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Common Methods for Tallgrass Prairie Restoration and Their Potential Effects on Bee Diversity

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ABSTRACT: Habitat restoration is considered critical for maintaining and restoring biodiversity of many species groups. A better understanding of how species respond to the restoration process is imperative to identifying practices that benefit the target organisms. Using survey responses from land managers about the restoration process in tallgrass prairie habitat, we identify common restoration and management techniques. These responses are then combined with current literature on bee and plant responses to these methods in tallgrass prairie habitat. While some widely used methods, such as burning, are believed to be fairly benign to bees, there are still many knowledge gaps about how bees may respond to many common practices such as tillage, pesticides, and grazing in tallgrass prairie. Other commonly used methods, such as broadcasting of seeds, are known to significantly affect plant diversity, which could hinder bee conservation efforts. The variability in bee and plant response to commonly used methods highlights why it is necessary to better understand how management methods affect plant and bee communities.

Index terms: bee, conservation, TGP, prairie, restoration, tallgrass prairie

INTRODUCTION

Habitat restoration has long been considered key for sustaining biodiversity (Society for Ecological Restoration International and IUCN Commission on Ecosystem Management 2004) and slowing rapid species declines (Young 2000; Society for Ecological Restoration International and IUCN Commission on Ecosystem Management 2004). In particular, the restoration of habitat is one of the primary methods recommended to curb the declines of native bees (Potts et al. 2010; Winfree 2010). Declines of bees, due to their important role in both food security and ecosystem stability (Knight et al. 2005; Klein et al. 2007), have elicited significant attention from public, scientific, and political circles, all of which are calling for increases in restored habitat to improve bee conservation efforts (Potts et al. 2010; Winfree 2010; Pollinator Health Task Force 2015). Restoration, however, is a diverse and complex process with myriad methods used to clear land, establish plants, maintain diversity, and manage success (Clewell et al. 2005). Consequently, the diverse methods used to establish and maintain landscapes are unlikely to have uniform conservation results for bees (Dixon 2009), and could significantly affect the efficacy of restoration as a conservation method for native bees and other species.

In this paper, we identify site characteristics and current methods used to establish and manage tallgrass prairie (TGP) habitat, and review how these methods may affect bee and plant diversity in prairie restorations based on current literature. Tallgrass prairie, which originally covered over 675,828 km^2 (167 million acres) and has been reduced to between 4 and 13% of its original extent, is characterized by high plant and forb diversity (Samson and Knopf 1994; Samson et al. 2004). Bees are known to be negatively affected by habitat loss and fragmentation (Winfree et al. 2009), which makes both pollinators and plants—of which an estimated 80% rely on animal pollination for seed set (Ollerton et al. 2011)—at risk in prairie landscapes. Thus, ongoing efforts to restore tallgrass prairie habitats could help both to conserve bee diversity and maintain plant diversity in restored patches; to our knowledge, however, no one has compared management methods with the known effects they have on bees. We focus specifically on the TGP and research relevant to this habitat, because bees with different evolutionary and ecological histories may not have uniform responses to restoration methods and disturbances (Williams et al. 2010).

During the spring and fall of 2013, land managers of TGP were contacted to discuss site characteristics and methods used to clear, establish and maintain prairie restorations-including both degraded remnant areas that have been restored and reconstructions of other habitats back to prairie. Questions were administered through phone calls and electronic surveys (See Appendix to view survey). Response rates varied between questions based on managers' varying knowledge of different stages of the restoration, as some were not involved in establishment of sites in vary-

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ing parts of the restoration process. Some respondents were anonymous, so follow-up clarifications were not always available.

A total of 28 land managers responded to our survey methods. Sixteen were reached first by phone and then sent a follow-up email survey, while the other 12 were reached only through the emailed survey sent to a prairie conservation group. Managers covered much of the TGP region, including the states of Illinois, Iowa, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin. Some responders also recommended others to contact so there was some clustering of responses. For some questions, responders could provide multiple responses, so percentages are for the number of responders identifying that method or option out of the total number who responded to the question. Thus, many categories total over 100%. Herein we summarize the responses and review-relevant literature on the effects of site characteristics, restoration establishment, and site management for bee conservation. Through this survey and review, we hope to identify significant holes in our knowledge for restoration managers and practices that may be more beneficial to maintaining wild bee diversity.

