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Can mixed stands of native and non-native tree species enhance diversity of epigaeic arthropods in plantation forests?

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ABSTRACT

In regions with low cover of natural forests and high cover of plantations predominately comprised of non-native species, inclusion of a native tree species with a more productive non-native species has the potential to enhance biodiversity and meet production goals. In this context, we tested the alternative hypotheses that: (i) equitable mixes of a non-native and a native tree species support greater diversity of ground-dwelling arthropods than single species stands; or, (ii) native ash stands support greater diversity of ground-dwelling arthropods than mixed or single species stands that include a non-native conifer species. Active epigaeic spiders (Araneae) and beetles (Coleoptera: Carabidae, Staphylinidae) were sampled using pitfall traps in three forest types in Ireland: single species stands of non-native Norway spruce (*Picea abies*) or native ash (*Fraxinus excelsior*), and mixed stands of these species.

Stands of Norway spruce did not negatively influence spider and staphylinid diversity, suggesting that they maintain a similar range of biodiversity to mixed plantations or stands of native ash. However, carabid beetle richness (but not abundance) was negatively affected by the presence of spruce suggesting caution when drawing conclusions about biodiversity impacts from single taxon studies. We found that equitable mixes of spruce and ash supported many species associated with native ash stands. Thus, we recommend that mixes with an equitable species ratio (e.g. 50:50) and containing a native species will enhance epigaeic arthropod diversity and heterogeneity in plantations. Furthermore, our finding that ash stands supported greater beta diversity than spruce stands supports current guidelines that recommend a range of stand types, including native species, to enhance diversity within and between stands.

1. Introduction

Encouraging development of mixed species forests has been proposed as a way of mitigating the negative impacts on biodiversity of environmental changes associated with intensification of wood production or climate change (Pawson et al., 2013; Bravo-Oviedo et al., 2014). In contrast to single species stands, mixes more effectively support (1) ecosystem functions, including nutrient cycling and soil processes, than do single species stands (Guckland et al., 2010; Brassard et al., 2013), (2) a greater capacity for pest control by natural enemies (Jactel et al., 2005; Knoke et al., 2008), and (3) a greater range of associated species (Butterfield and Malvido, 1992; Felton et al., 2010). These benefits may enhance ecosystem health and resilience (Knoke et al., 2008) as well as commercial yield (Mason and Connolly, 2013), and this has led to forest policies promoting diversification of tree species at stand, landscape and regional scales (Forest Service, 2000; European Commission, 2006; Forestry Commission, 2011).

Mixed species forests support biodiversity through provision of a wider range of resources and available niches, and typically have greater habitat heterogeneity than do single species stands (Saetre et al., 1997; Aubert et al., 2005; Cavard et al., 2011). This is important for organisms directly associated with particular tree species (Király and Ódor, 2010) but also may benefit those depending on characteristics of particular single species stands, such as light availability or soil quality (Cavard et al., 2011). Consequently, the influence of mixed stands on forest biodiversity likely results from the combination of the particular tree species present and the variety in resources they provide, rather than simply from increasing the number of tree species (Vehviläinen et al., 2007; Schuldt et al., 2011).

In the context of plantation silviculture, mixes of tree species are typically employed to enhance productivity of the commercial

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crop through amelioration of temperature or wind extremes or improved soil conditions (Kerr et al., 1992; Mason and Connolly, 2013). Recent research, however, has also focused on the capacity of mixed stands to provide benefits in terms of ecosystem function, resilience and species conservation (Knoke et al., 2008). This may be particularly important in regions with low cover of natural forest, in which plantations including non-native tree species also support native biodiversity associated with natural stands (Brockerhoff et al., 2008; Coote et al., 2012; Irwin et al., 2013, 2014; Graham et al., 2014). Furthermore, in countries such as Ireland or the UK where cover of natural forests is much lower than that of non-native plantations (⩽5% of forested area) (Watts, 2006; Forest Service, 2007), inclusion of native tree species in mixed plantations may enhance populations of flora and fauna associated with native tree species.

Mixed plantation forests are established at several spatial scales: at the stand level, by planting 'intimate' mixes of alternate tree species in rows, or at larger scales, by establishing a mosaic of single species in 'non-intimate' mixes within a forested landscape (Forest Service, 2000). However, whilst there is evidence that the latter policy leads to overall enhancement of biodiversity in such plantations (Oxbrough et al., 2005; French et al., 2008; Coote et al., 2012), there is little evidence that the intimate mixes established under current planting guidelines (Forest Service, 2000), offer biodiversity benefits (Oxbrough et al., 2012; Coote et al., 2012; Barsoum et al., 2013). In such intimate mixes the secondary species appears to have minimal impact on canopy or understory conditions (Oxbrough et al., 2012). Nonetheless, there is some evidence that more equitable mixes (40–60% of each species) can support greater biodiversity within plantations (Li et al., 2012; Barsoum et al., 2013), although this has yet to be explored at a large scale.

