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Negative impacts of felling in exotic spruce plantations on moth diversity mitigated by remnants of deciduous tree cover

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ABSTRACT

Moths are a vital ecosystem component and are currently undergoing extensive and severe declines across multiple species, partly attributed to habitat alteration. Although most remaining forest cover in Europe consists of intensively managed plantation woodlands, no studies have examined the influence of management practices on moth communities within plantations. Here, we aimed to determine: (1) how species richness, abundance, diversity of macro and micro moths in commercial conifer plantations respond to management at multiple spatial scales; (2) what the impacts of forest management practices on moth diversity are, and (3) how priority Biodiversity Action Plan (BAP) species respond to management. BAP species were selected as they represent formerly widespread and common species, which have undergone substantial declines in the UK and Europe. We assessed moth communities in three conifer plantations in Northern England and Scotland by light trapping, combining local (e.g. age of planting) and landscape level (e.g. proximity to felled areas) characteristics to evaluate the impacts of forest management on moths. We found no relationship between local factors and moth richness, abundance and diversity but the amount of clear felling in the surrounding landscape had a strongly negative correlation. In contrast, the amount and proximity of broadleaf cover in the surrounding landscape positively influenced macro moth richness and abundance. For six BAP species, abundances were lower close to felled areas but increased with the size of adjacent broadleaf patches. We conclude that clear felling negatively affects moths, probably through alteration of habitats, the loss of larval host plants, and by limiting dispersal. A shift to continuous cover and maintaining broadleaf tree cover within plantations will greatly enhance their value for moth communities.

1. Introduction

Maintaining and restoring biodiversity is a key tenet in sustainable ecosystem management, the paradigm currently guiding habitat management practices across Europe and North America (Ober & Hayes, 2010). This is driven by concern about world-wide declines in species and populations across a range of taxa (Dirzo et al.. 2014) and recognition that much of this is driven by habitat loss and fragmentation, caused by anthropogenic change (Thomas. 2004). In many countries the timber industry has responded to recognition of the importance of biodiversity by shifting focus from purely timber production to one which encourages sustainable practices that promote both wildlife conservation and sustainable timber yields (Macdonald et al., 2009). In Europe this has been driven by policy change initiated as a result of the Convention of Biological Diversity, requiring explicit consideration of environmental, economic and social objectives and a multi-purpose approach to forestry (Watts et al., 2008). However, efforts to assess the impact of forest practices can be challenging as there is often inadequate knowledge of the current distribution and abundance of many taxa in managed forest systems (Ober & Hayes, 2010).

Plantation forests are generally considered poor for biodiversity as they are primarily composed of non-native tree species, often in monocultures, which are under an intensive management regime (Brockerhoff et al., 2008). However, they usually constitute the largest patches of tree cover in many European countries and as such may be valuable for preserving biodiversity if managed sympathetically. One of the few studies carried out at a national scale demonstrated that plantations can support diverse invertebrate communities in the UK, and that invertebrate community composition and abundance is most affected by tree species planted and geographic location (Humphrey et al., 2003). The structure of the plantation was also important for some groups: ground dwelling Carabid diversity decreased with canopy

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cover whereas overall Coleopteran richness and abundance in the canopy increased (Humphrey et al., 2003). The effect of stand age on invertebrate communities can also vary between taxa. Higher abundance and diversity of Coleoptera has been associated with older *Larix kaempferi* (Larch) and *Picea sitchensis* (Sitka Spruce) plantations in Japan and Northern Ireland due to increased heterogeneity and regeneration of native trees (Ohsawa, 2005; Oxbrough et al., 2010). However, the high canopy cover in mature plantations can negatively affect other groups associated with open habitats (e.g. Arachnid diversity; Oxbrough et al., 2010).

Despite being a speciose taxonomic group and an important component of the invertebrate community, the impacts of plantation forestry on night active Lepidoptera are yet to be explored. Substantial declines of many moth species have occurred in the last few decades; two thirds of common and widespread species in the UK have suffered rapid population decreases (Conrad et al., 2006) with similar patterns occurring in Finland (Mattila et al., 2006) and Sweden (Franzén & Johannesson, 2007). Rapid economic development, urbanisation, changes to silvicultural management and agricultural expansion have all been implicated in causing these declines (Conrad et al., 2006; Fox et al., 2013). Taken together, these studies provide overwhelming evidence that moths are facing declines on a large geographic scale, across a range of habitats, which mirrors similar effects found in less species rich groups such as butterflies and bumblebees (Warren et al., 2001; Goulson et al., 2008). Such losses are likely to have substantial effects at both higher and lower trophic levels. Moths are a key component of terrestrial ecosystems, providing ecosystem services through modification of ecosystem functioning by saproxylic species (Merckx et al., 2012), impacting upon plant growth through larval feeding activity, acting as pollinators and providing food for a range of taxa such as birds, small mammals and bats (Fox et al., 2013).

