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The influence of forest management systems on the abundance and diversity of bark beetles (Coleoptera: Curculionidae: Scolytinae) in commercial plantations of Sitka spruce

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ABSTRACT

Sitka spruce is the most widely planted conifer tree species in the UK, and is generally grown in dense monocultures managed using the clear-cut system. This study investigates the influence of alternative management systems (shelterwood and selection systems) on captures of bark beetles and associated predators. Bark beetle abundance was significantly lower in stands managed by shelterwood and selection systems when compared to mid (21–40 years old) and mature (≥41 years old) stands managed by the clear-cutting method. The abundance of bark beetles, including individual species, within plots could not be fully explained however, using linear mixed model analysis that not only included the various site characteristics assessed within each plot (numbers of live and dead trees), but also the numbers of predatory beetles (Rhizophagidae and Salpingidae). This suggested that the influence of management type on bark beetle abundance was not entirely due to the bottom-up or top-down forces that were assessed in the study, and that other abiotic and/or biotic factors were likely to be influential. Bark beetle diversity was also influenced by the management system, however higher diversity values within some group selection managed plots were only apparent in circumstances when stands of Sitka spruce had been managed using this system for a considerable period of time, and the habitat had remained undisturbed for a relatively long period of time (i.e. no harvesting interventions). Significantly higher numbers of predatory beetles were captured within the mid and mature clear-cut managed stands. The results from the study indicate that adopting alternative management systems to manage Sitka spruce in the UK could be a potential strategy to mitigate likely increases in bark beetle populations associated with climate change.

1. Introduction

The bark beetles (Curculionidae: Scolytinae), together with other saproxylic insects and fungi, are key components of forest ecosystems and are important decomposers and nutrient recyclers (Goheen and Hansen, 1993). Primary bark beetles, those that colonize and kill live trees, are some of the most destructive insect pests in managed and unmanaged forests globally, having the potential to not only cause significant losses in forest productivity, but also widespread tree mortality (Christiansen and Bakke, 1988; Wermelinger, 2004; Raffa et al., 2008; Bentz, 2009). In Europe there are relatively few bark beetle species that are regarded as serious pests, the majority are secondary pests feeding and reproducing in dead and dying trees, and they rarely cause significant damage or losses, especially to live trees (Gregoire and Evans, 2004; Sauvard, 2004). However, maintaining a diverse bark beetle community within forest ecosystems is important since they play an essential role in the decomposition of harvesting and thinning residue and fulfil a vital function as forest nutrient recyclers (Goheen and Hansen, 1993). Within the UK the abundance and diversity of bark beetles particularly in conifer forest plantations, and the extent of damage and tree mortality that they cause is relatively unknown. Within stands of Sitka spruce (*Picea sitchensis* Bong. Carr.) the only primary bark beetle of concern in the UK is the great spruce bark beetle (*Dendroctonus micans* Kugelann), but its distribution is scattered and there have been very few recorded outbreaks that have led to significant tree mortality (Forestry Commission, 2012). The only other notable primary bark beetle

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that may pose a threat to Sitka spruce is *Ips typographus* (L.), but there is currently no known *I. typographus* populations in the UK, even though it has been intercepted at numerous locations on many occasions it has not become established (Forestry Commission, 2015).

Whilst most UK bark beetle species are not regarded as having any significant pest status, and considered of little economic importance, it is difficult to predict which species might become of more potential significance under a warming climate change scenario. Secondary bark beetles have been observed attacking healthy trees far more frequently, presumably in response to changing climate patterns, particularly increased drought periods (Kühnholz et al., 2001; Grégoire et al., 2001). Changing climate patterns may make current forest ecosystems, particularly coniferous monocultures, more vulnerable to insect pest outbreak events, and may favour the development of epidemic populations of certain species of bark beetles (Raffa et al., 2008). The outbreaks of the mountain pine beetle, *Dendroctonus ponderosae* (Hopkins) in North America demonstrate how a warming climate can lead to outbreak populations, leading to high rates of tree mortality and range expansion into previously unfavourable environments (Carroll et al., 2003; Bentz et al., 2010).