Site Characteristics

Age of Restoration

The majority of restored prairie habitats, over 60%, were established since the 1990s, but some sites have been restored and managed since the 1930s (see Table 1). Overall, site age seems to have variable effects on plant and bee diversity. Four studies examining TGP restorations ranging from one to 20 years since establishment, found a decrease in plant diversity as restored sites age (Sluis 2002; McLachlan and Knispel 2005; Carter and Blair 2012; Hansen and Gibson 2014). However, when compared to remnant areas, restored areas were found to have either the same (Carter and Blair 2012), or significantly lower, plant diversity (Sluis 2002; Martin et al. 2005). In cases where the plant diversity in reconstructed prairies was lower, many rare plant species were absent, but this may not significantly affect bee diversity. Although bee diversity is known to increase with more diverse plant communities (Hendrix et al. 2010) little work has specifically examined differences between bees in reconstructed and restored remnant prairies and how these change over time. Kwaiser and Hendrix (2008) found bee diversity in ruderal areas was much lower than remnant prairie but these areas are not an adequate comparison to reconstructed prairie areas which have much lower plant diversity. If older restored areas consistently lose flower diversity, they may be less likely to support bee populations. This may also suggest continual management will be necessary to prevent loss of floral and bee diversity as sites age. Further work examining reconstructed prairies of different ages is necessary to determine if and when restoration of tallgrass prairie peaks in bee diversity, trait diversity, or

Table 1. Summary of manager's responses on site characteristics.

Site characteristics	Number of respondents	Types	% respondents
Restoration size	21	0–10 acres	28.6
		11–100 acres	19.0
		101–1,000 acres	14.3
		1,001–10,000 acres	28.6
		>10,000 acres	9.5
Restoration age	18	1930s	5.6
		1970s	11.1
		1980s	22.2
		1990s	38.9
		2000s	22.2
Previous habitat type	25	Agriculture	60.0
		Pasture	44.0
		Remnant prairie	32.0
		Other	4.0
Surrounding landscape	25	Agriculture	60.0
		Woodlands	32.0
		Pasture	28.0
		Remnants/Restored land	16.0
		Suburban	8.0

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phylogenetic diversity. This additional work would provide valuable insight into how the reconstruction and restoration of habitat affects bee diversity.

Site Size

Land managers reported that the total area of their sites ranged from < 0.4047 km^2 to > 40.47 km^2 (< 100 acres to > 10,000 acres), with the median restoration between 0.4087 and 4.047 km^2 (101 and 1000 acres), suggesting there is wide range in the size of reconstructions (see Table1). In a meta-analysis across many habitat types, bee richness and abundance consistently decline with habitat loss (Winfree et al. 2009). The effects of site size on bee diversity, however, are dependent on the amount of connectivity between sites, which may explain why in some TGP habitats site size and bee diversity were not negatively correlated (Hopwood 2008; Hendrix et al. 2010). Increasing connectivity between sites may allow some bee species to persist in small patches, but this will also be dependent upon the ability of the bee species to move between patches. Unfortunately, a meta-analysis of functional traits (Williams et al. 2010) found that large and social bee species—which are often those that can move greater distances (Greenleaf et al. 2007)—are more highly affected and likely to be absent from this highly fragmented habitat. Including trait and phylogenetic analysis in assessments of bee diversity could help determine if particular bee species or groups are missing or affected by site size in TGP habitats (Bartomeus et al. 2013). Nonetheless, it is still encouraging that small prairie restorations could be a significant benefit to pollinator conservation given the size of most restoration efforts. Montero-Castaño and Vilà (2012) found that changes to surrounding landscape had a more profound effect on pollinators, most of which were bees, than patch size, further suggesting that patch size may not be as important as connectivity and other factors for conservation efforts.

