Ecological Indicators 94 (2018) 409–419

Contents lists available at ScienceDirect

Ecological Indicators

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

Landscape-scale effects of Christmas-tree plantations in an intensively used low-mountain landscape – Applying breeding bird assemblages as indicators

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ARTICLE INFO

Keywords:
Farmland bird
Indicator species analysis
Land-use change
Novel ecosystem
Species richness
Woodlark (*Lullula arborea*)

ABSTRACT

Novel ecosystems are characterised by recent establishment due to human activities and new species combinations. A characteristic example in farmlands are Christmas-tree plantations. The aim of this study is to evaluate the landscape-scale effects of the novel ecosystem Christmas-tree plantation on breeding bird assemblages in an important European stronghold of Christmas-tree production, the intensively used low-mountain landscape of the Hochsauerland (Central Europe), in comparison with currently competing land-use types.

The study revealed that the five studied landscape types differed in habitat composition and landscape diversity. Landscape diversity was significantly highest in the two types of Christmas-tree plantation landscapes and windthrow landscapes, differing from grassland and forest landscapes. Bird species assemblages clearly responded to the differences in habitat composition. This was especially true for threatened species having a peak of species richness and breeding-pair density in the two types of Christmas-tree plantation landscapes and slightly weakened at windthrow landscapes.

The high species richness of threatened breeding bird species in Christmas-tree plantation landscapes was driven mainly by high landscape heterogeneity. Densities of the threatened indicator species of the Christmas-tree plantation landscapes were probably promoted by (i) high availability of suitable food (arthropods, seeds) and (ii) high accessibility to the food resources due to bare ground (tree pipit [*Anthus trivialis*], woodlark [*Lullula arborea*]) or low-growing vegetation (linnet [*Carduelis cannabina*], yellowhammer [*Emberiza citronella*]) in the Christmas-tree plantations. For the woodlark, Christmas-tree plantations are even among the most important strongholds in the German Federal State of North Rhine-Westphalia.

1. Introduction

A large part of Europe's biodiversity is associated with agricultural land (Donald et al., 2006; Henle et al., 2008; Kleijn et al., 2009). Additionally, farmland constitutes the single largest habitat in Europe; more than 40% of the European (EU-27) (Eurostat, 2016) and 54% of the German (BMU, 2007) terrestrial land surfaces are used for agriculture. Consequently, agricultural landscapes play an important role for biodiversity conservation (BMU, 2007; Henle et al., 2008). Nevertheless, across different taxa such as plants, insects, and birds, farmlands exhibit the largest decrease in biodiversity (Donald et al., 2006; Flohre et al., 2011; Vickery et al., 2001). The two main drivers of the current loss in farmland biodiversity are (i) land-use intensification on productive soils and (ii) abandonment of marginal land (Foley et al., 2005; Henle et al., 2008; Kleijn et al., 2009). Both lead to homogenisation at the landscape and habitat scale with severe negative effects on biodiversity. Bird assemblages have been shown to be very good indicators of overall habitat and in particular farmland biodiversity (Donald et al., 2001; Graham et al., 2017; Maes et al., 2005; Newton, 2017). Land-use change affects birds mainly due to the alteration of the food supply and its influence on the breeding habitat (Benton et al., 2002; Newton, 2004; Vickery et al., 2001).

However, anthropogenic transformation of landscapes may also result in the emergence of novel ecosystems. Novel ecosystems are characterised by recent establishment, due to deliberate or inadvertent human action, and new species combinations, with the potential for changes in ecosystem functioning (Hobbs et al., 2006). A characteristic example in Central European farmlands are Christmas-tree plantations. As a result of agricultural overproduction during the early 1980s and, therefore, the introduction of a milk quota within the EU, many

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https://doi.org/10.1016/j.ecolind.2018.07.006
Received 22 January 2018; Received in revised form 29 June 2018; Accepted 5 July 2018
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grasslands in the study area, the low-mountain landscape of the 'Hochsauerland' in Central Europe (cf. Section 2.1), have been converted to Christmas-tree plantations (Fartmann et al., 2017; Rüther, 1990). Since then, their extent has increased continuously. The last significant expansion of Christmas-tree cultivation in the study area began in 2007 following the European storm 'Kyrill' (Fink et al., 2009). More than 2900 ha of Kyrill windthrows on former non-native spruce forests (*Picea abies*) have been planted with Christmas trees after salvage logging (Centre for Forest Ecosystems, 2013). Today, the Hochsauerland and adjacent low-mountain areas are important strongholds of Christmas-tree production in Europe, covering a total area of 18,000 ha (State Parliament NRW, 2013).

As Christmas-tree plantations have emerged as a novel ecosystem only very recently, scientific knowledge concerning their role for biodiversity conservation is very scarce (Fartmann et al., 2017; Gailly et al., 2017). However, Bagge et al. (2012) recently showed that conventionally managed Christmas-tree plantations in Denmark have higher carabid beetle species richness and abundance than organically managed ones. Additionally, Gailly et al. (2017) demonstrated that the introduction of Christmas-tree plantations into landscapes dominated by grassland with low hedge density in the Belgian Ardenne region increases bird species richness and abundance. However, they question the genuine quality of Christmas-tree plantations for birds due to the lack of data on breeding success.

