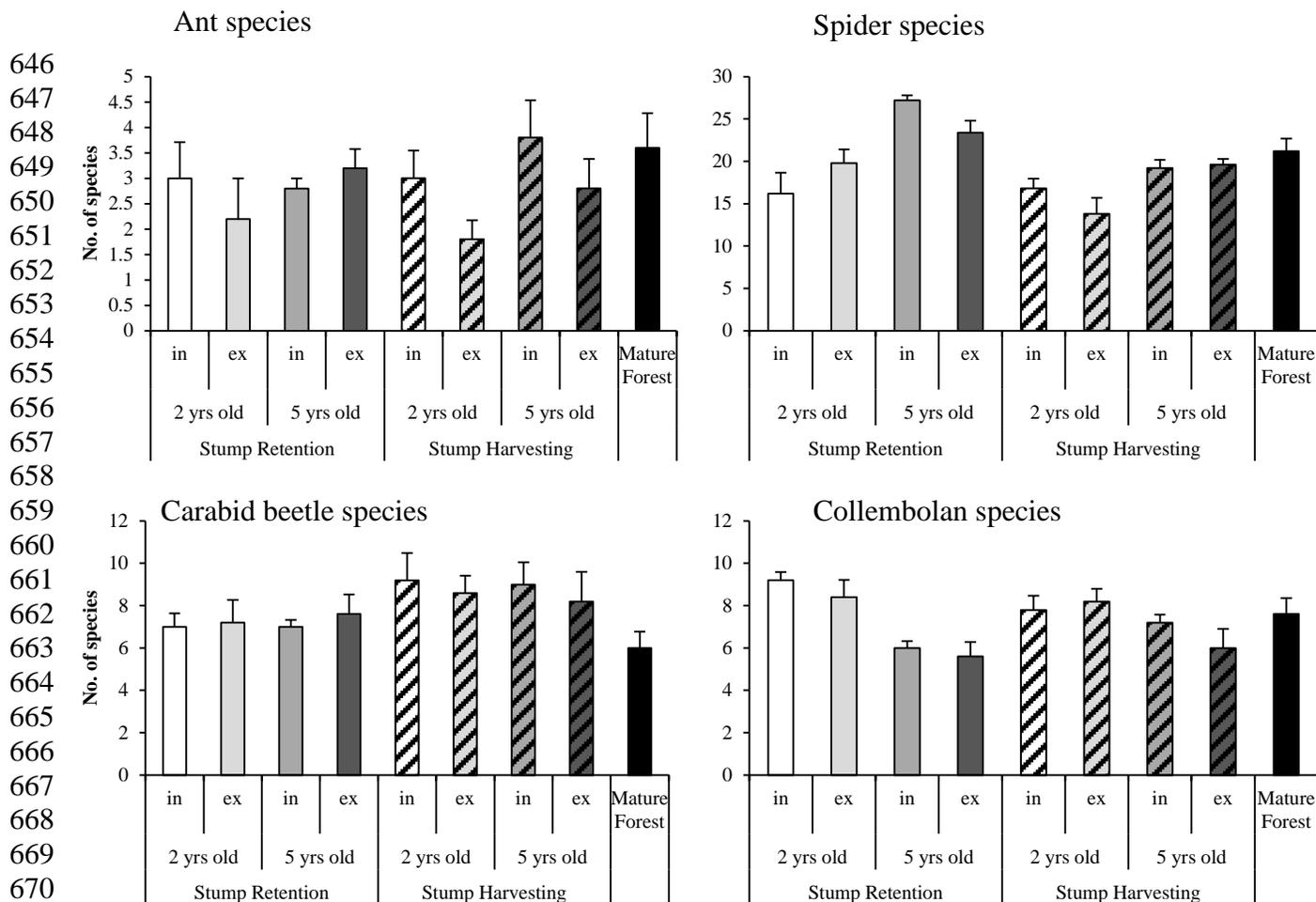


Figure 1. A diagram (out of scale) of the experimental setup of each clear-cut study site, showing the distance between pitfall traps and how the pitfall traps were placed in two parallel rows. Black circles represent traps on exposed mineral soil and white circles traps on intact forest floor. In the mature forest the setup was the same but all the eight traps were placed on intact forest floor.

