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Carabid beetle responses to herbicide application, shelterwood seed cut and insect defoliator outbreaks

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ABSTRACT

Managing forests to promote biodiversity requires understanding the effects of silvicultural practices on a range of forest species and communities. We evaluated carabid beetle (Coleoptera; Carabidae) responses to operational herbicide and shelterwood seed cut treatments in northern hardwood stands on the Allegheny National Forest, Pennsylvania, USA, from 1992 to 2000. There was substantial defoliation by elm spanworms (*Ennomos subsignarius* Hübner) or cherry scallopshell moths (*Hydria prunivorata* Ferguson) during four of the 9 years of this study, so we also evaluated effects of these lepidopteran outbreaks on carabids. We found no differences in carabid species richness between herbicide-treated and no herbicide plots overall or in any year, but carabid abundance was higher in herbicide-treated plots in the year following application. Carabid community composition differed among years and increased in dissimilarity over the course of the study but did not differ between herbicide-treated and no herbicide plots. Shelterwood seed cuts had no effects on carabid species richness, abundance or community composition. The relatively few significant effects of experimental treatments on individual carabid species tended to be small and responses we did find differed somewhat from previous studies. In 1992, carabid abundance was significantly correlated with elm spanworm defoliation and in 1995 both species richness and abundance were significantly higher in areas defoliated by cherry scallopshell moth. These results support previous findings that forestry practices that have relatively minor and short-term effects on forest vegetation are unlikely to have substantial effects on carabids; however, natural resource variation resulting from forest lepidopteran outbreaks may have important cascading effects for carabid communities that have not been fully explored.
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1. Introduction

Forests are increasingly managed for multiple and potentially conflicting objectives, including timber production and conservation of biodiversity (Perry, 1998). Balancing these goals, or at least making informed decisions regarding potential trade-offs, requires understanding relationships between forest management and the presence and abundance of species associated with forest habitats.

Herbicide application is a common and effective silvicultural practice for removing competing vegetation and promoting growth and survival of desirable tree seedling and saplings (Marquis, 1979; Horsley and Marquis, 1983; Horsley, 1994). In response to scientific questions, regulation, and public concern regarding non-target effects of herbicide use in forest management, numerous studies have evaluated their direct and indirect impacts on individual species and broader measures of biological diversity (Lautenschlager, 1993; Sullivan and Sullivan, 2003; Guynn et al., 2004; Tatum, 2004). The results of such studies vary widely depending on taxa studied, spatial and temporal scale of data collection, chemical formulation used and application frequency and method. However, most effects of herbicide application on animals are mediated through vegetation changes, and habitat use often recovers to pre-treatment levels within 5 years (Sullivan and Sullivan, 2003; Guynn et al., 2004).

Carabid beetles (Coleoptera; Carabidae) are diverse and amenable to study, and research on their responses to forestry practices and natural disturbances has produced abundant data regarding their ecology in managed forests (Work et al., 2008; Koivula, 2011). In general, natural or anthropogenic perturbations that alter habitat structure at large spatial scales (e.g., clearcuts, stand-replacing fire) are associated with the largest shifts in forest carabid communities (Buddle et al., 2006; Gandhi et al., 2008). Conversely, less intensive forest management practices (e.g., group selection, single tree selection, thinning) are usually associated with fewer and

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shorter-duration differences in carabid community composition (Koivula and Niemela, 2002; Ulyshen et al., 2006; Work et al., 2010). Many studies have found higher species richness in intensively managed forests than in old growth stands, and even recently cut or burned areas often have high carabid abundance and diversity due to tolerance of some forest species to disturbance combined with immigration of species that prefer open habitat conditions (Beaudry et al., 1997; Klimaszewski et al., 2005; Buddle et al., 2006). The overall increase in species richness resulting from forest management is often accompanied by population declines of forest specialist species, which may be of concern if carabids are recognized as indicators of forest change (Spence et al., 1996; Beaudry et al., 1997; Duchesne et al., 1999; Gandhi et al., 2008; Work et al., 2008). However, co-occurring carabid species frequently show divergent responses to forest management within studies (e.g., Duchesne et al., 1999; Gandhi et al., 2008; Iglay et al., 2012), demonstrating the importance of considering both community- and species-level effects.

Despite increasing use of herbicides in silviculture and publication of numerous studies evaluating carabid responses to a range of forest management practices, we know little about the effects of operational herbicide application on forest carabid communities (but see Iglay et al., 2012). Laboratory studies have found some direct physiological effects of herbicides on carabids (Kegel, 1989; Brust, 1990), but field studies in agricultural systems have mostly found relatively minor and short-term effects on behavior mediated indirectly through habitat alteration (Brust, 1990; Michalkova and Pekar, 2009). At least two studies that have examined effects of herbicides on carabids in forest systems did not include an appropriate control for identifying herbicide effects when not applied as part of another silvicultural practice (Duchesne et al., 1999; Cobb et al., 2007), making it difficult to interpret the results. Iglay et al. (2012) found community and species-specific effects of a single application of herbicide (imazapyr) on carabid communities in intensively managed pine plantations, suggesting that longer-term studies in a variety of systems are required to better understand the effects of operational herbicide use on forest carabids.

