Drought Influences Control of Parasitic Flies of Cattle on Pastures Managed with Patch-Burn Grazing ☆

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ABSTRACT

We compared the influence of patch-burn grazing to traditional range management practices on abundance of the most economically injurious fly parasites of cattle. Horn flies (*Haematobia irritans*), face flies (*Musca autumnalis*), stable flies (*Stomoxys calcitrans*), and horse flies (*Tabanus* spp.) were assessed at study locations in Oklahoma and Iowa, USA, in 2012 and 2013. Experiments at both locations were spatially replicated three times on rangeland grazed by mature Angus cows. Grazing was year-long in Oklahoma and seasonal in Iowa from May to September. One-third of patch-burn pastures were burned annually, and traditionally managed pastures were burned completely in 2012 but not at all in 2013. Because of significant location effects, we analyzed locations separately with a mixed effects model. Horn flies and face flies were below economic thresholds with patch-burn grazing but at or above economic thresholds in unburned pastures in Iowa. Pastures in Iowa that were burned in their entirety had fewer horn flies but did not have fewer face flies when compared with no burning. There was no difference among treatments in horn fly or face fly abundance in Oklahoma pastures. Stable flies on both treatments at both locations never exceeded the economic threshold regardless of treatment. Minimizing hay feeding coupled with regular fire could maintain low stable fly infestations. Horse flies at both locations and face flies in Oklahoma were in such low abundance that treatment differences were difficult to detect or explain. The lack of a treatment effect in Oklahoma and variable year effects are the result of a drought year followed by a wet year, reducing the strength of feedbacks driving grazing behavior on pastures burned with patchy fires. Patch-burning or periodically burning entire pastures in mesic grasslands is a viable cultural method for managing some parasitic flies when drought is not a constraint.

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Introduction

External parasites of beef cattle cause substantial financial losses, exceeding $2 billion annually in the United States (Byford et al., 1992). Parasitic flies of the order Diptera are some of the most damaging arthropods affecting grazing livestock (Huddleston et al., 1974). Production losses associated with fly parasites are directly attributed to blood loss, annoyance, disease exposure, reduced foraging time, and reduced gains (Harvey and Launchbaugh, 1982; Buxton et al., 1985; Boland et al., 2008). Considering that approximately 50% of the US beef cattle herd relies on the forage base of central North American grasslands, the ecology and management of these grasslands may have meaningful implications for fly parasite mitigation and profitability of beef enterprises (USDA-NASS, 2012).

Before European settlement, central North American grasslands burned regularly due to natural and anthropogenic ignitions followed by ungulate focal grazing on recently burned areas (Anderson, 2006). Over the past 2 centuries, settlement patterns and domestic livestock grazing have largely resulted in the removal of these fire and grazing disturbances in favor of a more utilitarian approach to rangeland management (Pyne, 1997). These changes have included removal of bison and replacement with domestic livestock, fire suppression, and moderate forage utilization across the landscape. Rangeland ecologists have recently suggested a different management paradigm is needed for conservation of patterns and processes essential to conserving biodiversity in these fire-dependent grasslands (Fuhlendorf et al., 2012). Rather than fire suppression and moderate utilization of forage across the landscape associated with traditional rangeland management, it is argued that fire

and grazing should be allowed to interact through space and time across the landscape (Fuhlendorf and Engle, 2001). The primary management tool to restore the fire-grazing interaction has been called *patch-burn grazing*. Functionally, it is applied by burning spatially discrete patches of a pasture and allowing cattle to select where they want to graze. Patch-burn grazing results in a mosaic of patches with variable probabilities of igniting or being grazed that shifts through space and time (Fuhlendorf and Engle, 2004).

The interaction of fire and grazing creates structural heterogeneity of the vegetation benefitting many trophic levels of wildlife (Fuhlendorf and Engle, 2004; Leis et al., 2013). Consequently, this regular application of fire also mitigates invasive plant encroachment and maintains native herbaceous plant dominance in grasslands (Cummings et al., 2007). Although the benefits to biodiversity are well documented, researchers have only recently reported benefits to livestock production. Patch-burn grazing can sustain cow-calf and stocker cattle production compared with traditional management and can stabilize losses associated with climate variability (Limb et al., 2011; Allred et al., 2014).

Patch-burn grazing also can reduce external parasites on cattle. Horn flies (*Haematobia irritans*) on cows during peak periods of activity were reduced on patch-burned pastures compared with pastures not burned at all (Scasta et al., 2012). Season-long tick burdens on cows and calves were also reduced with patch-burn grazing compared with not burning or burning the entire pasture (Polito et al., 2013). These results are encouraging because no other cultural livestock parasite management practice has been developed that can be logistically applied across large landscapes. Furthermore, using insecticides to control livestock parasite results in adverse effects including development of insecticide resistance by the parasite and off-target effects. These concerns drive the need to develop cultural methods that could minimize applications of insecticides (Spratt, 1997; Oyarzún et al., 2008).

