Forest Ecology and Management 349 (2015) 12–19

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Tree species influences diversity of ground-dwelling insects in afforested fields

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ARTICLE INFO

Article history:
Received 2 March 2015
Received in revised form 16 April 2015
Accepted 17 April 2015
Available online 29 April 2015

Keywords:
Afforestation
Carabidae
Formicidae
Novel ecosystem
Plantation forests
Restoration

ABSTRACT

Impaired natural ecosystems, such as agricultural lands, are restored toward original or other target stage. Because the long agricultural history has changed the physical, chemical and biological features of the soil, afforested fields can harbor novel species assemblages and interactions. Our overall aim was to quantify the diversity of ground beetles and ants in early successional afforested fields. In a large scale field experiment, we compared plots that had been afforested 25 years ago by planting monocultures of birch, pine or spruce trees. A total of 4080 carabid individuals representing 41 species, and 131,933 ant individuals representing 15 species were recorded. Both the carabid and ant assemblage included forest and open-habitat species, but were dominated by generalists, which is typical for early successional habitats. Tree species had a strong influence on carabid and ant assemblages. Species composition among pine plots was more homogeneous than among spruce or birch plots. The diversity of ground beetles and ants increased from pine to spruce to birch plots, most likely due to positive influence of leaf litter. Our results indicate that early successional afforested fields can harbor species rich arthropod assemblages. The diversity and species composition of these assemblages are influenced by tree species, already at early successional stages, and are likely to become more prominent as succession proceeds. Thus, the tree species used in afforestation is one important factor for consideration, if field afforestation has biodiversity objectives.

1. Introduction

Loss, fragmentation and deterioration of natural ecosystems are threatening biodiversity. Concomitantly, managed land is being abandoned, managed for new purposes or restored. For example, agricultural lands are afforested extensively worldwide for varying purposes, such as timber production, erosion prevention, water quality improvement, carbon sequestration or biodiversity maintenance (Navarro and Pereira, 2012). In Finland, almost 300,000 hectares have been afforested since 1970 (Finnish…2014). Given the large area of afforested fields in many regions, they can contribute to local and regional biodiversity. It is also clear that the chosen restoration and management measures influence the direction in which these ecosystems develop and consequently their biodiversity (Bremer and Farley, 2010; Plath et al., 2012; Skłodowski, 2014). However, little is known about biodiversity in afforested fields, especially in boreal forests (but see Wall, 1998; Lindgren, 2000).

Clearing a forest to a field is a disturbance that fundamentally changes physical, chemical and biological conditions. The agricultural activities then maintain the artificial open habitat, until afforestation initiates secondary succession (Bakker and van Wieren, 1998; Cramer and Hobbs, 2007). Vegetation succession of afforested fields depends on, for example, the agricultural history, time since cultivation ceased, physical and chemical qualities of the soil, climate, regional species pools, as well as restoration and management measures (Walker et al., 2007; Cramer et al., 2008). Agricultural activities, such as fertilization, have long lasting effects on the soil, because they increase the amount of organic matter, pH and nutrients (Mann, 1986; Johnson, 1992; Wall and Hytönen, 1996, 2005). Considering the long term succession of the afforested fields, the choice of tree species is possibly the most important factor influencing biota.

In Nordic countries, afforestation of arable land has been mainly done by planting indigenous tree species. In Finland, Scots pine was the most commonly used tree species in the 1970s and

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http://dx.doi.org/10.1016/j.foreco.2015.04.014
0378-1127/

1980s, but its use started to decline after failures in afforestation (Hynönen and Hytönen, 1997). Birches (*Betula* spp.) and Norway spruce (*Picea abies*) are better adapted to increased nutrient concentrations prevailing in agricultural soils and their use has increased. Before planting tree seedlings, soil is prepared mechanically. Following tree planting, the open field is colonized by annual plant species during the first growing season (Törmälä, 1982; Jukola-Sulonen, 1983). Arable fields contain large banks of germinable seeds, mostly of pioneer weed species (Paatela and Erviö, 1971); these seeds can remain viable for up to 20 years (Kiirikki, 1993). Subsequently, annual weeds give way to perennial herbs and grasses. Grasses often dominate the vegetation for a long time after afforestation, and thus the vegetation cover does not resemble that of normal forests even after 16–17 years from afforestation (Hynönen and Saksa, 1997; Hytönen, 1999). However, due to the slow succession of boreal vegetation, the precise outcome on afforested fields is generally not known (Wall, 1998). The outcome can be similar to the original pre-cultivation habitat, completely novel with unique biological communities without historical reference, or something in between (Hobbs et al., 2006; Cramer et al., 2008).