Within the Hochsauerland, recent studies provided evidence that Christmas-tree plantations are characterised by high arthropod densities (ground beetles, spiders) comparable to those of montane heathlands and windthrows (Freienstein et al., 2018; Höppner, 2014) and high seed availability (Streitberger and Fartmann, 2018). Additionally, they are meanwhile regularly used as breeding habitats by the threatened woodlark (*Lullula arborea*) (Fartmann et al., 2017; Höppner, 2014; Legge, 2009; Schulte, 2017). Since the first observation of about 20 breeding pairs in Christmas-tree plantations in 2008 (Legge, 2009), the size of the woodlark population has continuously increased (Fartmann et al., 2017; Schulte, 2017).

The aim of this study is to evaluate the landscape-scale effects of the novel ecosystem Christmas-tree plantation on breeding bird assemblages in an important European stronghold of Christmas-tree production, the intensively used low-mountain landscape of the Hochsauerland (Central Europe) (Fig. 1), in comparison with competing land-use types. For this purpose, we compared environmental conditions as well as species richness and density of breeding birds in landscapes dominated by (i) grassland, (ii) Christmas-tree plantations in open landscapes that had been established on former grasslands, (iii) Christmas-tree plantations that had been established on former windthrows, (iv) windthrows as a result of the European storm 'Kyrill' in January 2007, and (v) non-native spruce forests. Finally, we provide recommendations for the future management of Christmas-tree plantations.

2. Materials and methods

2.1. Study area

The 541 km^2 study area is located in the northern part of the 'Hochsauerland' (51°6′ N/8°5′ and 51°22′ N/8°33′ E, 250–550 m a.s.l.), a low-mountain range in the southeast of the German Federal State of North Rhine-Westphalia (Fig. 1). It is characterised by a rather cool and wet climate (mean annual temperature: 8.0 °C; mean annual precipitation: 1184 mm; meteorological station Eslohe [351 m a.s.l]; period: 1981–2010; Wetterdienst and (DWD), 2017). The dominating soils in the hilly landscape are originally nutrient-poor cambisols (= poorly developed brown soils) on acidic bedrock (Geologisches Landesamt Nordrhein-Westfalen (NRW) 1998). The landscape is characterised by intensive forestry and agriculture. Forests (47% of the total area, mainly non-native spruce forests), and improved grassland (23%, mostly silage grasslands or cattle pastures with high stocking rates) are the dominant habitat types, followed by arable fields and built-up area (11% each). Nutrient-poor habitats and hedges have become rare within the agricultural areas of the study area as a result of intensive land use and associated structural homogenisation of the landscape.

Christmas-tree plantations (mainly caucasian fir [*Abies nordmanniana*]) are now characteristic elements of the low-mountain landscape, covering 3813 ha (7%) of the study area. Christmas-tree plantations are characterised by the application of fertiliser and herbicides. However, intensive fertilisation is avoided as it leads to a rapid height growth of the trees with negative effects on sales opportunities (Matschke, 2005; Maurmann, 2013). Christmas-tree plantations have a rotation cycle of 8 to 12 years. Herbicides are usually applied prior to planting of the young trees and during the first three to four years each spring at the beginning of the growing season and each autumn after lignification of the tree shoots (Körner, 1988; Matschke, 2005). As a result, the rows between the Christmas trees are usually covered by mosaics of bare ground (~5–10% cover), gravel (~5–10%) and weeds (~40%) in summer (Höppner, 2014). In contrast, insecticides are normally not applied. Additionally, the herb layer between the tree rows is often mulched in late summer (Matschke, 2005). During the rest of the growing season there are usually no further management activities. To avoid browsing of the shoot tips by roe deer and partly red deer, the plantations are fenced (Legge, 2009). Hence, there is no public access, and the breeding birds are not disturbed by mountain bikers, hikers or walkers and their domestic dogs.

2.2. Sampling design

2.2.1. Plots

We compared five different landscape types characteristic for the study area and dominated by (i) grassland (GRASS), (ii) Christmas-tree plantations in open landscapes that had been established on former grasslands (CTOPEN), (iii) Christmas-tree plantations that had been established on former windthrows (CTWIND), (iv) windthrows as a result of the European storm 'Kyrill' in January 2007 (WIND), and (v) spruce forests (FOREST). Per landscape type, we randomly selected seven quadratic plots with a size of 40 ha and a cover of the focal land-use type of at least 40% within the plot ($N_{\text{plots}} = 35$, Fig. 1).

2.2.2. Habitat composition

For each plot, we mapped the habitat composition according to Riecken et al. (2006) and calculated the area of each habitat type using ArcGIS 10.2 (ESRI Inc.). For further analysis, the habitat types were summarised to the following nine main classifications: arable land, semi-natural grassland, improved grassland, fringe/clearing vegetation, Christmas-tree plantation, shrubland, deciduous forest, coniferous forest, and built-up area (Table 1). Additionally, we calculated the landscape diversity (H') of each plot using the Shannon Index (O'Neill et al., 1988):

$$H' = -\sum_i p_i \ln p_i \text{ with } p_i = \frac{n_i}{N}$$

where N is the total area of a plot and n_i is the area of each habitat type in the plot.

2.2.3. Breeding bird surveys

Mapping of the breeding bird territories was performed in all plots from the end of February to June 2016 (Fischer et al., 2005). Altogether, five surveys at early morning and two at night with an interval of at least 10 days between each visit were conducted. During each visit, we noted all observations of territorial behaviour, such as singing, according to Bibby et al. (2000) in a map (scale 1:1500) by following a non-linear transect covering all the study area. Breeding was assumed if a bird showed territorial behaviour twice within a distance of 10 days between each survey (Fischer et al., 2005). Additionally, for detecting

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