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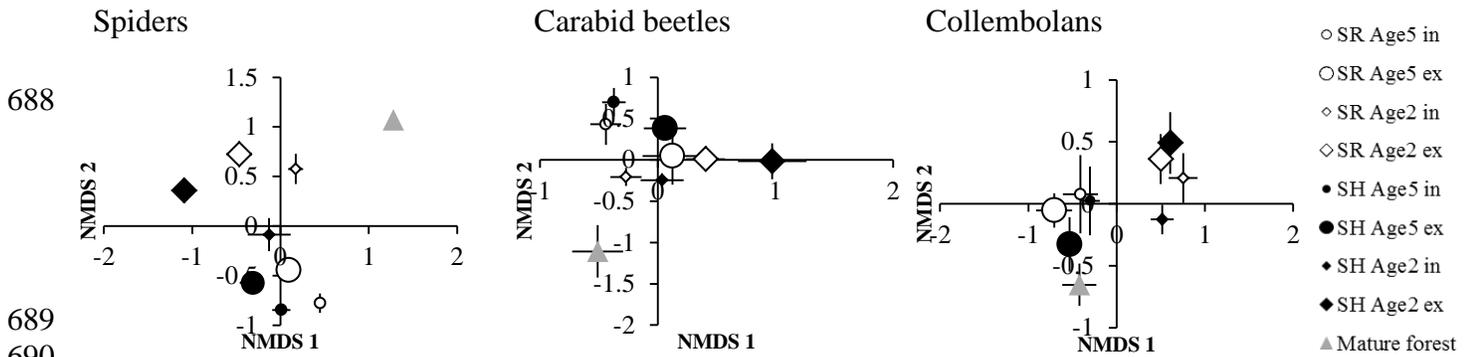
641 Figure 2. Mean numbers (\pm S.E.) of spiders, carabid beetles, harvestmen, ants and
642 collembolans per trap for different site types. Cross-hatched bars refer to stump
643 harvesting; clear bars (except black) to stump retention; black bars to mature forest; in =
644 intact forest floor; ex = exposed mineral soil.
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672 Figure 3. Mean species richness i.e. number of species (\pm S.E.) of ants, spiders, carabid
 673 beetles and collembolans for different site types. Cross-hatched bars refer to stump
 674 harvesting; clear bars (except black) to stump retention; black bars to mature forest; in =
 675 intact forest floor; ex = exposed mineral soil.

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696 Figure 4. Non-metric multidimensional scaling for the assemblage structure of spiders,
697 carabid beetles and collembolans among the study sites (n = 5 for each site category). In
698 the legend: SH = stump harvesting, SR = stump retention, ex = exposed mineral soil, in =
699 intact soil surface.

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701 Table 1. Total numbers of captured invertebrates and species during each sampling period
702 in the present study.
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Species group	Spring	Summer	Autumn	Total	No. of species
Spiders	2731	340	84	3155	113
Ants	3829	4056	438	8323	12
Harvestmen	163	284	1218	1665	Not identified
Carabid beetles	781	357	98	1236	36
Collembolans	4684	10224	12895	27803	9
Total	12188	15261	14733	42182	170

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Table 2. Test statistics from the split-plot ANOVA for the effects of soil-surface quality, stump harvesting and site age on the abundance and species number of the arthropod groups. Surface: in = intact forest floor, ex = exposed mineral soil. Harvesting: SH = stump harvesting, SR = stump retention. Age: 2 = two years old clear cut, 5 = five years old clear cut.