Surrounding Habitat

Most of the reconstructions were former agricultural or pasture land (reported by 60% and 44% of respondents, respectively) and as such, most sites were found within an agricultural landscape. Surprisingly, few were found near remnant prairies, with only 16% of land managers reporting this as part of the surrounding landscape. Prairie patches with greater amounts of grassland in the surrounding landscape had greater bumble bee diversity and abundance within patches (Hines and Hendrix 2005). It is still unknown whether this translates to all bee species or just those that are large enough to travel to the next nearest patch, because the ability to travel between sites is dependent on bee size (Greenleaf et al. 2007), the connectivity between sites, and the distance to the next nearest habitats. Many managers reported multiple habitat types surrounding prairie sites, including woodlands, remnant prairie, or suburban habitats. Few studies have examined how the presence of these habitat types affect bee diversity within restored prairie areas. A study of bees in grassland habitats did not find any effect of urbanization, so it is possible that sites in suburban habitats may not be adversely affected by increasing urbanization (Kearns and Oliveras 2009a). Additionally, Grundel et al. (2010) found specialist bees were more common in open or shrubby habitat than those with closed canopies, suggesting that woodland habitats near prairies may not significantly increase bee diversity. Further work is necessary to understand the effects of surrounding habitat on bee diversity within prairie patches.

Site Establishment

Land Clearing and Preparation

Sixty percent of managers reported that restored prairies began as farmland. Consequently, one of the primary methods to clear land was to harvest existing crops. The remaining sites were cleared by tillage, burning, or spraying with herbicides (see Table 2). Our survey did not track the types of crops harvested but some research found an increase in the plant diversity in reconstructed areas and therefore, are likely to help increase bee diversity (Martin et al. 2005). Tillage is generally believed to negatively affect bees, although the direct evidence for this is lacking (Winfree et al. 2009) due to few studies tracking the effects of tillage on bees (but see Shuler, Roulston and Farris 2005). Williams et al. (2010) found that tillage had significant effects on presence of social bee species and ground-nesting bees in a meta-analysis but again the sample sizes were small and this was not directly linked to damage to nests. It is important to note that bee response to tillage is dependent on the depth of tilling, as bees on average nest more than 17cm (Cane and Neff 2011). With over 80% of bee families nesting predominantly in soils (O'Toole and Raw 1991), tillage has the potential to not only disrupt existing bee nests, but to also change soil characteristics that may be important for encouraging nesting in restored areas. A number of different soil characteristics are believed to be important for ground bee nesting including soil texture, compaction, hardness, soil humidity and the amount of bare ground (Cane 1991; Potts and Willmer 1997; Wuellner 1999; Hines and Hendrix 2005; Potts et al. 2005; Sardiñas and Kremen 2014) many of which may be affected by tillage. Tillage is typically only used during the establishment of sites so is unlikely to have lasting effects once a site is established, but it could reduce the resident bee populations and possibly affect bee nesting rates by altering soil conditions. Some plant species were found to have lower seedling density when sites were tilled rather than mowed, which may suggest that tilling is not beneficial for plant establishment (Carrington 2014). Further work is needed to better understand bee use of sites after they are tilled, changes in soil conditions, the length of time tillage affects bee communities, and the effects this has on plant establishment. Although sparse, current information suggests that tillage adversely affects both plant and bee populations and should be avoided if bee conservation is a goal of a project.

Burning is used both to clear land and as a maintenance technique (see Tables 2, 3, and section on Site Management) and seems to have predominantly neutral to positive effects on most bees in prairie and other habitats (Potts et al. 2003; Campbell et al. 2007; Bowles and Jones 2013). Other

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Table 2. Summary of manager's responses on site establishment.