A recent study reported parasitic fly response to fire and grazing (Scasta et al., 2012), but the study reported only a single fly species, assessed only peak periods of activity, and compared only patch-burn grazing with no burning. Therefore, our objective was to expand on that previous work to better understand how fire and grazing interactively affect season-long numbers of the most injurious parasitic flies of beef cattle on central North American grasslands: (horn flies, face flies *[Musca autumnalis]*, stable flies *[Stomoxys calcitrans]*, and horse flies *[Tabanus* spp.]). Of these four species, horn flies are vectors of mastitis (McDougall et al., 2009), face flies are vectors of pinkeye and nematode eyeworms (Hall, 1984; O'Hara and Kennedy, 1991), stable flies transmit anthrax (Turell and Knudson, 1987), and horse flies are vectors of at least 30 viral, bacterial, protozoal, and helminth disorders including anaplasmosis (Krinsky, 1976; Hawkins et al., 1982). All species, except face flies, are vectors of bovine leukosis (Buxton et al., 1985). We hypothesized that 1) fire would result in lower numbers of parasitic flies compared with not burning, 2) patchy fires would result in a lower number of parasitic flies than burning an entire pasture, and 3) the effect of patch-burn grazing on parasitic flies would be similar across locations.

Materials and Methods

In 2012 and 2013, we examined patch-burn grazing experiments in Oklahoma and Iowa, United States, that were established in 1999 and 2006, respectively. Parasitism of cattle by four species of parasitic flies was assessed on pastures managed with patch-burn grazing (PBG) and compared with more traditional management. The traditional management approach was considered the control treatment in which a pasture was burned in its entirety followed by no burning the following 2 years, henceforth referred to as the grazing and burning (GAB) treatment. Experiments at both locations were spatially replicated three times with three patch-burn grazed pastures and three control pastures. All cattle were mature beef cows (*Bos taurus*) of the Angus breed (Franks et al., 1964). Mean pasture area was 55 ha in Oklahoma and 27 ha in Iowa. The Oklahoma experiment used year-long grazing with stocking rate of 2.6 ± 0.1 AUM · ha^{-1} in 2012 reduced to 1.8 ± 0.1 AUM · ha^{-1} in 2013 due to drought in 2011 and 2012. The Iowa experiment used seasonal grazed from May to September with stocking rate of 2.6 ± 0.3 AUM · ha^{-1} in 2012 and 2.4 ± 0.4 AUM · ha^{-1} in 2013.

At both locations, we used a 3-year fire-return interval. In PBG pastures, a different third of the pasture was burned each year. In Oklahoma, one-sixth of each PBG pasture was burned each spring (March or early April) and one-sixth burned each growing season (July through October depending on burn bans and fire weather). In Iowa, one-third of each PBG pasture was burned in the spring (March or early April). Cattle in the Oklahoma study were never removed from the study pastures, and they remained in the study pastures when pastures were burned. GAB pastures at both locations were burned in spring 2009 and again in spring of 2012. GAB pastures were not burned in 2010, 2011, or 2013. Pastures and patches were burned by lighting back-fires and flank-fires to build sufficient fire breaks before igniting headfires in a ring fire technique (Weir, 2009). In Iowa, cattle were put on pastures between April 20 and May 2, with an average of April 23 ± 2 days, regardless of treatment or when fires were conducted. In 2012, when all treatments were burned, mean time to stocking after fire was 42 ± 10 days and 47 ± 7 days, GAB and PBG respectively. Mean time to stocking after fire was 21 ± 6 days after fire in 2013 for PBG, but burning was more than 2 weeks later than 2012 due to weather constraints.

Vegetation at the Oklahoma study location is dominated by perennial C4-tallgrass prairie grasses including big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), and indiangrass (*Sorgastrum nutans* [L.] Nash). Vegetation at the Iowa study location is codominated by the aforementioned species, earlier successional grasses and forbs, and the exotic C3-grass tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.).

