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Red-listed species and forest continuity – A multi-taxon approach to conservation in temperate forests

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ABSTRACT

The conservation status of European temperate forests is overall unfavorable, and many associated species are listed in national or European red-lists. A better understanding of factors increasing survival probability of red-listed species is needed for a more efficient conservation effort. Here, we investigated the importance of current forest cover, historical forest cover and a number of soil and climate variables on the incidence and richness of red-listed forest species in Denmark. We considered eight major taxa separately (mammals, saproxylic beetles, butterflies, vascular plants and four groups of fungi), using mainly citizen science data from several national mapping projects. Taxa were selected to represent important forest habitats or properties (soil, dead wood, forest glades and landscape context) and differ in dispersal potential and trophic strategy. For all groups, presence and richness of red-listed species was positively related with current forest cover, but - for most taxa - forest cover 200 years ago was an even better predictor. The intersection of past and current deciduous forest was used to identify the area of continuous, lost and new forest. Continuous and lost deciduous forest cover were strong predictors of red-listed species occurrence in most groups, but surprisingly species richness of butterflies and hydnoid fungi, and presence of mammals, was significantly, positively affected by coniferous forest area. The positive effect of lost deciduous forests on red-listed species, suggest an extinction debt of at least 200 years, with some areas hosting more red-listed species than the current area of old forest can sustain in the long run. Our results suggest that current priorities for forest conservation in Denmark are not efficient in protecting red-listed forest species, and that more focus should be put on conserving deciduous forest with long continuity. Furthermore, a multi-taxa approach including a wide array of organism groups with contrasting habitat affiliations, results in a more comprehensive understanding of the requirements of red-listed forest species and necessitate a more focused approach to conservation planning.

1. Introduction

Due to historical loss of natural forest areas, many forest species in Europe are nationally or internationally threatened. Red-listed forest species often have specific habitat requirements and in order to ensure their survival, it is necessary to understand the factors affecting - negatively or positively - their survival probability. In temperate Europe, forest areas have been fragmented and lost to farmland with the increasing size of the human population (Kaplan et al., 2009). The forest area is now slowly increasing throughout Europe (Vilén et al., 2012), but most of the new forests are plantations, predominantly of conifers (McGrath et al., 2015), and decades to centuries are needed before they can support old growth forest habitats like veteran trees or large decaying logs (Nordén et al., 2014). Remaining old forestlands have typically experienced drainage and planting, and have been subject to coppicing, clear cutting or shelterwood forestry in order to promote production. As a consequence most of the current forest area in Europe lacks naturalness and ecological continuity (Bengtsson et al., 2000; Pătru-Stupariu et al., 2013). During the last decades, the extent of protected forest areas has increased in Europe, and recovery of old growth attributes and diversity has been reported from protected and managed forests (Vandekerkhove et al., 2011). Overall, the conservation status of temperate forests in Europe is however still considered unfavorable (EEA, 2015), and

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focused conservation efforts are needed to halt further biodiversity loss.

In Denmark the forest area reached a modern minimum around 1810, due to clearance for agriculture and centuries of logging and grazing in remaining woodlands (Mather et al., 1998; Fritzbøger, 2005). The resulting landscape was highly fragmented with forests constituting isolated patches in a farmland matrix. Since the foundation of the Danish Forest Protection act in 1805, the forest area has been quadrupled to now cover 14% of the country, mainly due to reforestation with introduced conifers in heathland and dunes on sandy soils. As a consequence of this forest history only a small percentage of the current Danish forest area can be classified as continuous forest (i.e. dating back to before 1800) (Naturstyrelsen, 2013). A very similar overall forest development has been reported from the Netherlands, the British Isles, Germany and Belgium (Buis, 1985; Watts, 2006; Schmidt et al., 2014; De Keersmaeker et al., 2015).

The relationship between forest area and species richness of different organism groups has been analyzed in numerous studies (e.g. Fahrig, 2003; Tikkanen et al., 2009; Martensen et al., 2012), some with special focus on forest fragmentation (Kolb and Diekmann, 2004; Hanski et al., 2013), others emphasizing the importance of forest history and continuity (Graae et al., 2004; Hermy and Verheyen, 2007) or remaining old growth structures (Fritz et al., 2008). Most of these studies have found a positive signal of intact forests areas on species richness of forest specialist or red-listed species, but they are typically restricted to single groups of organisms, and of limited relevance for more specific site selection and conservation planning.