Site establishment	Number of respondents	Types	% respondents
Vegetation clearing	12	Crop harvesting	50.0
		Tillage (including disking, tilling, plowing)	41.7
		Herbicides	33.3
		Burning	33.3
		Other	25.0
Planting method	27	Broadcast	92.6
		Drilling	18.5
		Plugging	11.1
Seed source	26	Harvested from a nearby remnant	80.8
		Nursery	19.2
Seed mix	20	More forbs than grass	55.0
		More grasses than forbs	30.0
		Even forb:grass ratio	15.0
Seed success	14	0–50% success	42.9
		50–80% success	21.4
		80–100% success	35.7
Planting season	24	Winter	54.2
		Fall	29.2
		Spring	20.8

methods used to clear land, such as herbicides, have a largely unknown effect on bee diversity. With the high diversity of herbicides used in agricultural areas (nine were reported in our survey), and with most managers reporting multiple herbicides used, it may not be possible to know the full effects of each individual or combined set of pesticides. Glyphosate, the most commonly reported herbicide, is used to assist in land clearing and as part of general maintenance to control invasive plant species. It has been shown to affect navigation and beta-carotene levels in honey bees (Helmer et al. 2014; Balbuena et al. 2015) among other effects, although this is not likely to be a long-term problem for bees in prairies due to the limited use after establishment and short persistence in soils (Syan et al. 2014). However, significant concern has been raised about the persistence of other agrochemicals, particularly neonicotinoids, in the soil after a site is reconstructed (Goulson 2013). Data are still lacking on the effects of these chemicals on bee presence and nesting, but TGP restorations may be particularly at risk because much of the habitat is being converted from corn and soybean production, which are two of the most common crops for neonicotinoid use (Douglas and Tooker 2015). One major limitation of our understanding of the ef-

Table 3. Summary of manager's responses on site management.

Site management	Number of respondents	Types	% respondents
General maintenance	24	Burning	91.7
		Mowing	25.0
		Grazing	16.7
		Haying	8.3
Season of burning	21	Fall	38.1
		Spring	61.9
		Winter	38.1
		Summer	14.3
Frequency of burns	16	yearly	68.8
		every 2–4 years	56.3
		variable	18.8

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fects of agrochemicals on native pollinators is that much of the work is conducted on honey bees, which can have very different responses than other species (Rundlöf et al. 2015). Further work should examine the long-term persistence of agrochemicals in the soils and the effects they have on native bees and ground-nesting bees in particular.

Seed Establishment

Seeds were most often harvested from nearby restorations and remnant prairies, with most making a specific effort to have mixes with more forbs than grasses (see Table 2). This suggests that many restorations will have similar plant diversity as other local remnant and restored prairies, which may be very beneficial to pollinators in the landscape. However, this would also mean that the landscape will likely be very homogenous and could limit the establishment of rare plant species that are of particular concern (Fiedler et al. 2012). Overharvesting of seed from remnant and reconstructed sites can also significantly affect the plant community in those sites, and, therefore, care needs to be taken when collecting seed (Meissen et al. 2015). The seedbank can contribute to maintaining diversity in a site, but the overall contribution of the seedbank declines as the site ages (Willand et al. 2013), suggesting that continually adding plants to a site may be necessary to maintain diversity. Managers reported using drilling, plugging, and broadcasting (see Table 2) to establish seeds in a site. These different seeding methods and the season in which they are used can have variable success at establishing plants (Yurkonis et al. 2010; Larson et al. 2011). In most restorations, seeds were broadcast, which has variable success depending on season of planting and site, with increased forb densities observed when broadcast during the winter (Larson et al. 2011). Most managers acknowledged that the success of their planting methods was less than 100%, and often multiple methods were used to help increase plant diversity. Efforts to increase plant diversity could specifically target plants that are highly preferred by bees but little data exists on which plants are most beneficial to pollinators (but see Tuell et al. 2008; Harmon-Threatt and Hendrix 2015). Harmon-Threatt and Hendrix (2015) identified four "bee plants" for Iowa prairies that, when included in seed mixes, should improve TGP benefits for pollinators if plants are successfully established. These bee plants—*Amorpha canescens* Pursh*, Ratibida pinnata* (Vent.) Barhnart*, Dalea purpurea* Vent.*, and Zizia aurea* (L.) W.D.J. Koch—are common throughout the TGP ecosystem and could also be added to other established restored or reconstructed prairies to increase their benefit for pollinator diversity. Successful establishment of plant diversity is critical to restoring bee diversity in TGP sites and managers will likely need to make specific efforts to ensure that plants known to be beneficial to pollinators are present in sites. Work in other habitats to restore plants known to benefit pollinators has been very successful in increasing bee diversity (Williams et al. 2015), but more studies are needed to assess the attractiveness of different species of plants to a diversity of bees, and the establishment of plant diversity under different methods.

