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Distribution of oribatid mites is moisture-related within red wood ant *Formica polyctena* nest mounds

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ABSTRACT

Abundant and species rich oribatid mite faunas live as ant associates in red wood ant nest mounds. Distribution of oribatids (as of many other groups) within mounds is unknown, yet there is an indication that many oribatid species favor moist microclimates. The ant mounds typically have a relatively dry core covered by a moister surface layer, but the moisture variance of mound parts has rarely been verified by measurements. We measured the moisture variance of nine *Formica polyctena* mounds (surface, rim, core) located in three different forest types in Finland. The moisture may affect the mounds' temperature maintenance, and we further investigated this relationship. We also hypothesised that the abundance, species richness and community composition of oribatids may be related to the moisture, and investigated these differences between the mound parts and forest types. The moisture varied significantly between the mound parts; moisture was highest in surface followed by rim and core. The surface moisture had a positive relationship with nest core temperature. A total of 18,614 oribatid mites belonging to 93 species and one higher taxon were recorded. The oribatids occurred predominantly on the surface (77.9%), followed by the rim (16.6%) and the core (5.5%) of the ant nest mounds. The abundance and species richness of oribatids was positively related to moisture and differed significantly between the mound parts and forest types. The mound volume had no effect on moisture, temperature or mite community composition. The results indicate that the moisture harbored in the surface layer of ant nest mounds is a vital factor for maintaining rich oribatid mite communities within mounds.

1. Introduction

Red wood ants of the *Formica rufa* group (Hymenoptera: Formicidae) are often described as ecosystem engineers (Jones et al., 1994; Folgarait, 1998; Jouquet et al., 2006) particularly due to their nest-building activity which alters the soil structure and nutrient distribution (Kilpeläinen et al., 2007; Domisch et al., 2008; Jurgensen et al., 2008; Frouz and Jílková, 2008). The *Formica rufa* complex ants (a group of several closely related species) in boreal and temperate forests build large, dense and long-lived above-ground mounds using organic plant material and soil particles (Kilpeläinen et al., 2008). Underneath the visible mound is an excavated tunnel network and the nests contain various elements, e.g. sites for food (Domisch et al., 2009) and food residues such as feces or pray remains (Hölldobler and Wilson, 1990), chambers for one or several queens (Rosengren and Pamilo, 1983) and chambers for brood (Hölldobler and Wilson, 1990).

Invertebrates such as ants are ectothermic with growth and reproduction dependent on the temperature of their habitat (Ratte, 1985; Chown and Nicolson, 2004). Temperature inside nest mounds is typically higher than ambient and mounds may retain relative warmth even during the cold periods enabling ants to overwinter (Frouz, 2000; Frouz and Finér, 2007; Rosengren et al., 1987). In general, invertebrates are vulnerable to desiccation (Chown and Nicolson, 2004) and the maintenance of moisture is important for the ant colony. By working together red wood ants employ techniques to regulate nest moisture content by active ventilation and closing the tunnels during rain (Hölldobler and Wilson, 1990). In general, ant nest material is thought to be dry in comparison with moist soil litter in the mound surroundings (Lenoir et al., 2001; Domisch et al., 2008; Jílková et al., 2015, 2017). Nest moisture may, however, vary within a forest as shaded mounds in inner forest and under tree branches are often moister than mounds in open habitats due to the decreased wind and solar radiation which reduces evaporation (Hölldobler and Wilson, 1990; Frouz and Finér, 2007; Sorvari et al., 2016). The study of Frouz (1996) shows that nest moisture content may also vary within species because mounds of *Formica polyctena* Förster in the Czech Republic were categorized as wet (> 35% moisture in the substrate) or dry mounds (< 20% moisture) (the other being intermediate mounds).

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The moisture variance within ant nest mounds has, however, remained rather unstudied. A few studies report observations that the surface layer of *Formica* ant nest mounds seems to be moister than other parts of the nests (Rosengren et al., 1987; Hölldobler and Wilson, 1990; Laakso and Setälä, 1997; 1998). Only recently was it verified, as a side observation of an ecological study, via actual moisture measurements, that *F. polyctena* nest surface was significantly moister than nest core both in Finland and in Czech Republic (Frouz and Finér, 2007). Moreover, Sorvari et al. (2016) reported that the surface layer of mounds of *F. aquilonia* Yarrow, in a Finnish coniferous forest was significantly drier in clear-cut areas when compared to mounds located in natural forest. The main reason for the moist surface layer is thought to be the high temperature inside the nest that increases evaporation, and when the humid air meets the colder ambient air, moisture condenses in the surface layer (Rosengren et al., 1987; Hölldobler and Wilson, 1990).

