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Effects of woodland restoration and management on the community of surface-active arthropods in the metropolitan Chicago region

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ABSTRACT

Restoration of woodlands that have been invaded by exotic plants has primarily focused on restoring vegetation structure by removing invaders and planting native species that have declined in abundance. Management practices to date continue to focus on plant communities, but if restoring ecosystem integrity is the goal of restoration, knowledge of how the fauna has recovered is essential. We examined the impact of vegetation restoration and management on the surface-active arthropod community across a spectrum of 22 woodland sites in the greater metropolitan Chicago region. Sites were grouped into three categories based on existing condition. Invaded sites had never been restored or managed ("*Control*", $n = 5$); had been undergoing restoration for 3–21 years ("*Managed-int*", $n = 12$) but were not yet near the management goal; or were restored plots (11–21 years of management) that land managers identified as representative of their restoration target based upon the vegetation present ("*Managed-REF*", $n = 5$). Each site was a one-ha plot containing four pitfall traps used to assess activity-densities of 35 taxa of epigeic arthropods. Permutational analysis of variance (PERMANOVA) and subsequent canonical analysis of principal coordinates (CAP) revealed that arthropod community structure varied between *Control* and *Managed-REF* sites, with the *Managed-int* sites demonstrating convergence toward the *Managed-REF*. The activity-densities of non-native isopods (detritivores) were nearly twice as high in *Control* sites compared to *Managed-REF* sites, whereas traps in *Managed-REF* sites had four times the number of Collembola (fungivores). Distance-based redundancy analysis (dbRDA) revealed that invasive woody plant cover and rates of uptake of soil P and NO_3^- by root simulators explained over 40% of the variation in arthropod community structure. Our findings suggest that restoration management targeted at the vegetation also restores the arthropod community in woodlands to a composition that has fewer non-native arthropods.

1. Introduction

Invasive plants have been a major cause of habitat degradation worldwide (Vitousek et al., 1997; Powell et al., 2011). Invasive plants can impact communities by altering nutrient cycling and availability (Ehrenfeld, 2003; Weidenhamer and Callaway, 2010), changing disturbance regimes (Mack and D'Antonio, 1998; Brooks et al., 2004), or by outcompeting the native plant community (Callaway and Aschehoug, 2000; Brown et al., 2002). As a consequence, the impact of invasive plants has been regarded as one of the most important global-scale factors threatening natural communities (MacDougall and Turkington, 2005; Moser et al., 2009).

In response to habitat degradation by invasive plants in the Chicago region, the Chicago Wilderness conservation alliance created its Biodiversity Recovery Plan as a guide "to sustain, restore, and expand the remnant natural communities of the Chicago region" (Chicago Wilderness Biodiversity Council, 1999). Restoration strategies utilized by agencies that are part of Chicago Wilderness usually include invasive plant removal, native replanting, and the implementation of prescribed burning, with the primary goal being to restore the composition and diversity of native trees, shrubs, and herbaceous vegetation (Wallis De Vries et al., 2002; Wagner et al., 2004; Knapp, 2010). Such management strategies, while comprising a vital step toward the restoration and preservation of natural communities in urbanized areas, must be reinforced by fundamental understandings of how the entire

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ecosystem responds to management (Morris, 2000; Wallis De Vries et al., 2002; Woodcock et al., 2005).

Epigeic (i.e. surface-active) arthropods are major components of the belowground food web (Coleman and Hendrix, 2000), and because they are active on the soil surface, also provide a link to aboveground food webs (Bardgett and Wardle, 2010). Surface-active arthropods are important players in litter decomposition, with implications for nutrient cycling (Swift et al., 1979; Petersen and Luxton, 1982; Seastedt, 1984; Lawrence and Wise, 2004). For example, Chamberlain et al. (2006) illustrated that springtail (Collembola) activity caused greater availability of carbon to the soil microbial community. Pieper and Weigmann (2008) demonstrated higher mobilization of several nutrients, such as litter-derived organic carbon, in the presence of isopods. A number of other studies have also demonstrated that soil fauna break down complex litter substrate and further release nutrients into the soil (Ayres et al., 2009; Carrillo et al., 2011; Bokhorst and Wardle, 2013), thus influencing rates of nutrient cycling in terrestrial ecosystems.

Recent studies have documented changes to epigeic arthropod diversity and community composition following the implementation of restoration techniques, but the pattern of results is mixed. For instance, Coleman and Rieske (2006) demonstrated that repeated prescription burns in an oak-pine forest in southeastern USA decreased the overall abundance of leaf-litter arthropods. Longcore (2003) found that replanting native vegetation in a sage scrub in southern California resulted in lower arthropod abundance and diversity compared to invaded plots – an unexpected result. Other studies have found that arthropod diversity and community composition are affected by particular restoration/management procedures, including prescribed burning (Morris, 1975; Hanula and Wade, 2003), invasive-plant removal (Gratton and Denno, 2005; Emery and Doran, 2013), and replanting native vegetation (Samways et al., 1996; Magoba and Samways, 2012).

