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ORIGINAL PAPER

The influence of fire on Illinois hill prairie Auchenorrhyncha (Insecta: Hemiptera) diversity and integrity

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Abstract Prescribed burning has been important in maintaining the structure of plant communities in the tallgrass prairie. However, implementation of these burn regimes often overlooks responses of other taxa, particularly arthropods. In this study, the timing and frequency of burns were examined on one of the most diverse and abundant groups of herbivorous insects, Auchenorrhyncha. These insects are ideal candidates in understanding the effects of fire on prairie arthropods because they are among the most numerous invertebrate herbivores in the prairie and they have ecological characteristics that confer a wide range of responses to prescribed burning. A total of 19 Illinois hill prairies were sampled along the Mississippi and Sangamon Rivers in the summer of 2006 using a modified leaf-blower vacuum. These sites exhibited a wide range of burn management, from unburned to recently burned, and having been burned multiple times. Species richness, Auchenorrhyncha Quality Index (with and without abundance data) and the mean coefficient of conservatism (with and without abundance data) were calculated for each site. Results suggest that unburned sites supported the greatest number of species and had higher Auchenorrhyncha Quality Index and mean coefficient of conservatism values than sites undergoing burn management. In order for land managers to maintain the prairie Auchenorrhyncha community and conserve vascular plants, this study recommends infrequent rotational burning with a minimum of 3–5 years; although additional studies are needed to determine the appropriate number of years between each burn.

Keywords Auchenorrhyncha · Habitat quality index · Tallgrass prairie · Prescribed burning · Hill prairie

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Introduction

Historically, fire has played a significant role in the maintenance of North American tallgrass prairies (Gleason 1913; Anderson 1990; Collins and Gibson 1990; Robertson et al. 1997). Burning can prevent invasion of trees and shrubs (Gibson and Hulbert 1987) and reduce the spread of invasive non-prairie species (Anderson 1972; Wilson and Stubbendieck 1997). Burning also can stimulate plant productivity, increase native perennial grass abundance, and aid in the production of seedlings (Anderson 1965; Glenn-Lewin et al. 1990; Seastedt and Ramundo 1990) although these increases in plant productivity is dependent on the timing of fire (Bragg 1995; Jog et al. 2006). Elimination of fire on prairie remnants has lead to an annual loss of 0.45–1.03% of plant species (Leach and Givnish 1996), potentially reducing ecological integrity of these remnants. In an attempt to reverse these changes fire has been re-introduced or increased on these remnants under highly prescribed conditions (Johnson et al. 2008). Controlled burning has now become a frequently used management tool for improving prairie remnant quality (Wright and Bailey 1980; Collins and Gibson 1990).

Despite these advantages prescribed burning has had a wide range of effects on other diverse and abundant groups of prairie organisms, in particular terrestrial arthropods (Rice 1932; Cancelado and Yonke 1970; Riechert and Reeder 1970; Nagel 1973; McCabe 1981; Opler 1981; Hansen 1986; Anderson et al. 1989; Bock and Bock 1991; Dana 1991; Orwig 1992; Fay and Samenus 1993; Hamilton 1995; Swengel 1996; Reed 1997; Harper et al. 2000; Panzer and Schwartz 2000; Swengel 2001; Panzer 2003). Swengel (1996) observed that most conservative butterflies inhabit sites that have not been burned for 4 or more years, whereas highly vagile butterflies, such as orange sulfurs, monarchs, and cabbage whites were common on burned sites. Evans (1984, 1988) found that sites unburned for 4 years or more supported more fire sensitive, forbs-feeding grasshoppers whereas grasshoppers specializing on grasses were more abundant on sites burned annually or biennially. On the other hand, Panzer (2002) found that most prairie-restricted insects, from seven insect orders, recolonized recently burned sites after 2 years or less. Carabid beetles (Larsen and Williams 1999), prairie ants (Trager 1990), and spiders (Halvorsen and Anderson 1980) were unaffected by burning.

Because terrestrial arthropods display a great degree of variation in response to controlled burning, no single burn management program to protect all arthropods has been successful. For instance, some studies show that 3-years rotational burns (Reed 1997) are adequate, other studies have found that 2-years rotational burns are successful (Panzer 2002), and other studies have found that a combination of rotational burning combined with an unburned refuge were effective in conserving many prairie-inhabiting butterflies (Swengel and Swengel 2006). Additional studies based on other diverse groups of prairie arthropods are required to provide land managers with a more complete understanding of the role of fire on terrestrial arthropod communities. This information would aid land managers in developing burn management practices that are less harmful to terrestrial arthropods, and in so doing conserve a greater proportion of the prairie biota.