In this context, we use arthropods as a model to indicate whether equitable mixes of two tree species, non-native Norway spruce *Picea abies* (L.) Karst and native Ash *Fraxinus excelsior* L., can enhance forest biodiversity relative to that in single species stands of either species. Arthropods are a key component of biodiversity in forest ecosystems and have been used in many studies to indicate responses to environmental change and inform forest management in plantations (Oxbrough et al., 2005, 2010, 2012; Mullen et al., 2008; Barsoum et al., 2013). We selected three taxonomic groups of epigaeic arthropods, spiders (Order: Araneae), and carabid and staphylinid beetles (Order: Coleoptera, Families: Carabidae, Staphylinidae), for study. Together these taxa represent major functional groups (predators, omnivores, fungivores and saprophages), have the advantage of being relatively well studied (in comparison with other invertebrate taxa) and are effectively sampled by the same method (Thiele, 1977; Bohac, 1999; Pearce and Venier, 2006). Here we test the following alternative hypotheses:

1. *Equitably mixed forest stands will support greater species richness and beta diversity than monocultures, will be characterised by the lower dominance, and will support species associated with each tree species*. Mixes will support species common to both single species stands, including specialist species associated with native ash forests, resulting in greater diversity. An intimately mixed plantation forest, in which both species are planted alternately in the same row, rather than in discrete patches of the same species, will result in greater beta diversity within stands than in either single species stand.
2. *Native Ash stands will support greater species richness and beta diversity than Norway spruce stands, will have the most distinct arthropod assemblages and the lowest dominance compared to both plantation forests*. In Ireland there are no native spruce species and only three native conifers (yew *Taxas baccata* L., juniper *Juniperus communis* L., Scots pine *Pinus sylvestris* L., (but see Roche et al., 2009)), as such there will be more species associated with single species stands of native ash than those containing up to 40–60% non-native spruce. Further, evenness will be greatest in ash single species stands, intermediate in mixes and lowest in spruce stands.

2. Material and methods

2.1. Study sites

Mixed stands of non-native Norway spruce (*P. abies*) (hereafter referred to as spruce) and native ash (*F. excelsior*) and single species stands of each of these species were selected for study in Ireland. These species are commonly found as mixtures in mature stands in Ireland. Candidate stands were selected from national forest databases of planting records, and chosen for study after ground-truthing site visits. The precise ratio of ash to spruce in mixed stands was estimated by walking five equally-spaced 100 m transects, separated by at least 30 m, and counting the stems of all tree species encountered. Mixed stands with between 40% and 60% ash, and which met the criteria outlined below, were selected for study; all were 'intimately mixed' with individuals of each tree species were planted together on a small scale.

A randomized complete block sampling design was used (Quinn and Keough, 2002). One plantation of each forest type (ash, mixed and spruce) was located in each of five sampling clusters (Table 1). These clusters were located within 40 km of each other to ensure similar climatic conditions and stands included within them were matched, in so far as possible, for site-specific characteristics such as tree development, site history, soil type, elevation and slope (Table 1). Single species stands of spruce and the mixes were at normal 'commercial maturity' and were matched for tree age as well as development and thinning within clusters. In all but one case, the origin of ash stands (planted or naturally regenerated) could not be determined from records. However, stands were chosen to best match development of trees in pure ash to those in mixed stands within each cluster of sites, and thus we presumed they were likely naturally regenerated following forest clearance at similar times. All stands were located on old woodland, as defined by continuous forest presence on 1840s and 1920s historical maps. This minimised possible impacts of prior land use.

2.2. Arthropod sampling

In each stand three sampling plots were established in representative areas that were >50 m from the stand edge and >50 m apart. Active epigaeic arthropods were collected using pitfall traps. A transect of five pitfall traps of 7 cm diameter by 9 cm depth were set 1–2 m apart in each plot. Traps contained c. 2 cm depth of ethylene glycol to kill and preserve the arthropods sampled. Pitfall traps were operated continuously for 12 weeks from early May 2012 to late July over the main spring-summer growing period, and emptied once every three weeks. Arthropods collected in the traps were stored in 70% ethanol and identified using Roberts (1993) for spiders, Luff (2007) for carabids and the sources listed in Supplementary Table S1 for staphylinids. Nomenclature follows the World Spider Catalog (Natural History Museum Bern, 2015), Luff (2007) and Duff (2012). Specimens from the staphylinid subfamily Aleocharinae were not identified since adequate taxonomic literature was not available. Voucher specimens are stored in the Edge Hill University Biology Department museum collection.