Heterotrophic organisms follow the changes in vegetation. Ground beetles (Coleoptera: Carabidae) and ants (Hymenoptera: Formicidae) are well-studied and ecologically important groups in northern hemisphere (Niemelä et al., 2007; Finér et al., 2013). Most carabids are predators, whereas ants are omnivores. The stand-level distribution and abundance of carabid beetles and ants is influenced by microclimate, as well as litter quality and quantity, which in turn are influenced by the identity of the dominant tree species, age structure of trees and canopy cover (Niemelä et al., 1996; Guillemain et al., 1997; Antvogel and Bonn, 2001; Jukes et al., 2001; Boulton et al., 2005; Vanbergen et al., 2005; Kilpeläinen et al., 2008; Janssen et al., 2009; Taboada et al., 2010; Silva et al., 2011; Staab et al., 2014). For example, increasing leaf litter and pH have generally a positive influence on both carabid and ant species richness, and they also influence species composition (Koivula et al., 1999; Magura et al., 2003; Sroka and Finch, 2006; Silva et al., 2011; Staab et al., 2014). This suggests that more species and different assemblages of carabids and ants can be found from broadleaved forests than in otherwise similar coniferous forests. Generally, there is a negative relationship between the number and/or abundance of carabids and red wood ants (*Formica rufa* group; Nilsson et al., 1988; Niemelä et al., 1992), probably due to interference competition (Reznikova and Dorosheva, 2004; Hawes et al., 2013). However, the sign of this relationship can vary depending on the dominant tree species (Neuvonen et al., 2012). It seems that the identity of the structural species (i.e. trees) can have ecologically significant effects on ground-dwelling arthropods and their interactions.

Our overall objective was to document diversity patterns of ground-dwelling arthropods in an early successional habitat, which has resulted from field afforestation 25 years ago. Based on an extensive field experiment, our specific aim was to analyse whether the identity of the structural species (Silver birch, Norway spruce or Scots pine) has influenced the carabid beetle and ant assemblages so far. Our first hypothesis was that species composition differs between tree species, due to the influence of leaf litter and microclimate. The second hypothesis was that afforested fields harbor both open-habitat and forest species, due to agricultural legacy and early successional forest vegetation. The third hypothesis was that the number of individuals and species, as well as diversity is higher in birch plots compared to conifer plots, due to the influence of leaf litter and microclimate. The fourth hypothesis was that there is a negative relationship between the number and abundance of wood ants and carabid beetles, due to interspecific interactions or difference in (micro)habitat selection.

2. Materials and methods

2.1. Study sites and experimental design

We studied eight afforested fields in western parts of central Finland in the summer of 2013 (Table 1). The study area belongs to the middle boreal vegetation zone (Hämet-Ahti et al., 1998). The sites were at least 1 km apart (median = 33 km), and surrounded mostly by early successional managed forests. The fields had been afforested during the year 1990, using Silver birch (*Betula pendula* Roth.), Norway spruce (*P. abies* L.) and Scots pine (*Pinus sylvestris* L.) (Ferm et al., 1993). The sites were mostly organic agricultural soils having a high organic matter content in the top soil classified as peat. On five of the fields mineral soil had been added during cultivation as amelioration agent. None of the sites had been fertilized after afforestation.

Soil quality was measured at the afforestation year. Volumetric soil samples were taken from the 0–10 cm top soil layer. Soil acidity was measured from a soil water 1:2.5 (v/v) suspension. The soil samples were dried at 60 °C and ground to pass through a 2 mm sieve. Bulk density of the soil samples was calculated as the ratio of dry mass (dried at 105 °C) to the volume of the sample. The soil samples were analyzed for their total nutrient concentrations after HCl digestion using an atomic absorption spectrophotometer (AAS-method). Nitrogen was analyzed with Kjeldahl method.

Table 1
Summary of the study sites. All sites were afforested the year 1990. Bulk density, pH and total nutrient amounts were measured in the 0–10 cm soil layer at the afforestation year.

Site	Soil[e]	Cultivation ceased	Last cultivated species	Thinnings[c]			pH	Ca, kg ha^{-1}	N, kg ha^{-1}	Bulk density, g dm^{-3}
				Birch	Spruce	Pine				
Alajärvi	P + M	1978[a]	Not known	Yes[d]	No	Yes	5.0	1640	2444	600
Alavus	P + M	1960s[a]	Not known	Yes	No	Yes	4.9	884	3247	469
Kuortane	P + M	1986[b]	Hay	Yes	No	NA	5.0	1941	5986	357
Lappajärvi	P	1988	Hay	Yes	Yes	NA	4.2	1196	6805	252
Petäjävesi	P + M	1988	Oat, barley, hay	No	No	No	5.4	4138	7006	579
Sarkala[f]	P	<1970	Not known	Yes	Yes	NA	4.9	1425	4044	185
Suosaari[f]	P + M	<1970	Not known	Yes	Yes	Yes	4.8	1155	3029	262
Töysä	P	1988	Oat	Yes	Yes	Yes	4.6	1656	3657	462

[a] Remained as fallow after cultivation ceased.
[b] Soil preparation was continued until afforestation.
[c] Yes = forest stand had been thinned, No = not thinned, NA = not applicable, i.e. plots of the given tree species were not studied in the site in question.
[d] Thinned during the study.
[e] P = peat soils, P + M = originally peat soil, but during cultivation mineral soil added in the top soil layer.
[f] These sites are situated in Kyyjärvi.