Forest Ecology and Management 429 (2018) 294–299

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Response of beetles (Coleoptera) to repeated applications of prescribed fire and other fuel reduction techniques in the southern Appalachian Mountains

Joshua W. Campbell[a,*], Steven M. Grodsky[b], Oliver Keller[a], Cynthia C. Vigueira[c], Patrick A. Vigueira[c], Evan S. Waite[a], Cathryn H. Greenberg[d]

[a] University of Florida, Entomology and Nematology Dept., 1881 Natural Area Dr., Gainesville, FL 32611, USA
[b] Department of Land, Air & Water Resources, University of California, Davis, Davis, CA 95616, USA
[c] High Point University, Biology Dept., One University Parkway, High Point, NC 27268, USA
[d] USDA Forest Service, Southern Research Station, 1577 Brevard Road, Asheville, NC 28806, USA

ARTICLE INFO

Keywords:
Beetles
Fuel reduction
Mordellidae
Appalachian Mountains
Nitidulidae
Prescribed fire
Mechanical thinning
Chrysomelidae

ABSTRACT

Coleoptera are important components of forest ecosystems and can be affected by forest management schemes aimed at limiting fuel build-up. Our research objective was to determine if repeated applications of fuel reduction treatments resulted in changes in abundance or diversity of beetle (Coleoptera) families, genera, and species within upland mixed hardwood forests in the southern Appalachians Mountains, North Carolina, USA. We established three replicate blocks (~56 ha) and split each block into four fuel reduction treatments. Treatments included prescribed burning, mechanical felling, a combination of prescribed burning and mechanical felling, and a control (*i.e.*, no fuel reduction techniques applied). We implemented treatments multiple times (2 mechanical thinnings and 4 prescribed burns) over the course of a 15-year period. Using pitfall and colored pan traps, we captured 7037 coleopterans comprised of 62 families over a three-year period. Total coleopteran abundance and diversity were similar across all treatments; however, some beetle families, genera, and species responded to treatments. Nitidulidae were significantly more abundant within controls compared to all other treatments in 2015, whereas Mordellidae generally had higher abundances in mechanical and burns compared to mechanical in 2015 and mechanical and controls in 2016. Chrysomelidae was significantly more abundant in mechanical and burns compared to all other treatments over the entire duration of the study. However, Staphylinidae abundance was significantly lower in mechanical and burns compared to the other treatments. Numerous genera and species also showed variable treatment-level responses. Burn treatments killed some mature trees and reduced forest canopy cover, resulting in higher light availability and thereby greater herbaceous cover and diversity on the forest floor. This vegetation in the understory of burned treatment units may be partially responsible for many of the treatment-level responses of beetle taxa we documented. This study took place after several rounds of fuel reduction techniques were applied over a 15 year period. Some beetle abundance responses were immediate; whereas other groups seemed to be influenced by the application of treatments over time, highlighting the need to examine long-term responses to forest management practices.

1. Introduction

Humans have long used fire to alter forested landscapes for multiple purposes. In the southern Appalachian region of the United States, fire was frequently applied by Native Americans to facilitate travel, augment fruit and nut availability for forage, and attract game animals to young foliage or grasses resulting from fire-mediated disturbance (Greenberg and Collins, 2016). Later, European settlers used fire to provide suitable land for livestock grazing (Brose et al., 2001). Today, foresters use prescribed fire to reduce fuels and the risk of wildfire, and to benefit vertebrate wildlife that feed on new plant growth. Prescribed burning is the most common fuel reduction method in forests, but it is used on a limited basis in the wildland-urban interface due to creation of smoke and risk of property damage. Fire-surrogates, such as mechanical thinnings and herbicide treatments, may accomplish many of the same management goals and are suitable for use near homes and other developed areas.