Site Management

Burning

Long-term management methods of prairie restorations including burning, grazing, mowing and haying; all are used to maintain floral diversity, remove woody or invasive species and reduce weed growth. Burning was by far the most common method of site management, with over 90% of managers burning with some frequency. While burning does not directly kill most bees nesting in the soil (Cane and Neff 2011), it is correlated with decreases in cavity-nesting bee species that rely on available twigs and stems for nesting habitat (Davis et al. 2008; Williams et al. 2010). To help preserve diversity of cavity-nesting species, it will be important to prevent burning entire sites. Burning is often done in a rotational manner with only some patches burned during a single year. These patchy burns create a more heterogeneous landscape, which is known to benefit many bee species in other habitats (Potts et al. 2003, 2005; Williams et al. 2010), and is likely to help cavity-nesting bees persist in the habitat. The overall effect of fire on bees is still poorly understood as there are few studies that have examined them specifically (Winfree et al. 2009; Williams et al. 2010). Furthermore, most of these studies were conducted in Mediterranean landscapes that have a very low fire frequency and, thus, are unlikely to relate to TGP habitat (Williams et al. 2010). The studies that found an increase in bees after fire predominantly attributed the increase to changes in floral availability and nesting sites (Potts et al. 2003, 2005). However, this increase in resources may depend on the time of burning.

To better understand the timing of fire, we asked follow-up questions about season and frequency of burning. This revealed that fire frequency was dependent on the age of the restoration, with some managers using fire yearly during the creation and establishment of a site and then every 2–4 years for maintenance (see Table 3). The majority of prescribed burning was reported to occur during winter and early spring when bees are largely inactive, but the timing and frequency of burns seem to have a significant effect on plant diversity and community heterogeneity (Collins 1992; Bowles and Jones 2013), with regular burnings increasing prairie diversity. However, some managers mentioned that spring burns, conducted by almost 62% of managers, shifted the community to be grass dominated, which could significantly affect bee communities by decreasing plant availability. This shift in community composition to grasses with less forb diversity was also observed by Towne and Craine (2014), which strongly suggests spring burning could negatively affect bee diversity. To date, season of burn has not been linked to bee diversity, but fire timing and frequency could significantly affect the types of bee species in a site, as yearly burns during establishment could exclude cavity-nesting bees. With burning being the most common method used to manage sites, and few documented negative effects, this management may be very beneficial to bees; however, further work is needed to better understand the relationship between fire, plants, and bees in the TGP ecosystem.

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Mowing and Haying

Burning is often accompanied by other management methods, such as mowing and haying, which seem to improve bee diversity in other non-prairie habitats (Weiner et al. 2011; Hudewenz et al. 2012). This may be mediated by changes in abiotic conditions that favor native plant diversity, while reducing invasive species cover (Gibson et al. 2011) and increasing bee nesting resources (Campbell et al. 2007). The response of bees and plants to mowing and haying will likely depend on the timing of these activities, as sites that were mowed more regularly had significantly lower native forb diversity (Prevéy et al. 2014). There is some concern that mowing, and similarly, haying, could remove flowering heads before they scatter seeds if not timed properly, and in some cases were shown to negatively affect forb diversity (Smart et al. 2013). Mowing and haying will also remove most older stems, which will negatively affect nesting habitat for cavity-nesting bees. Thus, mowing and haying may negatively affect pollinators. Direct comparisons between burning, haying, and mowing would be beneficial to identify if one method is superior to the others for bee diversity.