We assessed the same four species of parasitic flies at both locations: horn flies, face flies, stable flies, and horse flies. Sixty-four tabanid species have been identified in Oklahoma (Wright et al., 1986), but for this study, we identified tabanids only to genus. The most common tabanid species was *Tabanus abactor*, but several other species including *T. sulcifrons* were observed in our samples. Flies were assessed weekly from May to October in Oklahoma and May to August in Iowa. We collected digital photographs of one side of each of four randomly selected cows in each pasture at each sampling date taken between 0700 am and 1100 am (Thomas et al., 1989; Lima et al., 2002; Boland et al., 2008) from a distance of < 30 m and included the single side of each cow (Pruett et al., 2003; Castro et al., 2005). This procedure of randomly selecting new animals that are a subset of the total herd (or replicate group) for monitoring flies has been used in previous livestock entomology studies (Harvey and Brethour, 1979; Haufe, 1982; Kinzer et al., 1984; Kunz et al., 1984; DeRouen et al., 2009, 2010; Li et al., 2011). To assess face flies, we limited images to those in which cows were standing broadside to the camera with the head turned facing the camera so that eyes and nostrils were visible. Images were then systematically evaluated in the laboratory by the same trained technician for the duration of the project. The technician overlaid a digital grid on each image and used digital zoom to count the number of each fly species per cow. None of the herds received insecticides for fly parasites during the study.

Because cattle are free ranging, it is nearly impossible to position yourself the same distance for all photos. However, we used the optical zoom feature of the lens to account for this in the field and

when taking pictures filled the frame with the animal. We also took all pictures within a discrete time window (Thomas et al., 1989) with the sun at our back, which enhances the visible detection of flies on cattle. Thus, digital zoom in the laboratory accounts for any variability and at the distances images were collected overcomes detection probability issues. Furthermore, we consulted the entomological literature for appropriate methods, conducted sampling under the guidance of a livestock entomologist, used an independent laboratory technician for all identification and counting (independent meaning this person did not know the pastures or cows and did not take the pictures), used digital images that serve as a record that could be re-examined if needed, assessed cattle of uniform black color (Franks et al., 1964), and revised our methods from our 2011 study (Scasta et al., 2012) to incorporate digital technology.

Monthly precipitation and monthly mean temperature data from both state automated weather observation networks were collected from the Mt. Ayr, Iowa Mesonet station and Marena, Oklahoma Mesonet station and summarized (Iowa Environmental Mesonet, 2014; Oklahoma Mesonet, 2014). Precipitation was summarized on the basis of the accumulating monthly total for 2012 and 2013 and plotted with the long-term mean. Monthly mean temperature was summarized on a monthly basis and plotted with the long-term mean. Long-term means for the stations were calculated for 1893 to 2013 for Mt. Ayr, Iowa and 1999 to 2013 (the period of record) for Marena, Oklahoma.

Statistical Analyses

We aggregated fly abundance data from the sampling unit, the individual cow, into herd averages by fly species for each weekly sampling period. Fly counts were first analyzed with an ANOVA for each species to determine if abundance differed among treatments (PBG and GAB), years, and locations and to estimate residual covariance. After the initial analyses described earlier, significant location effects were observed for all four species ($P < 0.0001$) and significant year effects were observed for horn flies and face flies ($P < 0.05$). To better understand the role of interannual variation, we then assessed each location separately for year effects for all four species.

Due to significant location effects and variable year effects within locations, we then analyzed locations separately with a mixed effects model (PROC MIXED) using the residual maximum likelihood estimation method. The main fixed effect was a combination of treatment and year (PBG, 2012, 2013; GAB, 2012, 2013), and year was used as a random effect only for the instances where a significant year effect was identified. The season-long mean abundance for each of the four species of flies was the response variable for each analysis. Type III tests assessed fixed effects for significance. To further understand if the driving mechanism of reductions were associated with 1) treatment—how fire was applied (patchy vs. complete pasture) or 2) fire presence/absence—whether fire was applied at all (i.e., fire was applied in a pasture during the sampling year or was not applied during the sampling year), we then conducted a final series of analyses using treatments pooled across years and fire presence/absence pooled across years as separate fixed effects with year assigned as a random effect where previously identified as significant. The three herds (pastures) per treatment at each location were used as replicates, and the weekly sampling replicates were considered repeated measures in all analyses (Polito et al., 2013). Significance of ANOVA models was set at $P \leq 0.05$ (Littell, 2006; SAS Institute, 2011).

Results

Our three hypotheses were not true uniformly across species or study locations. First, fire in general did reduce some species of flies

in Iowa but not Oklahoma, indicating that the effects of fire are not uniform. Second, patchy fires compared with burning an entire pasture in Iowa was an advantage for reducing face flies but not horn flies, rejecting uniform application of our second hypothesis. Third, the effect of patch-burn grazing was not uniform across locations with evidence that localized drought can disrupt the feedbacks driving reductions. Location-specific differences for species were opposite as horn flies were four times higher in Oklahoma, whereas face flies were four times higher in Iowa. In comparison, stable flies and horse flies were in lower abundance than other species at both study locations. This overall abundance related to location and in the context of location should be considered by livestock managers combatting fly parasitism.