Prescribed fire and mechanical fuel reduction techniques can potentially affect invertebrates by altering forest habitat structure or by causing direct mortality during prescribed burns (McCullough et al.,

* Corresponding author.
E-mail address: joshw.campbell@gmail.com (J.W. Campbell).

https://doi.org/10.1016/j.foreco.2018.07.022
Received 5 March 2018; Received in revised form 25 April 2018; Accepted 8 July 2018

1998; Swengel, 2001). Forest managers have attempted to use arthropod indicator species (e.g., ants, beetles, spiders) to determine the sustainability and ecological soundness of forest management practices (Andersen et al., 2002; Schowalter et al., 2003; Vickers and Culin, 2014; Willett, 2001). Amongst coleopterans, Carabidae is the most frequently used family in environmental assessments of forest disturbances (Hodkinson and Jackson, 2005; Butterfield et al., 1995; Ulyshen et al., 2006). However, Cerambycidae (Maeto et al., 2002), Scarabaeidae (Davis et al., 2001), Staphylinidae (Bohac, 1999), and tiger beetles (Carabidae: Cicindellinae) (Rodriguez et al., 1998) are also used as ecological indicators. Additionally, researchers have looked to overall invertebrate community response as an indicator of forest health (Jansen, 1997; Greenberg et al., 2010).

Coleopterans comprise ∼40% of all insects and are taxonomically and behaviorally diverse. Many beetles are sensitive to environmental changes, and beetles found in undisturbed forests, such as old growth forests, do not rapidly disperse, making them suitable candidates as indicators of forest condition (den Boer, 1990). Additionally, the taxonomy of many beetle families in temperate zones is well understood, making them ideal for environmental assessments with high taxonomic resolution (Werner and Raffa, 2000). Previous studies have also demonstrated beetles to be responsive to forest disturbances. When forests are cut or fragmented, some beetles may increase in abundance and richness (Lenski, 1982; Butterfield et al., 1995), especially species that are found in open habitats (Werner and Raffa, 2000).

In earlier studies, we examined initial effects of prescribed burning and mechanical fuel reduction on pollinators (Campbell et al., 2007) and arthropod communities (Greenberg et al., 2010). However, response of beetle communities after multiple applications of fire and fire surrogate treatments is largely unknown. We assessed how beetle abundance and diversity responded to repeated fuel-reduction treatments including: (1) low-intensity prescribed burns; (2) mechanical understory reductions; (3) a combination of mechanical understory reduction followed by a high-severity burn and subsequent lower-intensity prescribed burns; and (4) controls in the southern Appalachian Mountains, USA. The vast majority of studies that examined arthropod responses to fuel reduction practices, primarily focused on the immediate responses of various treatments. Although we did collect beetles shortly after one round of treatments, our study was primarily interested in longer-term impacts of repeated applications of fuel reduction techniques. We hypothesized that some beetles that prefer disturbed habitats would increase in abundance immediately after treatments but would decrease in abundance over time. Additionally, these beetles' abundances may remain relatively high in treatments that resulted in canopy and shrub reduction. Alternatively, other beetle groups that are fungivores or use duff material for sheleter may decrease in abundance among treatments that allowed more sunlight to penetrate the canopy. Fungal growth should decrease within the hotter/drier conditions and prescribed burns could lead to the destruction of leaf litter and other coarse woody debris.

2. Methods

2.1. Study sites and design

We conducted this study on the 5841-ha Green River Game Land (GRGL) (35° 17′0900 N, 82° 19′42″W and 35°15′42″N, 82° 17′27″W) in Polk County, North Carolina, USA. GRGL lies within the mountainous Blue Ridge Physiographic Province of western North Carolina. The region receives an average of 164 cm of precipitation annually that is distributed evenly throughout the year, and the average annual temperature is 17.6 °C. Soils in GRGL are composed primarily of the Evard series (*i.e.*, fine-loamy, oxidic, mesic, Typic Hapludults); they are very deep (> 1 m) and well-drained in mountain uplands (Keenan, 1998). Elevation ranges from approximately 366 to 793 m. Oaks (*Quercus* spp.) and hickories (*Carya* spp.) were the primary trees in the upland hardwood forest. Shortleaf pine (*Pinus echinata* Mill.) and Virginia pine (*P. virginiana* Mill.) were dominant ridgetop species, and white pine (*P. strobus* L.) occurred in moist coves. The age of the forest within experimental units ranged from ∼85–125 years old. Mountain laurel (*Kalmia latifolia* L.) was the predominant shrub along ridgetops and on upper southwest-facing slopes, and rhododendron (*Rhododendron maximum* L.) was the most common shrub in mesic habitats. Prior to the 2003 prescribed burns conducted in this study, none of the study sites had been thinned or burned for a minimum of 20 years.