Grazing

Although grazing, like haying and mowing, can increase bare ground availability and plant diversity, which are good for ground-nesting bees, under most grazing regimes bee diversity is negatively correlated with grazing intensity (Kruess and Tscharntke 2002; Kearns and Oliveras 2009b; Kimoto et al. 2012). Similar effects were found on both Hymenoptera and other insect species in grazed sites in Europe and the Southwestern United States (Söderström et al. 2001; Debano 2006). The response to grazing, however, seems dependent on the type of bee and the grazing conditions. Kimoto et al. (2012) found sweat bees were largely unaffected, whereas bumble bees were significantly reduced in abundance and diversity in grazed areas. Carvell (2002) found bumble bees to be unaffected by grazing under certain conditions and in suitably large patches. These studies were performed in non-TGP habitat, so further work is necessary to better understand whether grazing significantly affects bee diversity in TGP. It is important to note that most of the studies and grazing in TGP are cattle based, which some managers mentioned is likely to be very different from the bison grazing it is meant to imitate. Although previous work found bison and cattle grazing sites were 85% similar in plant community, the observed small scale differences in plant richness and diversity (Towne et al. 2005) could significantly affect bees that have low mobility. Bison grazing can help increase rare plant species (Wilsey and Martin 2015), as well as landscape level heterogeneity (McMillan et al. 2011; Kohl et al. 2013), which could be important to bee diversity. Future studies should investigate differences in bison and cattle grazing on bee diversity mediated by differences in plant diversity.

Invasive Plant Species

Many managers mentioned that management was primarily conducted to limit invasive species. A number of grasses and legumes, such as sweet and red clovers (*Melilotus officinalis* Pall. and *Trifolium pretense* L.), and birdsfoot trefoil (*Lotus corniculatus* L.), were identified as being particular targets for management. It is important to note that some previous work (Fiedler et al. 2012) on invasive species removal in prairie restoration had no effect on bee diversity, which quickly rebounded after removal of glossy buckthorn, *Frangula alnus* L. However, this result may not translate to the removal of all invasive species if they provide vital resources to bee species (Roulston and Goodell 2011). Many invasive species can be beneficial to bees (Tepedino et al. 2008), and removal of them could hurt conservation efforts unless adequate nutritional replacements are quickly restored. Given that many of the species that managers identified were legumes, which tend to offer high quality pollen (Weiner et al. 2010) and can be very attractive to bees, habitat losses in the TGP of these invasive species may be of particular concern for bee conservation. Managers may need to more critically consider how to increase high quality forage, such as native legumes, to replace invasive plant species that are being removed.

While investigating these maintenance methods independently can provide insight into how bees respond to specific management techniques, it is important to note that managers often use these methods in combination. Significant interactions between different methods have been observed to affect bees negatively by Campbell et al. (2007) in a forested landscape and Hudewenz et al. (2012) in intensively managed grasslands. Thus, there may be similar interactions in TGP restorations, and managers may need to consider management intensity when planning for pollinators. Further research in this ecosystem is necessary to better understand how different methods interact to affect bee diversity in TGP.

CONCLUSIONS

Habitat restoration is consistently recommended as the primary method to limit the continual decline of pollinators (Dixon 2009; Potts et al. 2010; Winfree 2010). While non-target restoration can be effective at conserving pollinators (Williams 2011), it is imperative that we assess the methods used to restore and maintain land to maximize the benefit of restored areas to bee conservation. If bee conservation is to be either a primary aim or a secondary benefit of restoration projects, more research is needed to understand how bees respond to many of the most common practices conducted to restore habitat. Research in these areas will allow us to identify practices that may be the least detrimental to establishment and persistence of bees in prairie restorations.

While managers have little control over existing site characteristics, such as surrounding habitat, age, or previous habitat type—all of which may affect bee diversity within a site—they can control the methods used to establish and manage habitat. For example, tillage and herbicides, which are commonly used to clear land, are known to disrupt existing nests (Shuler et al. 2005) and potentially affect navigation for some

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species (Balbuena et al. 2015). Whether these patterns apply broadly to most bees is still largely unknown. Thus, it is important to expand research to more bee species to understand how many of the management methods affect bee diversity in general rather than one species in particular.