The purpose of this study is to determine the effects of prescribed burning on Auchenorrhyncha (i.e., leafhoppers, planthoppers, spittle bugs, treehoppers, and cicadas), with the intent of providing new insights in the design and implementation of burn management practices in prairies. Auchenorrhyncha are ideal candidates in understanding the effects of fire on prairie arthropods because are they among the most numerous invertebrate herbivores in the prairie, including many species restricted to prairie habitats and they have ecological characteristics that confer a wide range of responses to prescribed burning (Hamilton 1995; Harper et al. 2000; Panzer 1988; Panzer and Schwartz 2000, 2002, 2003; Hamilton and Whitcomb 2010). More specifically, these insects will be used to examine the following questions: (1) what is the response of prairie Auchenorrhyncha integrity (i.e., the native species that should be present given that their host plants occur on Illinois hill prairies) and diversity after prescribed burns; and (2) how does burn frequency influence prairie Auchenorrhyncha integrity and diversity. Since many prairie Auchenorrhyncha exhibit life history traits (e.g., low mobility, overwinter in dead vegetation or duff, and have low numbers of generations) that make them vulnerable to fire (Hamilton 1995; Reed 1997; Nickel 2003; Hamilton and Whitcomb 2010), we hypothesize that prairie Auchenorrhyncha integrity and diversity will respond negatively to recent and frequent burning.

Methods

Study sites

We sampled 19 Illinois hill prairies along the Mississippi and Sangamon Rivers in the summer of 2006 (Fig. 1). Study sites extended from Monroe County to Jo Daviess County. These sites ranged in size from 0.1 to 7 acres (Table 1). Many of these sites were maintained by controlled burn management: 6 sites had not been burned in 30 years (i.e. unburned), 3 sites were recently burned in the spring of 2006 (i.e. 0 year), 4 sites were burned in the spring of 2005 (i.e. 1 year), 3 sites were burned in the spring of 2004 (i.e., 2 year), and 3 sites were burned between the spring of 2001 and 2003 (i.e., 3–5 years) (Table 1). Also, these sites displayed a range in burn frequency: 5 sites were burned once, 3 sites were burned twice, and 5 sites were burned more than twice (Table 1). Besides timing and frequency of prescribed burns at the study sites, limited information was available regarding the implementation of these prescribed burns (e.g., rotational burns vs. entire unit) or other management practices (e.g., grazing). Land management history was provided by land managers and land owners.

Study sites were surrounded by secondary growth forest and dominated by prairie grasses, such as *Boueloua curtipendula* (Side Oats Grama), *Schizachyrium scoparium* (Little Bluestem), and *Andropogon gerardii* (Big Bluestem) and forbs, such as *Amorpha canescens* (lead plant). Furthermore, the majority of these sites, such as hill prairies in Monroe and Randolph counties (Fig. 1), was once part of a large complex of sites with similar plant species composition (Evers 1955; Robertson et al. 1995), and thus should harbor a similar Auchenorrhyncha fauna that are comparable between sites. Lastly, all prairies surveyed for this study were loess hill prairies, which are island-like openings of prairie that occur on steep slopes surrounded

Fig. 1 Distribution of 19 hill prairie remnants sampled within the Illinois tallgrass prairie, USA. *Circles* in selected Illinois counties represent the general location of each hill prairie sampled. Map was obtained from http://www.nationalatlas.gov/

