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The arthropod community of boreal Norway spruce forests responds variably to stump harvesting ☆

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ABSTRACT

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

1. Introduction

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

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

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et al., 2011a, 2011b). Thus, stump harvesting may not represent an "intermediate disturbance" but rather "an intensive disturbance" for many invertebrate taxa living in forest floor and concomitantly drastically alter forest biodiversity.

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

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

Spiders, ants and carabid beetles are important predators in boreal forest floor (Roberts, 1985; Hölldobler and Wilson, 1990). They feed on detritivores, herbivores and other carnivores, thus being top predators of forest-floor food webs (Roberts, 1996; Townsend et al., 2004; Miyashita and Niwa, 2006). Spiders and ants also act as a link between the below- and above-ground biota as they feed on fauna from both sources (Hölldobler and Wilson, 1990; Miyashita et al., 2003). The present study focuses on spiders, harvestmen, ants and carabid beetles because as top predators they are particularly prone to disturbances. Spiders and carabids also rapidly respond to changes in their habitat (Pearce and Venier, 2006; Koivula, 2011, 2012) and are easy to sample in sufficient numbers for statistical analyses (Nilsson et al., 2001). In addition, epiedaphic springtails (large collembolans) are an abundant prey in forest floor food webs (Siira-Pietikäinen et al., 2002).

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

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

2. Materials and methods

2.1. Study sites and experimental design

The study was carried out in central Finland (61°48′N, 24°47′E) in boreal Norway spruce (*Picea abies* (L.) Karst.) dominated forest stands (sites) growing on Myrtillus (MT) or Oxalis-Myrtillus (OMT) site types (Cajander, 1926). The field layer of MT forest is characteristically dominated by *Vaccinium myrtillus*, *Vaccinium vitis-idaea* and *Linnaea borealis*, whereas that of OMT forest is dominated by *V. myrtillus*, *L. borealis*, *Oxalis acetosella*, *Maianthemum bifolium* and *Convallaria majalis* (Hotanen et al., 2008). The soil in the study area was podzolised moraine with a 3–4 cm thick organic layer; mean annual temperature was 4.9 °C and annual precipitation was 646 mm in 2007. The ground was completely snow covered for approximately three months during the winter 2007 (Finnish Meteorological Institute, 2008).

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

At each site, a ca. 30 m × 30 m (900 m^2) study plot for vegetation and arthropod samplings (see below) was chosen by avoiding moist and rocky patches. The distance from the plot to the nearest stand edge was at least 30 m to avoid severe edge impact. The proportions of intact soil and the soil exposed to mineral surface were estimated for each plot (Kataja-aho et al., 2011a). Soil surface consisting of mixed mineral and organic soil layers was classified as disturbed mineral soil surface.

2.2. Sampling and sample treatments

Arthropods were collected using pitfall traps made of 2-dl plastic cups set flush with soil surface, and covered with 10 cm × 10 cm plastic sheets placed a few cm above the soil surface to prevent rain and litter from entering the traps. The traps were half-filled with 50% ethylene glycol to kill and preserve arthropods falling into the traps. Eight traps were set at each site; at harvested sites, four traps were placed on surface that had originally been exposed to mineral soil and four on intact soil surface. The traps were placed in two parallel rows ca. 5 m apart (i.e. 2 × 4 traps; Fig. 1). The type of surface for each trap was randomized in a pair-wise manner. At each mature-forest site, all eight traps were