Group	Treatment	df	Abundance			Number of species (SPP)		
			F	p	Difference	F	p	Difference
Carabids	Surface	1,16	0.665	0.427		0.042	0.840	
	Surface * Age	1,16	6.185	0.024		0.005	0.946	
	Surface * Harvesting	1,16	0.007	0.936		0.569	0.461	
	Surface * Age * Harvesting	1,16	1.810	0.197		0.042	0.840	
	Age	1,16	1.481	0.241		0.006	0.941	
	Harvesting	1,16	9.258	0.008	SH > SR	5.354	0.034	SH > SR
	Age * Harvesting	1,16	0.484	0.497		0.139	0.714	
Spiders	Surface	1,16	0.623	0.441		0.875	0.363	
	Surface * Age	1,16	20.31	<0.001		1.786	0.200	
	Surface * Harvesting	1,16	3.550	0.078		0.643	0.434	
	Surface * Age * Harvesting	1,16	1.255	0.279		13.02	0.002	
	Age	1,16	0.935	0.348		20.18	<0.001	5 > 2
	Harvesting	1,16	1.806	0.198		11.48	0.004	SR > SH
	Age * Harvesting	1,16	0.398	0.537		1.590	0.225	
Ants	Surface	1,16	12.39	0.003	in > ex	8.048	0.012	in > ex
	Surface * Age	1,16	0.323	0.578		2.333	0.146	
	Surface * Harvesting	1,16	2.376	0.143		3.857	0.067	
	Surface * Age * Harvesting	1,16	1.461	0.244		1.190	0.291	
	Age	1,16	2.853	0.111		1.523	0.235	
	Harvesting	1,16	0.027	0.872		0.009	0.926	
	Age * Harvesting	1,16	0.546	0.471		0.225	0.641	
Harvestmen	Surface	1,16	11.61	0.004	in > ex	Not measured		
	Surface * Age	1,16	0.118	0.736				
	Surface * Harvesting	1,16	0.967	0.340				
	Surface * Age * Harvesting	1,16	0.013	0.910				
	Age	1,16	2.033	0.173				
	Harvesting	1,16	3.499	0.080				
	Age * Harvesting	1,16	0.556	0.467				
Collembolans	Surface	1,16	14.96	0.001	in > ex	1.481	0.241	
	Surface * Age	1,16	12.41	0.003		0.533	0.476	
	Surface * Harvesting	1,16	0.407	0.533		0.059	0.811	
	Surface * Age * Harvesting	1,16	0.332	0.573		1.481	0.241	
	Age	1,16	1.086	0.313		22.38	<0.001	2 > 5
	Harvesting	1,16	1.541	0.232		0.000	1.000	
	Age * Harvesting	1,16	1.301	0.271		2.960	0.105	

Table 3. Test statistics from the univariate ANOVA for the differences between clear-cut sites (two- and five-years old) and mature forest; only samples from intact soil surface were considered. Abundance (TOTAL) and species richness (SPP) of different groups of macroarthropods. For significant differences, pair-wise comparisons were made using Tukey's post hoc test (*I-J* value). M = mature forest; 2 = two years old clear-cut, 5 = five years old clear-cut.

	Tukey's comparisons	df	<i>F</i>	<i>I-J</i>	<i>p</i>	Difference
Carabids TOTAL		2,22	0.06		0.940	
Carabids SPP		2,22	1.86		0.177	
Spiders TOTAL		2,22	14.04		<0.001	
	M - 5	2,22		-0.85	<0.001	5 > M
	M - 2	2,22		-0.44	0.035	2 > M
	5 - 2	2,22		0.41	0.015	5 > 2
Spiders SPP		2,22	6.73		0.005	
	M - 5	2,22		-2.00	0.658	
	M - 2	2,22		4.70	0.120	
	5 - 2	2,22		6.70	0.004	5 > 2
Ants TOTAL		2,22	1.32		0.287	
Ants SPP		2,22	0.35		0.707	
Harvestmen TOTAL		2,22	21.29		<0.001	
	M - 5	2,22		1.78	<0.001	M > 5
	M - 2	2,22		1.93	<0.001	M > 2
	5 - 2	2,22		-0.15	0.825	
Collembolans TOTAL		2,22	1.11		0.347	
Collembolans SPP		2,22	5.50		0.012	
	M - 5	2,22		1.00	0.346	
	M - 2	2,22		-0.90	0.419	
	5 - 2	2,22		1.90	0.008	2 > 5

Table 4. Multi-response permutation procedures (MRPP) for the effects of stump harvesting, age of the site and soil-surface type on the species composition of spiders, carabid beetles and collembolans. The test statistic (T), chance-corrected within-group agreement (A) and statistical significance (p) are presented. A summary of non-metric multidimensional scaling (NMDS) for the assemblage structure of spiders, carabids and collembolans among the study sites ($n = 5$ for each site type).

MRPP	Spiders			Carabids			Collembolans		
	T	A	p	T	A	p	T	A	p
Stump harvesting	-10.93	0.15	<0.001	-4.50	0.037	<0.001	-1.49	0.023	0.083
Age	-17.64	0.25	<0.001	-7.12	0.058	<0.001	-10.13	0.157	<0.001
Soil-surface type	-5.21	0.05	<0.001	-1.18	0.007	0.123	-4.71	0.049	0.002

NMDS	Spiders	Carabids	Collembolans
Final stress	15.8	23.5	7.2
Solution	2-dimensional	2-dimensional	3-dimensional
Final instability	0.0021	0.0029	0.0000
No. of iterations	200	200	200
Plot of stress vs. iteration number	46.93	67.21	38.71