Table 1 Distribution of 19 sites

Site	County	TSLB	Frequency	Acres	Spp.	N	$meanCC_{w/N}$	$AQI_{w/N}$	$meanCC_{w/outN}$	$AQI_{w/outN}$
MSP	Madison	1 year	More than twice	0.5	5	7	8.21	18.37	7.95	17.78
Brickey-GontB	Monroe	0 years	More than twice	1.1	6	28	5.26	12.88	6.88	16.84
Olin	Madison	0 years	More than twice	1.8	6	15	6.98	17.11	9.75	23.88
Brickey-GontA	Monroe	0 years	More than twice	1.9	7	16	5.69	15.05	7.75	20.50
Jennings	Calhoun	2 years	More than twice	2	9	89	11.96	35.89	9.94	29.83
Gonterman	Randolph	1 year	Once	0.1	7	215	12.30	32.53	11.71	30.99
Grubb Hollow	Pike	3 years	Once	2	25	203	11.42	57.11	7.60	38.02
Demint	Randolph	2 years	Once	2.4	11	57	10.99	36.44	8.52	28.27
ChalfinA	Monroe	2 years	Once	3	7	21	10.43	27.59	9.50	25.13
ChalfinB	Monroe	1 year	Once	5	8	45	10.51	29.73	10.09	28.55
Hanover	Jo Daviess	1 year	Twice	0.1	8	120	11.12	31.44	10.13	28.64
Principia	Jersey	3 years	Twice	0.6	10	121	12.72	40.23	11.50	36.37
Fults	Monroe	5 years	Twice	3.1	12	101	10.73	37.16	10.88	37.67
Gunterman	Monroe	Unburned	None	0.16	16	102	12.28	49.14	10.44	41.75
Bland	Greene	Unburned	None	0.8	14	208	11.89	44.50	11.57	43.30
Walnut Grove	Pike	Unburned	None	3	20	196	10.80	48.31	8.64	38.63
Housen	Pike	Unburned	None	3	19	280	11.60	50.57	8.91	38.83
OstermanB	Calhoun	Unburned	None	6	13	179	12.44	44.84	8.91	32.12
OstermanA	Calhoun	Unburned	None	7	10	61	12.59	39.83	10.98	34.71

Time since sites were burned last (TSLB), burn frequency, acres, total species richness (spp.), total abundance of all auchenorrhynchan species found on each site (N), mean coefficient of conservatism values with and without abundant for each site, and AQI values with and without abundance for each site. Mississippi Sanctuary Prairie (MSP), Brickey-Gonterman A (Brickey-GontA), Brickey-Gonterman B (Brickey-GontB)

by forests that are adjacent to major rivers in the Midwestern United States (Evers 1955; Robertson et al. 1995). Loess hill prairies are often characterized by having a thick layer of loess composed of windblown silt and clay particles. These prairies represent some of the last remaining prairie habitat in Illinois.

Sampling protocol

Three 40 m-linear transects were placed perpendicular to a 50 m baseline. Each transect was 5 m apart from the neighboring transect. All transects were placed within the prairie away from edges, which increased the likelihood of collecting most of the prairie Auchenorrhyncha. Auchenorrhyncha were collected with a modified leaf blower vacuum for approximately 5 min and stored in 95% ethanol. Sampling took place between 1200 and 1800 h, between the third week of July and second week of August, 2006, when Auchenorrhyncha abundance and species richness are at their peak (Blocker et al. 1972; Blocker and Reed 1976). All adult Auchenorrhyncha were identified to species, individuals were tallied, and specimens were deposited at the Illinois Natural History Survey Insect Collection. Auchenorrhyncha nomenclature followed DeLong (1948), Wilson and McPherson (1980), Whitcomb and Hicks (1988), Bartlett and Deitz (2000).

Weighted indices of Auchenorrhyncha integrity variables

Auchenorrhyncha integrity was measured by computing the following variables:

S = total number of species encountered at a site.
AQI = meanCC*$\sqrt{S}$; MeanCC = Mean coefficient of conservatism value for all species encountered per sampling effort (site); $\sqrt{S}$ = Square root transformation of the total number of species encountered at the site sampled (Wallner 2010).
The AQI was also computed using abundance (i.e., AQIwN).
AQIwN = $\sum [(n_i/N) * CC_i] * \sqrt{S}$, in which n_i = total number of individuals for species i; N = total number of individuals for all species; CC_i = Coefficient of Conservatism for species I; $\sqrt{S}$ = square-root transformation of the total number of species encountered per sampling effort (Wallner 2010).

The CC values are calculated scores from 0 to 18 assigned to each auchenorrhynchous species encountered. Species that are adapted to frequent disturbance (e.g. fire management) and feed and overwinter on a variety of host plants received values ranging from 0 to 5. Species that can tolerate moderate levels of disturbance, are found in edge habitat and in native grassland, and feed and overwinter on prairie and some non-prairie plants received values ranging from 6 to 10. Species that are sensitive to disturbance, restricted to native grassland, and feed and overwinter on native grassland vegetation received values ranging from 11 to 18 (Appendix).

Data analysis

One-way ANCOVAs using site area as covariant, followed by Tukey's post-hoc test were used to determine the impact of prescribed burns (i.e., timing and frequency) on Auchenorrhyncha integrity and diversity. Area was included in the analysis because studies have shown a direct relationship between species diversity and area (MacArthur and Wilson 1967; Simberloff and Wilson 1969), and thus area may influence Auchenorrhyncha integrity and diversity. Kolmogorov–Smirnov test was used to test for normality and the Levene's test was used to examine if the data had equal variance (Ott and Longnecker 2001). All statistical tests were performed with Systat 11 (Systat Software Inc. 2004). Changes in Auchenorrhyncha species composition among different prescribed burn management treatments were also documented. Means and standard errors are reported. Lastly, with the exception of one statistical result considered significant at 0.055 (due to its biological significance), all statistical significance was considered at $P \leq 0.05$.

