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Can ground-based assessments of forest biodiversity reflect the biological condition of canopy assemblages?

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ABSTRACT

Biological assessments of forest systems often involve a single ground-invertebrate sampling method that may ignore the biological component of the non-sampled canopy. Pitfall trapping for ground-active arthropods is a widely implemented technique for biological assessment in forested and open habitats. Although much evidence highlights the biases of pitfall trapping, this evidence typically comes from open-habitat crop and grassland systems. In forest systems where much of the biodiversity is found within the above-ground structure, management recommendations based solely on ground sampling may not represent the diversity within the three dimensional forest habitat. We provide evidence from combined ground and canopy sampling of three major forest types within the study region. We use canopy insecticide fogging to compare with more traditional ground-based pitfall trapping, and use spiders as a comparative species-rich biota that is able to colonise most terrestrial habitats and is strongly affected by changes in environmental condition.

We identified 3933 spiders from 109 species from the 18 forest patches sampled. Both types of sampling defined differences in community composition between forest types in a similar manner; hence, either method could be used to evaluate differences or test management regimes in well-replicated experiments of forest type. However, the association in community composition between ground and canopy assemblages at the individual site-based level was weak; we found low correlation between the two data sets indicating that surrogacy between methods was not supported at this level. Furthermore, disparities in spider habitat association, body size, hunting guild and vertical stratification of spider families indicates that where detailed species and family-based information is required, or if inventorying is necessary, then multiple targeted surveys are essential.

1. Introduction

Biodiversity must be sampled in a way that fits research questions but also meets time and financial budgets. Often these constraints lead to the use of a single survey procedure to derive data with which to draw conclusions that inform policy and management. This leaves questions regarding the consistency of those conclusions if an alternative sampling strategy had been chosen. In complex systems, such as forested landscapes, the three-dimensional structure poses problems for capturing representative samples across vegetation layers (Pinzon et al., 2011). The importance of forest systems (Ozanne et al., 2003), coupled with the potential of sample bias, means there is a growing need to validate sampling strategies to strengthen management recommendations based on these single survey practices.

Arthropod diversity is frequently used to assess biological condition in applied forest research (Spence et al., 1996; Berndt et al., 2008; Pedley et al., 2014) and more fundamental aspects of ecology, including fragmentation and disturbance (Vasconcelos et al., 2006; Pedley and Dolman, 2014). New DNA barcoding techniques (Yang et al., 2014), which negate the often laborious taxonomy associated with arthropod sampling, are enabling quicker processing times that may proliferate the use of arthropod monitoring (Ji et al., 2013). However, conventional taxonomic and many contemporary DNA barcoding techniques rely on traditional invertebrate collection methods. One of the most commonly employed

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sampling techniques for epigaeic arthropods is pitfall trapping. Pitfall trapping provides a passive means of surveying that, once established, can continuously trap active species with only brief visits needed to service traps. Although pitfall trapping has a long history in ecology, its ability to provide non-bias sampling of habitat has been brought into question (Topping and Sunderland, 1992; Lang, 2000). Pitfalls by their nature target active ground-dwelling species, and can underrepresent less mobile, small-bodied species and species typical of higher strata (Greenslade, 1964; Lang, 2000; Standen, 2000). Furthermore, pitfall catches are a representation of animal density, conditional on animal activity; if activity is disproportionally affected by vegetation structure, shading or animal interactions between sites, then catches may not be comparable (Greenslade, 1964; Melbourne, 1999). Where environmental conditions are similar, comparisons across sites are suitable as long as pitfall trap data are used as an index of the density based on activity and not a species inventory of the sampled habitat (Luff and Eyre, 1988; Oxbrough et al., 2006).

Much of the available methodological literature concerning pitfall trap bias comes from crop and grassland studies (e.g. Topping and Sunderland, 1992; Standen, 2000). However, extensive arthropod monitoring of closed-canopy forests has been conducted with ground-based methods (e.g. Docherty and Leather, 1997; Oxbrough et al., 2005; Berndt et al., 2008). Many studies of this nature make comparisons between the arthropod biodiversity of different forest types with inherently different ground, understory and canopy structures (Fuller et al., 2008; Barsoum et al., 2014). Although such studies do not imply that pitfall trapping will reveal the biodiversity related to the entire three-dimensional structure of the forest, there are few studies that can elucidate the non-sampled aboveground component of forest biodiversity in a similar manner to the methodological papers concerning crop and grasslands (but see Pinzon et al., 2011). This problem of the non-sampled biodiversity is perhaps more significant within forest systems as forest canopies contain a large proportion of the total arthropod diversity on Earth (Erwin, 1982; Lowman and Wittman, 1996).

