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Arthropods and Fire: Previous Research Shaping Future Conservation☆

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ABSTRACT

Fire is a natural process in grasslands that maintains an open canopy and creates variable vegetative structure and composition over time. Although there is a wealth of knowledge on plant and avian responses to fire in the Great Plains, there are few generalizations for arthropods. We conducted a literature review to synthesize research on arthropod responses to fire in the Great Plains to offer more insights to land managers, policy makers, and researchers. Overall, we found that there was variation in how arthropod communities responded to fire; metrics of both abundance and diversity were found to respond positively, negatively, or not at all. We then delved into two potential factors that might help us understand this important variation. First, we looked for effects from the amount of time since fire. Although much of the literature focused on arthropod responses to burning in the first 6 mo after fire, there were still both positive and negative results regardless of timeframe. We also hypothesized that taxonomy may provide insights and found that some orders tended to respond negatively (Araneae, Lepidoptera) or positively (Coleoptera, Orthoptera) to fire; however, responses were still variable and likely dependent on additional factors. To help enable managers to make better decisions about fire application, we used the literature to identify three traits—mobility, life stage, and feeding guild—that can predict responses to fire at a species level when research is lacking. Management recommendations vary on a species-by-species basis, but available research suggests that arthropod communities do not simply respond negatively to fire. Knowledge gaps remain concerning the origin of those community responses, particularly in terms of individual species' responses and specific mechanisms that allow individuals to persist after fire. Future research should focus on theoretical and applied basis for arthropod conservation using prescribed fire.

Introduction

Short History of Fire in Great Plains

Fire is a natural ecosystem process that has been repeatedly manipulated and used by humans to create disturbance in the Great Plains of North America (Higgins et al., 1986; Fuhlendorf and Engle, 2001; Allen and Palmer, 2011). Fire is imperative to the formation and continuation of grasslands, as the interaction of fire, climate, and grazing maintains a heterogeneous mixture of herbaceous vegetation while controlling the spread of woody species (Samson and Knopf, 1994; Anderson, 2006; Hartley et al., 2007). Historically, American Indians used the interaction of fire and grazing for hunting, along with many other purposes (Levy, 2005). Fire was widely suppressed after European colonization (Umbanhowar, 1996), but the need for fire in grasslands remained. Subsequently, fire suppression led to increased woody encroachment (Ratajczak et al., 2012; Twidwell et al., 2013), extreme wildfires, and decreases in biodiversity (Coppedge et al., 2001; Fuhlendorf et al., 2012). More recently, land practitioners have reintroduced fire to benefit grassland biodiversity and stability (Hovick et al., 2015; McGranahan et al., 2016). While research has focused on the influences of fire on plants (MacDougall et al., 2013; Koerner et al., 2014) and birds (Fuhlendorf et al., 2006; Hovick et al., 2014), arthropods as a group have received relatively less attention.

Fire for Manipulating Arthropods

Arthropods may be researched much less than other organisms in the same system (Dunn, 2005; Limb et al., 2016), yet they have critical connections with plants and animals (Meyer et al., 2002; Conway and Stapp, 2015). Fire is applied to manipulate arthropods to influence these plant and animal interactions. For example, fire was traditionally used as a means to reduce pest species like locusts and other grasshoppers that feed on grassland plants and could compete with livestock (Warren et al., 1987; Branson et al., 2006) or pests such as ticks and horn flies that transmit diseases to livestock and people (Fischer et al., 1996; Scasta et al., 2012; Polito et al., 2013). Conversely, fire has also been used to increase the arthropod biomass available for game birds

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that require arthropods for protein during brood rearing (Hess and Beck, 2014). Altogether, manipulation was not focused on benefiting arthropods for their own conservation but rather for the benefits of other organisms.

Fire for Conserving Arthropods

Land managers need to be able to conserve arthropods beyond simply decreasing or increasing total arthropod biomass. As conservation concerns for communities (e.g., pollinators, specific species) continue to grow (Conrad et al., 2006; Lebuhn et al., 2013), best management practices will be vital for conserving and bolstering many populations. Successfully using natural ecosystem processes, like fire, in grasslands are important for maintaining significant ecosystem functions and services provided by arthropods (Engle et al., 2008; Ehrlich and Harte, 2016). If land managers have a better understanding about how arthropods respond to fire, they can effectively modify management to improve conservation of the arthropod community or particular species (Swengel, 2001; Vogel et al., 2010).