Intensified silvicultural practices have been suggested as one major driver of the decline in moth diversity and abundance (Fox et al., 2013). However, most studies have only focussed on the negative effects that a reduction in traditional deciduous forest management practices has had on lepidopteran species, and have not considered the role that non-native plantations may play. Reductions in deciduous forest management techniques such as coppicing and opening up rides have resulted in lower moth diversity by increasing structural complexity and changing botanical communities (Fox et al., 2013; Merckx et al., 2012; Warren and Bourn, 2011). In general, moths associated with deciduous trees have declined throughout Europe, with larval host plant specificity a key factor in extinction likelihood in parts of Scandinavia (Mattila et al., 2006; Franzén & Johannesson, 2007), whilst species associated with conifer trees have increased (Fox et al., 2013). Our current knowledge of moths in non-native coniferous plantations comes largely from studies which have focused on the management of pest species, and to the best of our knowledge no research has explicitly explored moth community composition and the impacts of forest management in exotic plantations.

Whilst little is known about the impacts of timber harvesting on Lepidoptera in non-native plantations, studies in native hardwood forests have suggested that effects are largely negative. In Indiana and Ohio, Summerville and Crist (2002, Summerville, 2014) demonstrated that clear felling in native hardwood forests disrupted moth communities beyond the stand being felled, limiting the diversity of species able to persist within the landscape. Impacts of timber harvest on Lepidoptera can persist for up to 60 years (Summerville et al., 2009), although Summerville (2013) suggests that less intensive practices such as shelterwood harvest (removal of 15% standing wood) may support a higher richness and abundance of moth communities. In native conifer forests in Oregon, moth dominance and diversity was associated with greater canopy cover whereas richness was only affected by elevation, with higher species richness at lower elevations (Ober & Hayes, 2010). These studies from North America demonstrate that managed native forest systems can support diverse lepidopteran communities, but the extent to which this is true in managed non-native plantations has not yet been examined. Specifically, in this study we aim to assess the impact of the following on moth abundance, richness, diversity and dominance in conifer plantations:

1. Influential, local scale plantation characteristics (e.g. age of planting, ground cover);
2. Proximity and prevalence of clear felling in the surrounding landscape;
3. Proximity and prevalence and of broadleaf tree cover within the surrounding landscape.

Since declining moth species might respond differently to the wider moth community, we examined the impacts of the above characteristics for moth communities as a whole, and separately for priority biodiversity action plan (BAP) species. These are formerly widespread and common species which have undergone population declines of between 70% and 90% in the last few decades, and as such are of particular scientific interest (Fox et al., 2013).

2. Methods

The study was conducted in three plantation forests in Central and Southern Scotland and Northern England (Fig. 1). Widespread deforestation had already occurred in this area by the Holocene; prior to the planting of the plantations in 1920–1940, the sampling areas would have consisted of open, upland moorland predominantly used for sheep grazing, with small patches of remaining broadleaf. The three forests were chosen for their large size (ranging from 30,000 ha in Cowal and Trossachs to 60,000 ha in Kielder and 114,000 ha in Galloway), high productivity and the predominance of *Picea sitchensis*, the most commonly planted and intensively managed coniferous tree species in the UK, and a common plantation tree species in Europe (Boye and Dietz, 2005). Within each forest, multiple sites, a minimum of 4 km from each other, were selected using a Forestry Commission sub-compartment database within a Geographic Information System (GIS) (ArcMap 10.1, ESRI) based on stand (a unit of plantation management) age and species composition (Fig. 1).

In total, seven sites were surveyed in Cowal and Trossachs, 12 in Galloway Forest and 12 in Kielder Forest. Where possible a stand of trees at each management stage was selected in each site, which was a maximum of $2km^2$ in size. Not all sites had all stands of each management age resulting in an unbalanced design of between four and six stands per site and a total of 285 stands across 31 sites. See supplementary data (4) for a description of the different stand types.

2.1. Invertebrate trapping

Each site was surveyed for one night. Moths were trapped using portable 6 W heath light traps using E7586 9″ actinic tube lights, powered with 12 V batteries which were activated 15 min after sunset and switched off after 4 h (approximating the duration of the shortest night in the study area). This ensured that species flying at dusk and during the night were surveyed regardless of night duration. Species flying at dawn would most likely be missed as traps were often turned off before dawn. Surveys were only conducted on nights that were above 8 °C in temperature and wind speed of less than Beaufort 4, and were randomised as far as possible during the survey season between the different geographical areas. We recognise that surveying each site only once provides a coarse estimate of local moth assemblages; however, we are primarily interested in comparisons between stand types to identify potentially influential characteristics, which requires a large sample size. This same approach has been used to identify the influence of woodland characteristics on species richness, diversity and abundance of moth populations in both agricultural and urban landscapes (Fuentes-Montemayor et al., 2012; Lintott et al., 2014). In addition,