While canopy sampling is considerably more challenging than many ground sampling methods due to the difficulties in accessing tree canopies, ground-based insecticide fogging can negate these access problems. Insecticide fogging of canopy-dwelling species has proven a reliable survey method but has received less consideration in temperate and boreal zones than in tropical regions. Canopy fogging has proven an effective way to sample temperate canopy invertebrates and to measure biodiversity patterns within single species, across temporal dynamics and between forest types (Southwood et al., 2005; Hsieh and Linsenmair, 2012; Pedley et al., 2014). However, fogging is limited by weather conditions, with at least several hours of dry, still weather required for successful sampling. This method may also overlook some species such as aphids or other phloem feeders (Stork and Hammond, 1997), or those within certain life stages, such as within cocoons, retreats or burrows and those attached by silken threads. While these sampling biases will affect inventorying canopy invertebrates in much the same way as pitfall trap biases do for ground-based invertebrates, it is likely that standardised canopy fogging will allow for comparisons to be made across sampled forest sites.

Among the arthropod groups frequently investigated in ecological surveys, spiders provide an effective means of habitat assessment as they are greatly affected by changes in habitat structure (Duffey, 1968; Robinson, 1981) and respond quickly to brief or sudden changes in environmental conditions, such as variations in prey density, pesticides, or pollution (Marc et al., 1999). Spiders are a species rich group and, being one of the top macro-invertebrate predators, have strong influences in food webs (Wise, 1993; Schmitz et al., 2000). Differences in spider community assemblages within forest types have often been attributed to differences in habitat heterogeneity (Pinzon et al., 2011; Pedley et al., 2014). The assemblage composition of the forest-floor is influenced by light availability, volume and decay stage of debris, moisture and temperature (Ziesche and Roth, 2008); while canopy leaf/needle density and branch architecture has been shown to influence community composition above the ground layer (Gunnarsson, 1992; Halaj et al., 2000). Although some understanding of the factors influencing community composition in these habitats exists, we do not yet know if common sampling techniques differentially interpret community dissimilarities between forest types.

In the current study, we selected three distinctive forest types that were likely to vary in spider composition, semi-natural ash (*Fraxinus excelsior*) forests, semi-natural oak (*Quercus petraea*) forests and Sitka spruce (*Picea sitchensis*) plantations. We did not attempt to directly compare species richness or abundance between canopy and ground trapping, as sampling effort is not consistent between the two methods. Rather, we examined whether there is correspondence between the two methods for defining differences in assemblage structure between the three forest types. For each of the following hypotheses we looked for idiosyncratic and corresponding changes in biodiversity structure across forest types for the ground and canopy sampling techniques. (1) Assemblages sampled in the canopy and the ground differ similarly between the forest stands and forest types. (2) Patterns of hunting guilds (active and web spinners), habitat specialism (woodland and generalist), and body size will be inconsistent across forest types for ground and canopy sampled assemblages. (3) Spider families will show vertical stratification between ground and canopy sampling. Finally, we discuss whether there is possible surrogacy between ground and canopy methods. This is one of the first studies to compare and interpret forest biodiversity obtained from canopy and ground trapped invertebrate assemblages.

2. Methods

Three closed-canopy forests types were sampled across Ireland (Appendix A); six ash (*F. excelsior*) dominated semi-natural woodlands, six oak (*Q. petraea*) dominated semi-natural woodlands and six second-rotation Sitka spruce (*P. sitchensis*) plantations (hereafter referred to as ash forest, oak forest and spruce plantation, respectively). All stands were a minimum of 6 ha in size and 100 m in width. Sitka spruce plantations were selected as they are the dominant species in the Irish forest estate, comprising approximately 60% of the forest cover and are a non-native species (Forest Service, 2007). Ash and oak forests were selected as they are the most common native tree species in Irish semi-natural forests, comprising 22% and 18%, respectively (Higgins et al., 2004), and were expected to have contrasting biodiversity to spruce plantations. The semi-natural forest types considered in this study comprised a mix of tree species, i.e. oak-dominated forests included oak, birch and holly, while ash-dominated forests included ash, oak and hazel. Semi-natural ash and oak forests were at least 150 years old, whereas sampled spruce plantations ranged from mid rotation 20–30 year old closed-canopy stands to 60-year-old commercially mature stands.

2.1. Canopy sampling

Canopy fogging was conducted once at each of the 18 study sites. In each sampled forest stand a fogging plot was established in a representative area of the site in terms of stand structure and vegetation cover. A target tree was selected at the centre of each fogging plot that corresponded to the forest type being