Studies to date have examined the impact of a single management activity on epigeic arthropods, rather than examining the effects of a suite of restoration and management techniques – hereafter termed "comprehensive vegetation management". Land managers and restoration practitioners often practice a combination of techniques concurrently and rarely employ just one technique as a part of their management regime (Chicago Wilderness Biodiversity Council, 1999; Lindenmayer and Franklin, 2002; Knapp, 2010). Thus, in order to understand how restoration management directed at the plant community affects the entire ecosystem, it is important to have an understanding of the cumulative effects of comprehensive vegetation management on major ecosystem components such as the epigeic arthropod community.

Changes in both biotic and abiotic environmental factors will drive the response of epigeic arthropods to comprehensive vegetation management. Epigeic arthropod densities and community structure are affected, directly or indirectly, by soil characteristics, microclimate, depth and quality of leaf litter, and plant diversity and structure (e.g. Uetz, 1979; Bultman and Uetz, 1982; Samways et al., 1996; Haddad et al., 2001). Kappes et al. (2007) demonstrated that species richness of snails and woodlice decreased with decreasing soil pH. Average activity-densities of ground beetles (Carabidae), rove beetles (Staphylinidae), and spiders (Araneae) can be twice as high in soils richer in several nutrients (N, Ca, K, S, Mg, and P) (Mäder et al., 2002). Several studies have reported a positive relationship between epigeic arthropod diversity and floral species richness (Siemann, 1998; Knops et al., 1999; Haddad et al., 2001), or structural complexity of the vegetation (Schwab et al., 2002; Diehl et al., 2013).

The consequences of comprehensive vegetation management cannot readily be investigated through replicated, controlled experiments due to the large number of sites needed, the need to assign treatments at random, and the number of years required before conclusions could be drawn. We took advantage of one-ha sites that are part of a "natural experiment," the Chicago Wilderness Land Management Research Program (Heneghan et al., 2012) to investigate the degree to which comprehensive vegetation management has led to the restoration of the epigeic arthropod community in metropolitan woodland ecosystems. Our study compared communities of epigeic arthropods across a gradient of restoration and management efforts and outcomes. We asked two questions: (1) How does comprehensive vegetation management affect the community structure of epigeic arthropods? (2) Which biotic and abiotic environmental variables correlated with restoration and management activities potentially explain observed changes in the epigeic arthropod community?

2. Methods

2.1. Overview of sites and management categories

Sites were located in northeastern Illinois in the Chicago metropolitan region (Fig. 1), and represent a subset of plots that are part of the Chicago Wilderness Land Management Research Program (CWLMRP), a collaborative project between land managers and research ecologists. The CWLMRP has established over 100 one-ha long-term study plots that include remnant prairie, abandoned agricultural lands being restored to prairie vegetation, woodlands and savanna habitats. Sites were selected to represent a gradient of management efforts and success. Initial phases of the CWLMRP involved collection of baseline vegetation and soil-nutrient data; baseline data relevant to this study are reported here.

We sampled the epigeic arthropod community on 22 one-ha oak-dominated sites (*Quercus alba*, *Quercus macrocarpa*, or *Quercus rubra*) on which vegetation structure and composition are highly variable, ranging from dense understories of invasive shrubs to open savannas with scattered herbaceous vegetation (Table 1). A major restoration activity on these sites has been the removal of invasive shrubs such as *Rhamnus cathartica* (European buckthorn), *Lonicera* spp. (honeysuckle), *Berberis thunbergii* (Japanese barberry), and *Rosa multiflora*; and herbaceous species such as *Alliaria petiolata* (garlic mustard). These invasive plants present many challenges, most notably because high numbers of seeds are produced that can remain viable for many years.

At the inception of the CWLMRP, plots were selected by local land managers that could be placed into one of three categories reflecting management history and the managers' perceptions of site quality: *Control*, *Managed-int*, and *Managed-REF*. We selected a subset of CWLMRP sites to reflect these categories. *Control* sites ($n = 5$) were unmanaged, never restored, and considered by the managers to be degraded. These were generally dominated by invasive plants such as *R. cathartica*, *Lonicera* spp., *A. petiolata*, and *B. thunbergii*. Understories were usually homogenous, mainly composed of dense thickets of buckthorn and other invasive shrubs. *Managed-int* sites ($n = 12$) had been undergoing restoration and management for 3–21 years, and were currently being managed. The understory for these sites was highly variable, ranging from little or no herbaceous layer to dense layers of herbaceous vegetation (both non-native and native species). The *Managed-REF* category consisted of restored sites ($n = 5$) that land managers identified as representing high-quality woodlands for the region, with each site having <10% cover of invasive plants on average. These sites had been under active, long-term management for 11–21 years, and serve as examples of a target for restoration – hence their designation as "reference" sites. *Managed-REF* sites were characterized by an open understory with few or no