Plant diversity in tallgrass prairie is likely to be one of the most important features of restored habitats to helping increase bee diversity. But some of the most common methods used to establish plants, such as broadcasting, which is used by over 92% of managers, are known to have variable success rates dependent on season and site (Larson et al. 2011). If increasing forb diversity is most important for bees, it will be important to broadcast during the winter, which is currently done in about half of sites, and possibly to continuously add seed or to drill plant species known to be important for bees. More data on plants that are important for bee diversity are likely to be very important to improving these efforts.

Maintenance of the restored areas will also be critical to maintaining plant diversity and encouraging bee diversity. Over 90% of managers reported burning their sites, which is important for increasing forb diversity. Burning, which can adversely affect cavity-nesting bees, is expected to be good for bee diversity in general by increasing plant diversity and clearing plant debris. Nonetheless, burn intervals may be very important for creating a heterogeneous landscape; however, to date there has been little work to determine if there is an optimal burn frequency that allows cavity nesting bee species to persist, encourages plant growth, and clears land for ground-nesting bees. Other maintenance methods like mowing and haying are largely unexplored and many questions remain about the efficacy of cattle grazing (used by almost 17% of respondents) for helping to maintain bee diversity.

With only 11% of managers explicitly considering bees in the restoration process (see Table 4), many restoration decisions could inadvertently do more harm than good. Given the holes in our knowledge presented here, even managers who are attempting to consider bees during restoration may not have the information needed to make the best decisions for bees. Restoring land specifically for bees is especially important, given that previous studies examining both butterflies and bees in TGP found that they were negatively correlated, so efforts to target one species cannot appreciably spillover to the other (Davis et al. 2008). This is particularly alarming as more easily identified and charismatic species, such as butterflies, may be inappropriately used as surrogates for habitat suitability for bees. More targeted monitoring of bees would assist with identifying the effects of particular restoration methods. Unfortunately, only about one-third of all managers reported monitoring insects at all, with butterflies being the most monitored group. This bias in sampling further supports the need for monitoring bee diversity in restored and remnant habitat to better quantify the potential benefit of TGP restoration to bee conservation efforts. Many managers mentioned a desire to increase monitoring if time and funding permitted, which suggests that partnerships with other universities or agencies could significantly help increase bee monitoring efforts.

Increased monitoring could also help fill some of the significant knowledge gaps that exist in bee responses to management of TGP. While many studies in other habitats can suggest general bee responses, we advocate for more ecosystem specific sampling, as the ecological and evolutionary history of bees and plants are very different between habitats. For example, much of the work on fire and bees was conducted in Mediterranean habitats where fire is infrequent and plant communities are predominantly shrubs (Ne'eman et al. 2000; Potts et al. 2003, 2005). This habitat is unlikely to be very similar to TGP, where fire was historically frequent and forbs are the dominant flowering plants. Even within TGP, different microclimates seem to affect how plants respond to fire (Bowles and Jones 2013), so across this vast region there may be significantly different responses

Table 4. Summary of manager's responses on site monitoring.

Site monitoring	Number of respondents	Types	% respondents
Monitoring	20	Some monitoring	80.0
		Regular monitoring	20.0
		No monitoring	20.0
Groups monitored	15	Plants	100.0
		Insects	33.3
		Birds	13.3
		Other	13.3
Consideration of bee needs	18	No	55.6
		Only generally	33.3
		Specifically	11.1

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of communities to fires and management methods. Therefore, although many more studies exist on bees and response to some of these methods, we resist making broad comparisons and hope to simply highlight some of the known response of bees and link them to some common methods in TGP habitat.