Horn Fly (H. irritans)

Cows in the Oklahoma study had four times more horn flies than cows in the Iowa study ($P < 0.0001$), but significant effects of prescribed fire applications were only apparent in Iowa. Furthermore, year was not significant for horn flies in Iowa ($P = 0.75$), but in Oklahoma, 27% more horn flies were observed on cows in 2012 (mean $\pm$ SE, 275 ± 15) than in 2013 (201 ± 17) ($P = 0.001$). In Iowa, cows in patch-burned pastures both years had fewer horn flies than cows in traditionally managed pastures in 2013 when it was not burned, but horn flies were similar between treatments in 2012 when traditionally managed pastures were burned ($P < 0.0001$) (Fig. 1A). The driving mechanism of the reduction in Iowa is a function of both treatment and fire presence/absence as cows in patch-burned pastures had fewer horn flies than traditionally managed pastures ($P = 0.04$) and the cows on traditionally managed pastures the unburned year had more horn flies (86 ± 9) than pastures with patchy or complete pasture fires (61 ± 5) ($P = 0.02$). Furthermore, in burned pastures in Iowa, horn flies were always below the economic threshold of 100 flies per cow side but without any fire horn flies were at the threshold (Gordon et al., 1984; DeRouen et al., 1995). Burning reduced horn flies in Iowa, but in Oklahoma there was no treatment effect (Fig. 1A). Horn flies in the Oklahoma study did not differ by treatment ($P = 0.62$) or fire presence/absence ($P = 0.60$). Horn flies in Oklahoma exceeded 200 per cow side in all treatments, which was much greater than the economic threshold (Gordon et al., 1984) (Fig. 1A).

Face Fly (M. autumnalis)

Iowa cows had four times more face flies than cows in Oklahoma ($P < 0.0001$), and similar to horn flies, significant effects of prescribed fire applications were only apparent in Iowa. In Oklahoma cows had more face flies in 2012 (mean $\pm$ SE, 2 ± 0.3) than in 2013 (1 ± 0.3) ($P = 0.02$), but this was not the case in Iowa ($P = 0.33$). Face flies were at or below the economic threshold of five flies per cow face (Powell and Barringer, 1995) in Iowa in patch-burned pastures both years and fewer than for cows on traditionally managed pastures whether pastures completely burned (10 ± 1) or not burned at all (9 ± 1) ($P = 0.0002$) (Fig. 1B). The driving mechanism of the face fly reduction in Iowa is attributed to how fire was applied rather than simply fire presence/absence because fire presence was not significant ($P = 0.39$), but treatment was ($P < 0.0001$). In Oklahoma, there was no treatment effect ($P = 0.16$) or fire presence/absence effect ($P = 0.16$) (Fig. 1B). Face flies in Oklahoma were below the economic threshold all years for all treatments (Fig. 1B).

Stable Fly (S. calcitrans) and Horse Fly (Tabanus spp.)