Sitka spruce is by far the most widely planted and the most commercially important conifer tree species planted in the UK. Coniferous woodland in the UK currently covers around 1.308 million hectares, and of this some 665,000 ha, is planted with Sitka spruce (Forestry Statistics, 2015). This exotic tree species, which is native to North America, is very much suited to the north and west of the UK due to the high annual rainfall in these locations. It is generally planted in even-aged, single species stands and managed principally using the clear-cutting silvicultural system (Hibberd, 1991). Coniferous monocultures are generally regarded as being poor structurally, lacking in biodiversity and highly susceptible to pest, pathogens and climate change (Koricheva et al., 2006; Jactel and Brockerhoff, 2007; Brockerhoff et al., 2008). Over the past couple of decades however, there has been increasing pressure to promote sustainable forest management, which includes utilising alternative silvicultural systems to improve the spatial heterogeneity and hence biodiversity of coniferous plantation forests in the UK. In recent years the development and use of alternative silvicultural systems, protection of trees against pests and diseases, and the maintenance of biodiversity within managed forests have become key policy objectives within UK forestry (Forestry Commission, 2014). The UK Forestry Standard (UKFS) and the UK Woodland Assurance Standard (UKWAS) promote the use of alternative silvicultural methods where suitable, to enhance forest structure and biodiversity, and to ensure the future resilience of forests to pests and diseases (Forestry Commission, 2011; UKWAS, 2012). Similarly the policy of the Welsh Assembly Government in their strategy for woodlands and trees highlights the need to avoid clear-felling and adopt alternative management systems where they would make a better contribution to ecosystem services (Woodlands for Wales, 2009).

From a UK perspective there is a need to ensure forest ecosystems are resilient to the potential negative affects of climate change particularly drought, flooding, and extreme events such as storms and windblow events. Drought events in particular are likely to stress forest trees making them more susceptible to attack by insect pests such as bark beetles (Bentz et al., 2010; Kolb et al., 2016). One potential method of ensuring that stands of Sitka spruce are more resilient may be to adopt alternative management systems within these coniferous forests rather than utilising the current clear-cutting system, since more spatially heterogeneous forests are likely to be more resilient to a changing climate (Brang et al., 2014). However, whilst the use of alternative management systems, are likely to increase the structural complexity of forest stands, there is still very little information on how insect/invertebrate communities might respond to these changes in forest management.

Stand structural complexity has not only been identified as a key determinant of biodiversity, but essential for forest biodiversity conservation (McElhinny et al., 2005; Lindenmayer et al., 2006). Spiecker (2003) and Kerr (1999) highlight how the use of silvicultural systems, which would lead to improvements in stand structure, might be utilised to enhance biodiversity within plantation forests in Europe and Britain. However, whilst there is an increasing emphasis on the merits of increasing structural complexity to enhance biodiversity, there are very few studies that have investigated whether increasing stand structural complexity influences the population dynamics of insect pests, particularly bark beetles, within forest plantations (Seidl et al., 2008; Björkman et al., 2015). Numerous silvicultural approaches have been utilised in an attempt to manage defoliating insects and bark beetles (Muzika and Liebhold, 2000; Fettig et al., 2007; Jactel et al., 2009; Fettig and Hilszczański, 2015), and many studies support the observation that thinning operations can influence the population dynamics of bark beetles, and the rates of bark beetle-induced tree mortality, in a variety of forest types (Fettig et al., 2007 and references therein). Whilst most of the studies on the effects of thinning operations have been conducted in North American pine forests, these studies have generally demonstrated that thinning has an immediate effect on increasing tree vigour and altering stand micro-climate (Fettig et al., 2007 and references therein). Stands that have a high tree density have often been associated with the occurrence of bark beetle outbreaks, since trees growing in these conditions tend to be stressed due to the intense competition for limited resources. Trees growing at high densities in unmanaged stands tend to have diminished vigour and reduced resistance mechanisms against bark beetle attack (Mitchell et al., 1983; Christiansen et al., 1987). Hence, trees with low vigour are generally considered to be at a greater risk of being attacked by bark beetles leading to subsequent tree mortality (Sartwell, 1971; Larsson et al., 1983; Schroeder, 1987). Thinning stands causes changes in tree physiology that generally lead to increases in tree vigour and decreased competition between residual trees, which reduces tree mortality caused by bark beetles, and ultimately leads to lower bark beetle populations (Nebeker and Hodges, 1983; Fettig et al., 2007). Thinning operations also tend to cause changes in stand micro-climate, altering among other factors the amount of incident radiation, temperature, light and wind speed, which may adversely effect bark beetle populations (Bartos and Amman, 1989). However, thinning stands also creates fresh slash material (coarse woody debris), stumps, and causes injury to other trees, all of which some bark beetle species are attracted to. Additionally the micro-climate can actually improve in some instances to favour bark beetle development (Hindmarch and Reid, 2001).

The aim of the current study therefore had several objectives, one of which was to determine whether utilising uniform shelterwood and group selection systems in monoculture stands of Sitka spruce, as an alternative to the current clear-felling management system effected bark beetle abundance and diversity. We also investigated whether some of the key predators of bark beetles in stands of Sitka spruce (the Rhizophagidae and Salpingidae) were influenced by the management system evaluated. The study also provided an opportunity to gather information on the bark beetle community composition within the UK's most widely planted non-native conifer. This is important for establishing whether alternative management strategies might need to be adopted in the future to mitigate against a changing climate that might favour increased bark beetle development, and which could shift endemic populations to epidemic levels leading to wide-scale outbreaks (Berryman, 1982; Raffa et al., 2008; Bentz et al., 2010).