Results

We collected 65 auchenorrhynchan species on these 19 sites, from 53 genera and 11 families (Appendix). Of these, 64 (98%) were native, while 1 (2%) were non-native. Of the native taxa, approximately 28 species (43%) are considered remnant dependent and sensitive to disturbance; 15 species (23%) can tolerate a moderate amount of disturbance and are associated with prairies, ecotonal habitat, and non-prairie habitat; and 22 species (34%) are adapted to frequent disturbance and are not denizens of prairies (Appendix). Numbers of species per family were: Cicadellidae (44), Dictyopharidae (5), Delphacidae (4), Caliscelidae (4), Cercopidae (3), Membracidae (1), Acanalinoiidae (1), Achilidae (1), Cicadidae (1), and Fulgoridae (1). The most speciose genus was *Polyamia* with 4 species.

Unburned sites had significantly more species than recently burned sites (Fig. 2) and frequently burned sites (Fig. 3). Species richness differed based on time since last burn ($F = 4.87, P = 0.01$), but was not affected by site area ($F = 0.43$, $P = 0.52$). Species richness was significantly higher on unburned remnants (15.20 ± 1.90; Tukey's test, $P < 0.05$) compared to remnants burned most recently (0 year; 6.33 ± 0.33) and 1 year ago (7.50 ± 0.90), but not 2 years and (9.00 ± 1.15) and 3–5 years ago (15.67 ± 4.70; Fig. 2). Species richness differed based on burn frequency ($F = 3.23, P = 0.055$), but was not affected by site area ($F = 0.50$, $P = 0.49$). Unburned sites (15.33 ± 1.54; Tukey's test, $P < 0.05$) had significantly more species than sites burned more than twice (6.60 ± 0.68), but not sites burned once (11.60 ± 3.43) and twice (10.00 ± 1.16).

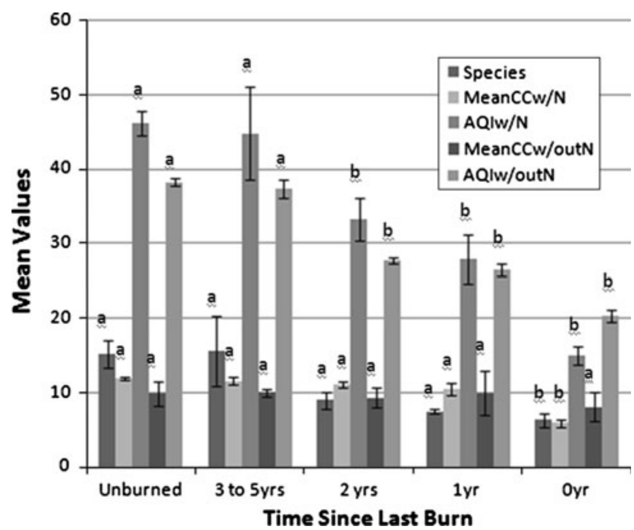

Fig. 2 Summary of responses to time since a prescribed burned from 19 hill prairies in Illinois for Auchenorrhyncha integrity and diversity measures. Each *bar* depicts the mean (±SE) Auchenorrhyncha integrity and diversity measures. *Bars* with different *letters* indicate significant differences between burn treatments (post hoc Tukey's test, $P < 0.05$)

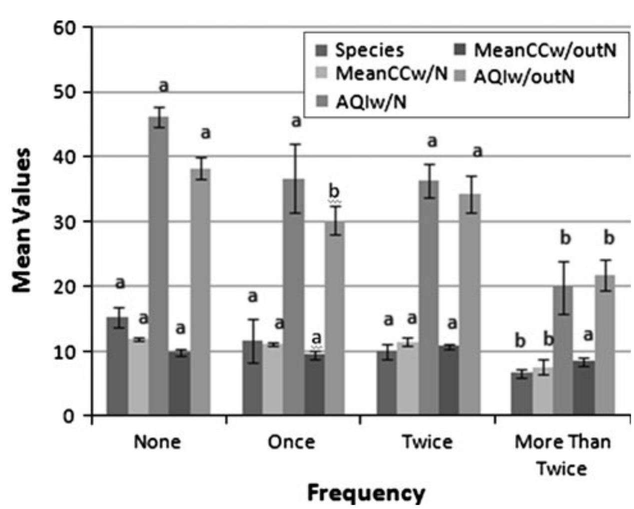

Fig. 3 Summary of responses to frequency of prescribed burns from 19 hill prairies in Illinois for Auchenorrhyncha integrity and diversity measures. Each *bar* depicts the mean (±SE) of Auchenorrhyncha integrity and diversity measures. *Bars* with the different *letters* indicate significant differences between burn treatments (post hoc Tukey's test, $P < 0.05$)