Lastly, although presented separately, it is likely that the methods used to restore and maintain habitat interact with one another and have combined effects on bee and plant diversity. While this will be very difficult to assess, it may be important to consider for bee conservation as particular combinations may be more or less harmful to bees. In general, the TGP habitat has not been extensively studied for bee responses to management and further work is needed in this area to develop a suite of practices that can be widely applied across the region.

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Appendix. Non-interactive sample of online survey.

Survey on Tallgrass Prairie Reconstruction and Management

Hello, and thank you for participating in this survey. My name is Kristen Chin and I am currently writing a review with Dr. Alex Harmon-Threatt about prairie restoration and maintenance and their impacts on solitary bees. Dr. Harmon-Threatt and I are researching all of the different aspects of prairie restoration--from clearing techniques to plant diversity to post-restoration monitoring and maintenance--and attempting to draw a conclusion about their effects on the solitary bees that live in remnants. When maintaining prairies, for example, although fire may cause an immediate decrease in bee population it can also lead to increased bee abundance and diversity in the long run. The survey should take no longer than 15-20 minutes and your answers will help us collect data on current restorations and their management. If you have any questions about this project, feel free to type your question into the last answer box with a name and email for me to reach you at. All personal information is strictly confidential.

Thank you for your time and best of luck this season!
Sincerely,
Kristen

PLEASE NOTE: Some of these questions ask for seed mix ratios/specific amounts of seed--if you don't have an exact ratio, any sort of estimate, or something along the lines of "Heavy on the forbs" is equally as helpful. Thank you!

General Questions about Plot

What kind of land do your restorations take place on?
- o Cropland
- o Poor restorations
- o Old pasture
- o Other:

Type of prairie:

What types of invasives were present before clearing the land?

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Appendix (*Continued*). Non-interactive sample of online survey.

Survey on Tallgrass Prairie Reconstruction and Management (*Cont'd*)

Describe the surrounding landscape of your restoration.

If you are taking the survey in regards to one restoration site, in what year did you begin the restoration?

Size of plot:

Planting Methods
o Hand broadcast
o Mechanical broadcast
o Plugs
o Drill
o Other:

Seeds per acre (in lbs)
o 1-5 lbs/acre
o 5-10 lbs/acre
o 15-20 lbs/acre
o Other:

Estimation of the forb to grass ratio of seed mix?

Where do you get your seeds from?
o 0-50 mi. radius
o 50-100 mi. radius
o >100 mi. radius
o Supplier

If you marked "Supplier," please list the name of the seed company and any commonly used mixes.

In what season do you plant the seed mix?
o Winter
o Early spring
o Fall
o Other:

Are there any invasive species that you feel have become more aggressive/are newly established since restoration began?

Please list the forbs that you feel are most important to the seed mix. If possible, try to indicate relative amounts and any other considerations regarding seedling amounts of forbs.

Please list the grasses that you feel are most important to the seed mix. If possible, try to indicate relative amounts and any other considerations regarding seedling amounts of grasses.

Do you have an percent estimate of your success rate of seedling establishment?
o <25%
o 25-50%
o 50-75%
o 75-100%

Can you give a separate percentages of the success rate of establishment you observe in forb seedlings versus grass seedlings?

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Appendix (*Continued*). Non-interactive sample of online survey.

Maintaining the Prairie (*Cont'd)*

What methods do you use to maintain the prairie once the seed has been planted?
o Burning
o Mowing
o Grazing
o Haying
o Weeding (includes mechanical and manual weeding and use of pesticides)
o Reseeding

In what season/what months do you apply these methods?

If you practice rotational burning/grazing, please explain the way in which you have divided the restoration and the frequency at which you apply these methods.

How have these methods changed in frequency and intensity over time?

Do you/how often do you reseed?

Monitoring

Do you continue to monitor the prairie after having planted seed and helped it to establish? What do you monitor (eg: insects, birds, plants, etc)

Is there any pollinator-specific monitoring?
o Yes
o No

Are there any general trends amongst plants/animals that you have noticed since restoring the prairie?

Are bees taken into consideration as prairies undergo reconstruction?

o Yes
o No

Any Additional Questions or Concerns

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