Stable flies and horse flies were in lower abundance compared with other species across locations and treatments. Oklahoma cows
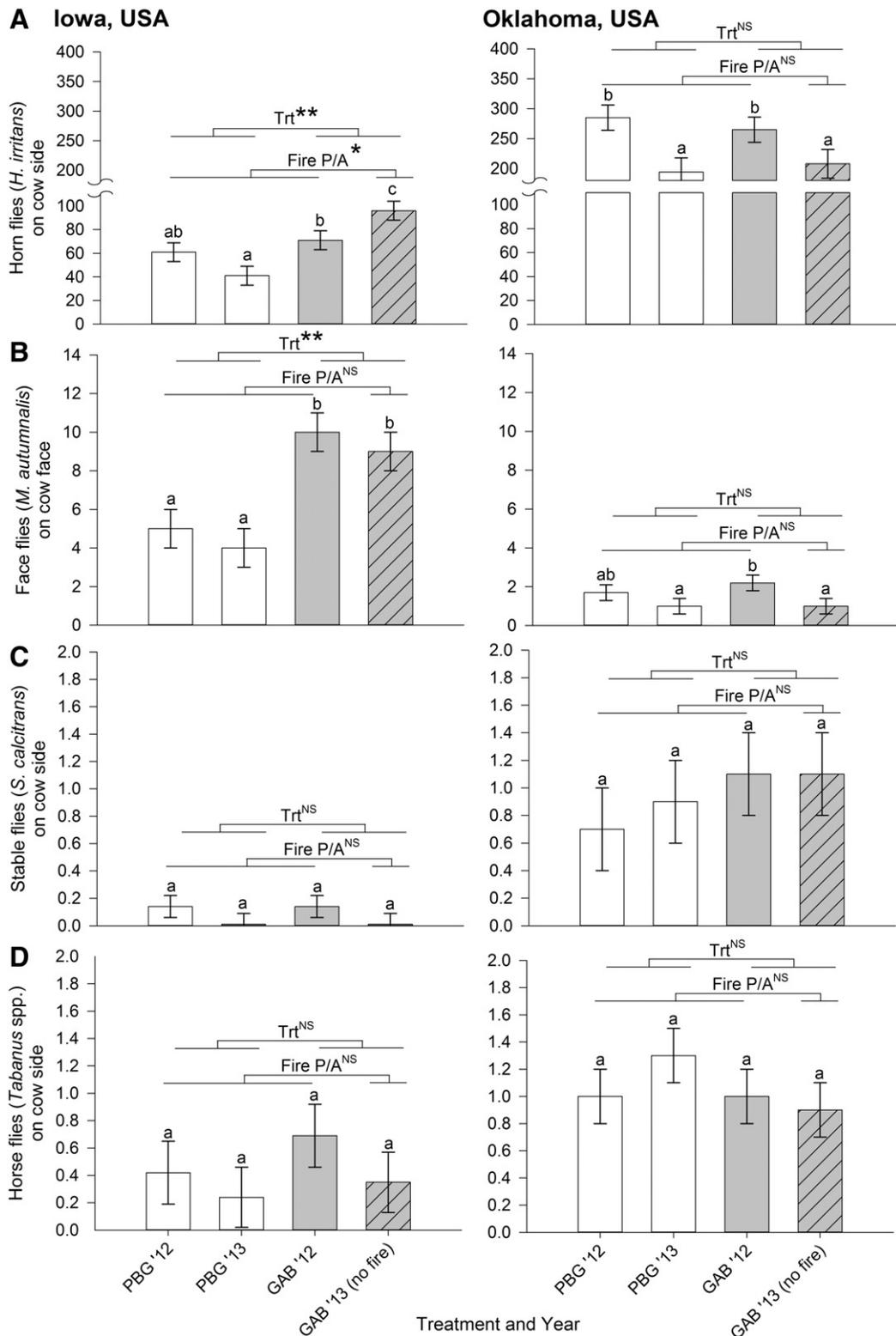
Fig. 1. Treatment notation is PBG (patch-burn grazing, burning a different one-third of the pasture annually with free grazing access to the entire pasture) and GAB (traditional management in which pastures are grazed every year and burned in their entirety every third year). Each bar represents three herds/pastures at that location, year, and for that treatment ($n = 3$). Dashed lines indicate that no fire was applied in that treatment that year. Iowa is in the left column, and Oklahoma in the right column. **A,** Horn flies per cow side. **B,** Face flies per cow. **C,** Stable flies per cow side. **D,** Horse flies per cow side. Horizontal lines also indicate differences between treatments (Trt) and fire presence/absence (Fire P/A). Fire presence/absence is defined as fire was applied in a pasture during the sampling year or was not applied during the sampling year. ** indicates $P < 0.01$, * indicates $P \leq 0.05$, and NS indicates not significant or $P > 0.05$.

had 13 times more stable flies than cows in Iowa ($P < 0.0001$). In Iowa, cows had more stable flies in 2012 (0.14 ± 0.05) than 2013 ($<0.01 \pm 0.05$) ($P = 0.04$) but this was not the case in Oklahoma ($P = 0.87$). Stable flies were well below the economic threshold of three to five flies per leg regardless of location or treatment (Campbell et al., 1987; Campbell et al., 2001) (Fig. 1C). In Iowa, stable

flies were in low abundance, occurring on ~1% of the observed cows, but in Oklahoma, stable flies occurred on ~11% of the observed cows. In Iowa and Oklahoma, there were no differences among treatments and years ($P > 0.05$), treatments pooled by year ($P > 0.05$), or fire presence/absence ($P > 0.05$).

Horse flies at both locations were also in low abundance with fewer than 1 horse fly per cow side regardless of location. Oklahoma cows had 2.5 times more horse flies than cows in Iowa ($P < 0.0001$). Year was significant in Iowa as cows had more horse flies in 2012 (0.6 ± 0.01) than 2013 (0.3 ± 0.01) ($P = 0.017$), but year was not significant in Oklahoma ($P = 0.66$). Horse flies occurred on ~10% of the cows observed in Iowa and ~28% of the cows observed in Oklahoma. There was no difference among treatments ($P = 0.21$) or fire presence/absence ($P = 0.09$) in Iowa (Fig. 1D). In Oklahoma, mean horse flies per cow ranged from 0.9 ± 0.2 to 1.1 ± 0.1 across all treatments and there were no differences among treatments and years ($P = 0.52$), treatments pooled by year ($P = 0.55$), or fire presence/absence ($P = 0.66$) (Fig. 1D).