Without fire in the Great Plains, communities will transition from grassland arthropods to woodland arthropods (Hartley et al., 2007), making the use of fire necessary. The indirect effects of fire, particularly altering the plant community, can enhance available resources, population longevity, and arthropod diversity (Engstrom, 2010; Baum and Sharber, 2012; Evans et al., 2013). However, fire can directly cause mortality and impact individuals through flame and heat stress (Warren et al., 1987; Zelhart and Robertson, 2009), especially to remnant-dependent species in small reserves (Panzer, 2002). Consequently, there is a disturbance paradox for many arthropods (Swengel, 2001; Tooker and Hanks, 2004; Moranz et al., 2014). The disturbance management paradox makes it difficult for managers and conservationists to apply fire when burn effects are unknown for certain species and because fire responses are dependent on numerous covariates such as season of burn, postfire use, and fire frequency (Warren et al., 1987).

Given the importance of fire as a disturbance necessary for grassland management and conservation, our objectives are to 1) use published literature to ask how fire affects arthropods in the Great Plains; 2) investigate how time since fire might influence arthropod responses; 3) discuss how differences among arthropods, including species traits, can predict responses to fire; and 4) identify knowledge gaps that should be addressed by future research.

Methods

We searched for peer-reviewed, indexed articles in Web of Science and Google Scholar between February and March of 2016 to find research published on arthropod responses to fire in the Great Plains. In these search engines, we used key words including fire*, burn*, or wildfire* with orders and common names for insects and some arthropods (Table 1). Our main objective was to determine fire effects on insects (Class Insecta), but we also included several important groups of insect relatives that are in Arthropoda, including Araneae, Chilopoda, and Diplodoa. We also used key words to search trap types in combination with fire in case arthropods were not exclusively studied. If our search returned too many results, we narrowed the search to only include studies that included the key words and phrases grass*, prairie*, range*, or Great Plain*.

We obtained more than 110 papers during our initial search but completed a secondary evaluation of articles to make sure they met our requirements. We confirmed that research was conducted in the Great Plains, which included Colorado, Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming. However, we also used research conducted in the central United States, adjacent to the Great Plains.

All studies had to investigate how arthropods respond to fire. Most of our analyses were on communities or species assemblages, but in one case we used data from papers that studied fire at the species level. Fire treatments could be prescribed fires or wildfires that compared burned with nonburned areas or compared different fire return intervals. At our coarsest level of assessing the effects of fire, we categorized the results of these studies by whether fire positively (and significantly) changed a particular response variable, negatively (and significantly) changed a response, or had a neutral effect (nonsignificant results). Changes in response variables could be through time (before fire vs. after fire) or through space (comparing a burned area with a nearby nonburned area). Our approach to assess arthropod responses to fire was less quantifiable compared with a meta-analysis because there were not enough studies to complete a comprehensive meta-analysis. We would have had to group across taxa, response, and time after fire to get enough studies from available research, reducing our interpretability. Additionally, most studies did not report the required phenology and temporal changes necessary to consider in a meta-analysis (Koricheva et al., 2013). Although there are limitations when conducting a vote count (Nakagawa and Poulin, 2012), this is an appropriate method to use when research is lacking to identify knowledge gaps and focus future research (Koricheva et al., 2013).

The first and most general question we asked was how fire affected arthropod communities. To be included, studies had to investigate the entire arthropod community or focus on an assemblage of species. We used response variables most frequently encountered in the literature to evaluate arthropod community responses to fire. The six metrics we found can be roughly categorized as being related to the number of individuals or the community diversity. In the number of individuals' category, we found that studies measured abundance, density, and biomass. Abundance is traditionally a relative measure of the number of individuals, whereas density measures population size per unit area. Biomass is similar but also accounts for the weight of given individuals (or species). In the diversity category, we found that studies measured species richness, evenness, and diversity. Richness is a simple count of the number of species, whereas evenness looks at the relative abundance of the different species in an area. Finally, diversity metrics account for both richness and evenness. We answered our initial question by comparing the response of fire (positive, neutral, or negative) to each response variable individually and then combined.

We attempted to understand the variable results of our overall pattern by asking two more detailed questions. The first of these asked how fire affects arthropods through time. We answered this question at both the community level and species level. The community level question used the same data as in the first question but with the additional variable of knowing how much time had passed between when fire occurred and when arthropods were measured. We excluded studies that did not explicitly give this information but did include multiple points from the same study if they measured the community at multiple times or with multiple response variables. We grouped together all community level response variables. We repeated our methodology to ask the same question for studies that measured fire responses for individual species.

Table 1
Search terms and phrases used in synthesis to find peer-reviewed, indexed journal articles concerning arthropod responses to fire in the Great Plains

Searches always included fire* or burn* or wildfire* *and* an additional factor:
Arthropod classification
Araneae, Blattodea, Coleoptera, Collembola, Diptera, Ephemeroptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, Neuroptera, Odonata, Orthoptera, Thysanoptera, Thysanoptera, or Trichoptera
Common name
Beetle, fly, flies, caddisfl,* cricket,* grasshopper,* damselfly,* dragonfly,* lacewing,* spider,* wasp,* ant,* bee,* bumble bee,* insect,* or bug*
Sampling method
pit-fall trap,* sweep net,* or vacuum

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