The red wood ant nests maintain high concentration of organic nest material, stable internal moisture and relatively high core temperature. Due to these properties their mounds are also a suitable habitat for a large variety of invertebrate ant associates such as other insects (Hölldobler and Wilson, 1990; Laakso and Setälä, 1998; Rettenmeyer et al., 2011; Härkönen and Sorvari, 2014; Robinson and Robinson 2013; Parmentier et al., 2014), spiders (Cushing, 1997), and soil mites (Eickwort, 1990; Lehtinen, 1987; Uppstrom, 2010; Berghoff et al., 2009; Campbell et al., 2013). Though ant mounds are complex constructions with differing moisture patterns, and comprise varied elements for the ants themselves, the distribution of ant associates within mounds has rarely been studied. In Bulgaria, it was shown that myriapods predominantly inhabited the surface layer and below-ground part of *F. pratensis* Retzius, and *F. rufa* Linnaeus, mounds, whereas the central core and rim harbored low abundance of myriapods (Stoev and Lapeva-Gjonova, 2005). In Finland, Laakso and Setälä (1997) found an aggregation of earthworms in the surface layer of *F. aquilonia* nest mounds, which was suggested to be due to the moister litter layer in the surface compared to the other drier parts of the nest (the moisture was not measured). Moreover, when this study was repeated (Carpenter et al., 2013) in England by investigating *F. rufa* nests that lacked the humid surface layer, only a few earthworms were found. These results indicated that the moisture of the nest surface layer may be important for maintaining the rich associate fauna within nest mounds.

Oribatid mites, common and abundant soil-dwelling decomposers (Schatz and Behan-Pelletier, 2008; Siira-Pietikäinen et al., 2008; Huhta et al., 2011), are one of the most numerous, yet little studied ant associates (Laakso and Setälä, 1998; Arroyo et al., 2015; Elo et al., 2016). In our previous study we showed that the *F. polyctena* nest mounds in a Finnish oak forest were inhabited by equally abundant and species rich oribatid assemblages as the surrounding soil, but these two habitats were predominantly occupied by different oribatid species (Elo et al., 2016). The questions of why oribatids live in ant nests, and where they occur there, remained unanswered. It was, however, noted that most species inhabit various habitats in nature, and likely live in ant mounds as facultative associates favoring the optimal conditions (Weigmann, 2006; Elo et al., 2016).

While there are xerophilous species (Weigmann, 2006), most oribatids may be thought of as hygrophilous, since they are commonly abundant in moss and on the surface of vegetation covered soil (approximately 200,000 specimens and 50 species m^{-2}) (Schatz and Behan-Pelletier, 2008; Huhta et al., 2011). Oribatids also live in other moist and stable microhabitats such as decaying wood (Siira-Pietikäinen et al., 2008), under tree bark (Lindo and Winchester, 2008) and tree hollows (Taylor and Ranius, 2014). Moreover, in the studies conducted in Sweden drought decreased and irrigation increased the oribatid abundances in soil (Lindberg et al., 2002; Lindberg and Bengtsson, 2006). Similar results have also been presented for other arthropod groups (Frampton et al., 2000), suggesting that moisture is one of the key determinants of the abundance of soil animals.

Here we investigate the distribution of oribatids within ant nest mounds and hypothesise that the distribution is linked to moisture and especially to the suspected moist surface layer of mounds. We study nine *F. polyctena* nest mounds that are located in three forest types on the island of Ruissalo, SW Finland. First, we study i) if there is variation in moisture content between three parts of a nest mound: the surface layer, rim and central core, and ii) if the variance in moisture is connected to temperature. We also investigate iii) if the abundance, species richness and community composition of oribatids differ between the three parts, and iv) if they are related to the moisture variance. Lastly, we relate these results to the mound volume and forest type.

2. Materials and methods

2.1. Study site and species

The study was conducted on the island of Ruissalo, Turku, southwestern Finland (60° 12′N, 22° 35′E). The island of Ruissalo is around 900 ha and is located close to the mainland (for a map see Elo et al., 2016). Ruissalo is one of the most plant-rich areas in Finland hosting hemiboreal oak forest mainly in the eastern part, spruce forest in the western part, and mixed coniferous and deciduous forest between (Table 1).

The polygynous and polydomous (several queens per nest, colony contain several mounds) red wood ant *F. polyctena* was selected as the study species since it is the dominant ant species in southern Finland

Table 1
Vegetation in the study area in the island of Ruissalo, SW Finland, including the tree species (100%) and herb species (100%), and in addition the nest mound material of the *Formica polyctena* ants (collected by the ants from the nearby forest).

	Vegetation	Area 1	Area 2	Area 3
		Oak forest	Mixed forest	Spruce forest
Tree layer	Oak (*Quercus robur*)	80%	30%	10%
	Spruce (*Picea abies*)	5%	30%	70%
	Scots pine (*Pinus sylvestris*)	5%	30%	10%
	Other: Linden (*Tilia cordata*), Hazel (*Corylus avellana*), Birch (*Betula* sp)	10%	10%	10%
Herb layer	Lily of the valley (*Convallaria majalis*)	50%	50%	–
	Wavy hair-grass (*Deschampsia flexuosa*)	50%	10%	10%
	Bracken (*Pteridium aquilinum*)	–	10%	10%
	Bilberry (*Vaccinium myrtillus*)	–	20%	70%
	Common hepatica (*Hepatica nobilis*)	–	10%	–
	Cow-wheat (*Melampyrum* sp)	–	–	10%
Nest material		Hay, roots, birch and pine seeds, sticks	Needles, sticks roots, pine seeds	Needles, sticks, spruce seeds