Discussion

In this study that assessed four of the most injurious and economically detrimental parasitic flies of beef cattle in North America, we quantified reduction of some species with patch-burn grazing and with entire-pasture burning. However, our data are good evidence that drought can disrupt the feedbacks driving reductions. Furthermore, our results demonstrate that the application of spatially and temporally distinct fires and livestock grazing is a novel approach to culturally manage livestock parasites at the landscape scale. These results are relevant to science and management because effective livestock parasite management has been hindered by development of chemical resistance, expense of insecticides, and labor required for conventional parasite management programs (Spratt, 1997; Oyarzún et al., 2008).

The lack of an effect of patch burning on horn flies in Oklahoma compared with previous studies and the significant year effect for other species, and locations may be attributed to climatic variation.
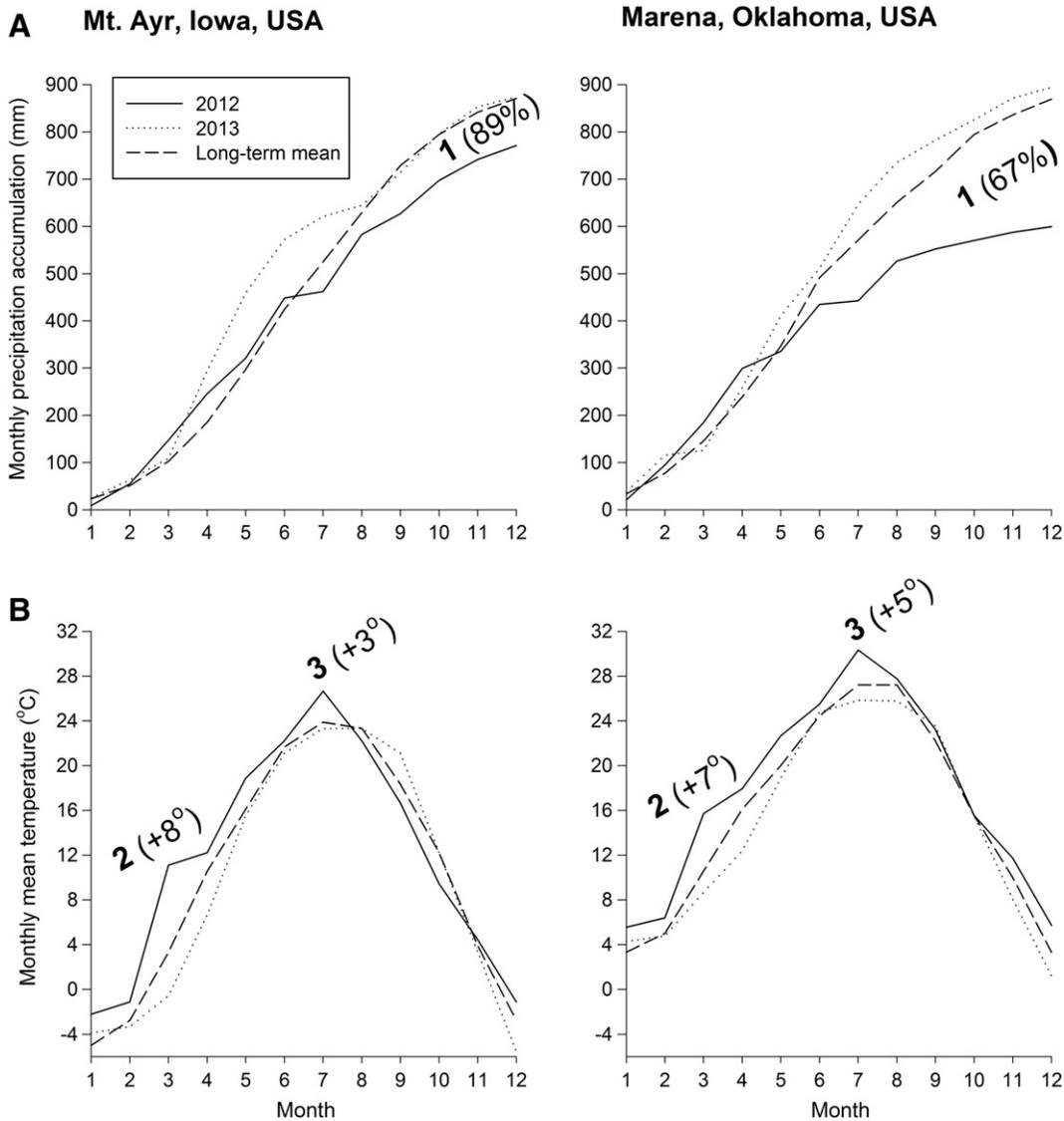