It is well known that ecosystem changes resulting from land use or climate change may not be fully apparent for several decades, owing to long response times in ecological systems (Dullinger et al., 2013). Among insects, delays in extinction are known to extend well beyond 100 years, while even longer delays to forest fragmentation have been reported among forest plants (Tilman et al., 1994; Hanski, 2000; Vellend et al., 2006; Bulman et al., 2007). Similar time scales may be needed for formation of specific forest habitats in reforested or heavily managed forest areas (Nordén et al., 2014), and delays in recolonization of forest specialists into such areas may be substantial, especially for slow dispersing species (Jacquemyn et al., 2001). In addition other biotic and abiotic factors, e.g. climate and soil conditions may influence the value of old and new forest for biodiversity (e.g. De Keersmaeker et al., 2014; Heilmann-Clausen et al., 2014), which may further complicate efficient conservation planning.

The principle of complementary site selection is a cost-effective way to cover biodiversity in a conservation network (e.g. Pressey et al., 2007). Despite its statistical effectiveness, complementarity also has weaknesses, e.g. if species distribution patterns are incompletely known or changing over time. Further, there are often legislative or political constraints to reserve network selection which may lead to a quest for compromises. In this study we do not attempt to identify a cost-effective reserve network but rather to inform conservation planning on a general level, by investigating the major drivers of red-listed species in selected species groups with complementary habitat needs (cf. Maes and Bonte, 2006; Simila et al., 2006).

Our overall objective was to investigate the importance of forest history, soil and environmental variables for the presence and richness of red-listed forest species, with the aim to evaluate and qualify conservation planning, both in Denmark and in adjacent regions (especially Northern Germany, Benelux, Great Britain and S. Sweden) with comparable forest history and biodiversity. We included nationally red-listed species from eight different organism groups: mammals, saproxylic beetles, butterflies, four groups of fungi and vascular plants. As elaborated in the next section, the eight organism groups differ in their habitat requirements, and hence we expected them to show different relationships to the included forest variables. Following the species-area relationship, we expected (1) to find a general increase in the number of red-listed species with an increase in general forest area in all groups, but (2) to find a better fit with the historic or continuous deciduous forest area in groups dependent on old growth forest habitats or forest continuity (saproxylic beetles and fungi, mycorrhizal *Phlegmacium* & *Ramaria* species and vascular plants). Finally, we expected (3) to detect an influence from soil type variables on soil and root associated organisms (vascular plants and the three groups of non-saproxylic fungi). Since climate is known to be an important driver of biodiversity, we included annual precipitation and temperature as co-variables to account for possible effects. Similarly, we added distance to coast as a co-variable because coastal forests in Denmark seem to have suffered less from human impact, including air pollution, than inland forests.

2. Materials and methods

2.1. Study area

For this study we used datasets covering the entire country of Denmark, a total area of 43,094 km^2. The climate in Denmark is temperate with an average annual temperature of 8.3 °C and an average annual precipitation of 593 mm (climate normals 1961–1990, data available from www.dmi.dk).

The forest area in Denmark was estimated to 6081 km^2 or 14.1% of the total land area in 2013, following the FAO forest definition (Nord-Larsen et al., 2014). Of the forest area, 39.5% is pure coniferous forest, 40.8% is pure deciduous forest and 11.3% is mixed forests. The remaining 8.4% consist of work areas, roads and temporarily non-vegetated areas. The natural climax vegetation in most of the area is nemoral mixed forests composed of *Acer* spp., *Alnus glutinosa*, *Betula* spp., *Carpinus betulus*, *Corylus avellana*, *Crataegus* spp., *Fagus sylvatica*, *Fraxinus excelsior*, *Prunus* spp., *Quercus* spp., *Tilia* spp. and *Ulmus* spp. *Juniperus communis*, *Taxus baccata* and *Pinus sylvestris* are the only native conifers occurring in the area, but *Picea abies*, native to nearby parts of South Sweden and North Germany, is now the most common tree species (Nord-Larsen et al., 2014).

2.2. GIS work

All data was gridded in ArcGIS using a 10 × 10 km grid. The same grid has been used in several biological atlas surveys in Denmark and consists of 633 grid cells (Lund, 2002; Larsen et al., 2008). On the original grid, the grid cells along the border between UTM zones 32 and 33 have been modified, so that area and shape deviate somewhat from the standard 10 × 10 km cells. Since not all data on the explanatory variables included in this study was available in all 633 grid cells, 146 cells where omitted from the final dataset used in the statistical analyses, leaving 487 cells in the final grid (Fig. 1). The omitted cells include two of the rare important calcareous areas in Denmark (Høje Møn, Himmerland) known to host many red-listed species associated with calcareous soils. In all other aspects we consider the reduced dataset as representative for Danish forests in general.

2.3. Species data

We selected eight organism groups to represent the width of Danish forest biodiversity in respect to ecosystem functions and habitat requirements. Saproxylic fungi and beetles were selected to represent biodiversity connected to dead wood and veteran trees. The latter group has a preference for sun-exposed and