We selected three replicate study areas (hereafter “blocks”) within GRGL. To ensure consistency in baseline conditions among the blocks, we considered size (*i.e.*, capacity to accommodate four experimental units each), forest age, cover type, and management history. Each of the three blocks was either bordered or traversed by perennial streams.

In order to accommodate a 10-ha “core” area surrounded by 20-m wide buffers, experimental units within blocks were a minimum of 14-ha. Some experimental units were separated by dirt roads or fire lines. A number of experimental units were traversed by wooded trails, but none were crossed by roads or fire lines. Within each of the three blocks, we randomly assigned three fuel reduction treatments and an untreated control (C), resulting in a total of 12 experimental units. Treatments were: (1) repeated prescribed burns (four times, in February or March 2003, 2006, 2012, and 2015; B); (2) repeated mechanical felling of all shrubs and small trees > 1.4 m tall and < 10.2 cm in diameter at breast height (dbh) with a chainsaw (twice, winters 2001–2002 and 2011–2012; M), and; (3) initial mechanical cutting of the understory (winter 2001–2002), followed by four prescribed burns (as for B, above; MB); and (4) untreated controls. Cut trees and shrubs were left scattered onsite in MB and M.

We conducted prescribed burns (*i.e.*, B and MB) by hand-ignition using spot fire and strip-head fire techniques, as well as helicopter-assisted spot fire ignition. The initial prescribed burns in March 2003 resulted in flame lengths of 1–2 m throughout all burn units. However, topography and intersecting flame fronts contributed to localized areas of erratic fire behavior where flame lengths reached up to 5 m in height (Waldrop et al., 2010). As a result of these high intensity burns, numerous trees were killed in MB, resulting in a dramatic alteration of forest structure (e.g., canopy openings). Felling of the shrub layer on MB contributed to a load of fine woody fuels that was approximately 2-fold larger than C and B, thus contributed to the higher intensity fires. Average fire temperature at 30 cm aboveground was much hotter in MB than B (370 °C and 180 °C, respectively; Waldrop et al., 2010). Subsequent burns of the MB produced lower-intensity fires than the initial burn (Waldrop et al., 2010). The second burn (March 2006) produced flame lengths generally < 1.5 m, and the average temperature 30 cm aboveground was 155 °C in B and 222 °C in MB (Waldrop et al., 2016). The third and fourth burns were of low-intensity, producing flame lengths < 2 m, but measurements of fire temperature were not collected.

2.2. Sampling procedure

Within each treatment unit, we established two pitfall trap arrays spaced > 50 m apart. Arrays consisted of a 4 oz (118 ml) cup filled halfway with soapy water, with three 30-cm long aluminum flashing drift fences trenched into the ground that radiated from the center of the cup and were oriented at 120° to the neighboring drift fence. We also used sets of colored pan traps filled with soapy water, both in the midstory and on the ground to capture beetles unlikely to be captured in pitfall traps. For the colored pan traps, we attached blue, red, white, and yellow pans at each corner of a 66 cm square of metal remesh (Nucoar) with binder clips (Campbell et al., 2018). Colored pan traps have been successfully used to sample forest Coleoptera (Meng et al., 2013), and many beetle groups are known to be attracted to various colors (Francese et al., 2005; Campbell and Hanula 2007). At each of the two locations (> 50 m apart) within each treatment unit, we hoisted one