Our study was part of a multi-year experimental assessment of the effects of a single application of glyphosate and sulfometuron methyl on target and non-target taxa in a northern hardwood forest (Ristau et al., 2011; Stoleson et al., 2011). Carabid beetles were collected before, immediately following and for several years after herbicide treatment, allowing us to evaluate potential short-term effects and longer-term carabid community dynamics in herbicide-treated plots compared to untreated forest. Specifically, we examined potential differences in species richness, abundance, community composition and capture frequency of individual species. We also considered potential effects of shelterwood seed cutting and outbreaks of lepidopteran defoliators to better understand the relative importance of herbicide application and other potential sources of environmental variation for carabid community dynamics. Results of this study complement and connect previous research on effects of herbicide on forest biodiversity and effects of forest management practices on carabids.

2. Methods

2.1. Study sites and experimental design

This study was conducted from 1992 to 2000 in ten 6.5 to 8 ha sites in the Allegheny National Forest in northwestern Pennsylvania, USA. All sites were mature second growth northern hardwood stands that originated following clear cutting in the early 1900s. When this experiment was initiated, black cherry (*Prunus serotina* Ehrh.) comprised >25% of the basal area of overstory trees with red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.) comprising most of the remaining basal area. Woody species in the seedling and sapling layers were generally representative of the overstory but were shaded by varying amounts of striped maple (*Acer pensylvanicum* L.), American beech and birch (*Betula lenta* L. and *B. allegheniensis* Britton) in the midstory. Most sites had dense understory vegetation dominated by hayscented fern (*Dennstaedtia punctilobula* (*Michx.*) *T. Moore*) or New York fern (*Thelypteris noveboracensis* (L.)), a condition typical of stands in which herbicide is used to increase understory diversity and encourage regeneration of desirable tree species (Horsley and Marquis, 1983; Horsley, 1994). Ristau et al. (2011) provide more detailed description of the sites and their preexisting vegetation.

Each site was divided into two plots to which the herbicide and no herbicide treatments were assigned randomly (the latter is henceforth referred to as the control plot, though it is only a control with respect to herbicide treatment). Sampling was conducted in 1992 and 1994 to assess baseline conditions prior to implementation of the herbicide treatment. In late summer of 1994 (after that year's sampling was completed), a skidder-mounted air blast sprayer was used to apply a tank mix of 364 mL glyphosate and 24 mL sulfometuron methyl in 38 L water per hectare to the understory and midstory of the herbicide treatment plots. This application method and rate is standard operational herbicide use for these stand conditions on the Allegheny National Forest. Five of the sites received a shelterwood seed cut 4–6 years before the experiment was initiated and the other five received this treatment in the winter of 1995–1996. Shelterwood seed cuts reduced stand relative density to approximately 60%, leaving healthy seed trees and creating conditions suitable for recruitment of desirable seedlings (Marquis, 1979). This resulted in an experimental design in which paired herbicide and control plots were nested within sites and sites varied in the time since shelterwood seed cut.

A regional outbreak of elm spanworm (*Ennomos subsignarius* Hübner) resulted in slight to severe defoliation at all of the sites in 1992 and 1993. Elm spanworms are large (~5 cm), polyphagous larvae of a geometrid moth native to the eastern US, where their relatively uncommon outbreaks can cause severe defoliation in mixed hardwood forests. In 1993, at the peak of the outbreak, the defoliated area within the proclamation boundary of the Allegheny National Forest covered approximately 340,000 acres and tended to be most severe in stands dominated by black cherry (Morin et al., 2004). All study sites were within a large area aerially sprayed with the insecticide Thuringicide 48LV in May 1994 to control the outbreak and there was little defoliation from elm spanworm for the remaining years of the study. However, an outbreak of another geometrid, the cherry scallopshell moth (*Hydria prunivorata* Ferguson), peaked in 1995 on the Allegheny National Forest and resulted in black cherry defoliation at six sites (Morin et al., 2004).

2.2. Carabid sampling

Pitfall trap arrays consisting of 10 smooth-sided plastic containers (~1 L capacity with a 15 cm diameter) arranged in a "Y" formation and connected by drift fences were placed in each plot to capture carabids. Individual traps were located at the center of the array and then at 2.5, 6 and 15 m out along each of the three drift fences. Containers were filled with approximately 5 cm of 25% formalin and were open for five nights during early growing season (late May – early June) and then again during later growing season (mid late August) each year. For analyses presented here, carabids collected from all 10 traps during each of these two sampling periods were combined. The same trap locations were used throughout the study and sampling effort (e.g., trap days) was equal for all years. Although pitfall trap data are most accurately understood as a function of true density and some capture probability related to frequency and distance of movements (Spence and Niemela, 1994; Thomas et al., 2006), we used the number of individuals captured