Fig. 2. A, Annual accumulated precipitation (mm) and **B,** monthly temperature (°C) for experiment locations in Mt. Ayr, Iowa, United States, and Marena, Oklahoma, United States, during 2012 and 2013, and the long-term mean from each respective location. 1) Oklahoma experienced one of the most severe droughts in recorded history in 2011 and 2012 with the Oklahoma Mesonet station at Stillwater reporting only 67% of the long-term mean annual precipitation in 2012. 2) Both locations reported earlier warming trends and 3) higher peak temperatures in 2012 compared with 2013 and the long-term mean.

The drought year of 2012 followed by the wet year of 2013 (Fig. 2A) likely reduced the strength of positive and negative feedbacks driving grazing behavior on pastures burned with patchy fires. The drought of 2012 was one of the most severe on record and caused us to reduce stocking rate. Furthermore, earlier warming in 2012 than average, later warming in 2013 than average, and greater heat peaks compared with long-term means (Fig. 2B) may have reduced fuel continuity, burn completeness (defined as the extent of horizontal consumption of fuels in), and contrast between burned areas and unburned areas. This reduction in burn efficacy may weaken the combustion of parasite habitat and attraction of cattle to recently burned areas, ultimately reducing the strength of the fire-grazing interaction.

Our results were complicated because results differed between the two study locations, which can be explained by several probable factors at play. First, seasonal grazing was used at the Iowa location and year-long grazing at the Oklahoma location. In Iowa, movement of the privately owned cattle to the research pastures typically occurred in May after flies had become active. A large-scale study in Texas reported lower horn flies following movement of cattle to pastures 11 km and 19 km away in July and September, respectively (Pruett et al., 2003). The maximum distance from a private cattleman's headquarters and a research pasture in our Iowa study location was 15 km. Secondly, the pastures in Iowa have a large component of tall fescue, an exotic C3 grass that harbors a toxic endophyte *(Acremonium coenophialum)* (McGranahan et al., 2012). Specific alkaloids associated with this endophyte can cause toxicity to mammals and invertebrates. In particular, loline alkaloids have been implicated in invertebrate toxicity. Entomological studies have reported that both horn flies and face flies have lower pupation and pupal liveweights in feces from cattle fed endophyte-infected fescue due to loline exposure (Dougherty and Knapp, 1994; Dougherty et al., 1998; Dougherty et al., 1999; Parra et al., 2013). At the Iowa site, consumption by cattle of *S. arundinaceus*, and therefore consumption of lolines, might potentially be increased in the most recently burned patch. Previous studies have shown that fire can overcome cattle aversion to plants containing secondary compounds including tannins in *Lespedeza cuneata* (Cummings et al., 2007).

Our study confirms that differences in life histories and habitat requirements among these parasitic flies can explain some of the results of our experiment. Each of the fly species assessed in our study has a unique biological cycle so that mechanisms of coping with fire may be species specific. Horn flies are obligate blood-sucking parasites that only leave cows to deposit eggs in fresh manure and pupae overwinter in fecal pats (Foil and Hogsette, 1994). The timely application of dormant-season fire, as well as subsequent combustion of dry feces containing fly larvae before emergence, is suspected to be the primary causal effect for horn fly reduction following burning of pastures (Scasta et al., 2014). However, the physical burning of fecal pats that contain overwintering fly pupae do not carry over to the next year if fire has not been applied between when larvae oviposit in the fall and when cattle are turned out and flies begin to emerge from fecal pats in the spring. Because the GAB pastures were not burned again after spring of 2012, emergence in 2013 of fly larvae from fecal resources in 2013 was not disrupted.

In comparison, horse flies are one of the most livestock-independent species that need few blood meals, and larval habitats are independent of livestock (Foil and Hogsette, 1994). Eggs are generally deposited in vegetation that is in or over water and larvae drop into the water after hatching (Huddleston et al., 1974). Other studies have reported that horse fly distribution is associated with landscape structure. Biting activity is not associated with landscape structure but instead is rather a function of attractiveness to herds, dispersal ability of horse flies, and weather (Baldacchino et al., 2014). Consequently, the effects of patch-burning on horse flies in Iowa are

difficult to interpret considering the low population of horse flies coupled with the absence of a clear influence of burning on the habitat or life cycle of the horse fly.

Stable flies are even less dependent on livestock than are horn flies. They require blood for survival and reproduction, but they spend a relatively small amount of time with the host. Stable flies lay eggs in feces and other substrates such as decaying vegetation, particularly accumulated wasted hay around hay feeding sites (Talley et al., 2009). Thus, a potential reduction mechanism for stable flies, as well as a potential explanation for the difference in stable fly abundance between study locations, could be attributed to hay feeding practices. In Iowa, seasonal grazing does not require hay feeding on the treatment pastures, whereas in Oklahoma, year-long grazing requires some hay feeding during extreme winter weather. Therefore, the lack of hay feeding may partially explain the lower abundance and occurrence of stable flies in Iowa. Furthermore, periodic application of fire may help maintain stable fly numbers below economic thresholds, as all of our locations were burned at least once during the 2-year study period.

Lastly, life history and habitat requirement can explain the results related to face flies, which do not rely on blood meals taken from bites they initiate but rather from mucus secretions from the eyes and nose. Face flies also overwinter in feces and have an affinity for woody plants for thermal regulation (Krafsur and Moon, 2008). Thus reduction of shrubs and trees and combustion of fecal pats with fire may reduce face fly habitat. However, it appears that patchy fires and the potential differences in fire completeness among treatments caused the treatment difference in the Iowa study. The lack of grazing in long-unburned patches results in rapid fuel accumulation, and greater fire intensity will result in greater scorch and mortality of woody plants (Van Wagner, 1973; Kerby et al., 2007). For example, in the traditionally managed pastures in Iowa, the completeness of burn was as low as 65% but in the patch-burned pastures, the lowest was 95% (data not presented). Furthermore, although face flies have recently been detected northeast of our Oklahoma study site, they were in low abundance during our study (Krafsur and Moon, 2008; Talley, 2012).

The origin and developmental adaptation to fire-grazing disturbances of each of these species may also explain reductions realized with patch-burn grazing. Horn flies and face flies are considered to be nonindigenous to North America as they were both introduced from Europe (Huddleston et al., 1974; Fincher et al., 1990). Origin of stable flies has been debated, but it is generally accepted that they also are nonindigenous to North America (Colautti et al., 2006). These nonindigenous flies were brought to North America with the introduction of cattle. The horse fly species assessed at our study sites, however, are considered to be indigenous to North America (Goodwin, 1994). Thus the nonindigenous species for which we observed a reduction after burning may be less adapted to the fire-grazing disturbance. Furthermore, alternative management strategies for fly parasites are especially relevant in the current period of record beef cattle prices because as price rises, the economic thresholds for treating for these fly parasites decrease (Gordon et al., 1984).

We posit patch-burn grazing more effectively reduces parasitic flies on cattle as compared with entire-pasture burning via five mechanisms. First, fire combusts or reduces overwintering fecal habitat that contains puparium (Scasta et al., 2014). Secondly, spatially discrete burned patches attract animals to the patches where overwintering fecal habitat has been reduced, a potentially parasite free area due to fire (Allred et al., 2011). Third, fire mitigates woody plant encroachment and consumes plant litter that serves as habitat for some species (Bragg and Hulbert, 1976; Fuhlendorf and Engle, 2004). Fourth, moving fire and preferentially grazed areas around

the landscape through space and time moves the disturbance of habitat around the landscape (Vermeire et al., 2004). Last, creating livestock movements and fire and grazing disturbances at an effective landscape scale disrupts the biological cycle as new generations emerge so that they may not effectively disperse to new hosts (Allred et al., 2013). Although several of these mechanisms are also possible from burning a pasture completely, the movement of livestock and fire disturbances around the landscape through time is a unique aspect of patch-burn grazing that is beneficial for reducing other parasites such as ticks (Polito et al., 2013).

Implications

Patch-burn grazing can reduce parasitic flies but may not reduce all parasitic flies at all times. Because the treatment of parasites is often reactive, the strategic application of fire could be a proactive approach to altering fly habitat. Additional research is needed on the effective spatial application of fire because flies can disperse great distances upon emergence to find a host. At the Iowa location where fire was effectively applied, the distance between a burn patch in 2012 and a burn patch in 2013, center to center, ranged from 230 m to 565 m and mean patch size was 9 ha. Additional research is also needed on how severe drought inhibits fire operations and animal distribution relative to burned areas. This information will help managers and researchers understand how patchy fires could be integrated with other chemical and biological control strategies because chemical resistance continues to limit the efficacy of insecticides and the current high beef cattle market has lowered economic thresholds for treatment. Given the potential to reduce parasites with fire (Scasta, 2015), specifically patchy fires, patch-burn grazing should be considered as another tool in the toolbox for managing livestock production and natural resources.

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