Unburned sites yielded significantly higher $\text{meanCC}_{w/N}$ values than recently burned (Fig. 2) and frequently burned sites (Fig. 3). $\text{MeanCC}_{w/N}$ differed based on time since last burn ($F = 15.27$, $P = 0.00$), but was not affected by site area ($F = 0.07$, $P = 0.95$). $\text{MeanCC}_{w/N}$ was significantly higher in unburned prairie remnants (11.93 ± 0.27; Tukey's test, $P < 0.05$) than sites burned recently (0 year; 5.98 ± 0.52), but was not significantly greater than sites burned 1 year (10.54 ± 0.86), 2 years (11.13 ± 0.45), and 3–5 years ago (11.62 ± 0.58). $\text{MeanCC}_{w/N}$ differed based on burn frequency ($F = 7.21$, $P = 0.00$), but was not affected by site area ($F = 0.23$, $P = 0.88$). $\text{MeanCC}_{w/N}$ was significantly higher in unburned sites (11.93 ± 0.27) compared to sites burned more than twice (7.62 ± 1.20; Tukey's test, $P < 0.05$), but was not significantly greater than sites burned once (11.13 ± 0.34) or twice (11.52 ± 0.61).

Unburned sites showed significantly higher $\text{AQI}_{w/N}$ values than recently burned (Fig. 2) and frequently burned sites (Fig. 3). $\text{AQI}_{w/N}$ differed based on time since last burn ($F = 16.13$, $P = 0.00$), but was not affected by site area ($F = 0.56$, $P = 0.47$). $\text{AQI}_{w/N}$ values were significantly higher on unburned sites (46.20 ± 1.61; Tukey's test, $P < 0.05$; Fig. 2) than sites burned 0 year (15.01 ± 1.22), 1 year (28.02 ± 3.27), 2 years (33.31 ± 2.86), and marginally greater than sites burned 3–5 years ago (44.83 ± 6.20; $P = 0.06$). $\text{AQI}_{w/N}$ values differed based on burn frequency ($F = 8.66$, $P = 0.00$), but were not affected by site area ($F = 0.44$, $P = 0.52$). Unburned sites (46.20 ± 1.61; Tukey's test, $P < 0.05$) yielded significantly higher $\text{AQI}_{w/N}$ values than sites burned more than twice (19.86 ± 4.12), but did not significantly differ from sites burned once (36.68 ± 5.32) or twice (36.28 ± 2.56).

Unburned sites had higher $\text{meanCC}_{w/outN}$ values compared to recently burned (Fig. 2) and frequently burned sites (Fig. 3). However, $\text{meanCC}_{w/outN}$ values did not differ based on time since last burn ($F = 0.97$, $P = 0.46$) and were not affected by site area ($F = 0.16$, $P = 0.70$). Also, $\text{meanCC}_{w/outN}$ values did not differ based on burn frequency ($F = 2.22$, $P = 0.13$) and site area ($F = 0.17$, $P = 0.68$).

Unburned sites yielded significantly higher $\text{AQI}_{w/outN}$ values compared to recently burned sites (Fig. 2) and frequently burned sites (Fig. 3). $\text{AQI}_{w/outN}$ values differed based on time since last burn ($F = 15.02$, $P = 0.00$) and were not affected by site area ($F = 2.31$, $P = 0.15$). $\text{AQI}_{w/outN}$ values were significantly higher on unburned sites (38.22 ± 1.72; Tukey's test, $P < 0.05$) than sites burned at 0 year (20.41 ± 2.03), 1 year (26.49 ± 2.96), and 2 years ago (27.74 ± 1.38), but were not significantly different from sites burned 3–5 years ago (37.35 ± 0.50). $\text{AQI}_{w/outN}$ values were significantly higher on prairies burned 3–5 years ago compared to prairies burned recently (0 year) and 1 year ago, but not significantly greater than sites burned 2 years ago. $\text{AQI}_{w/outN}$ values differed based on burn frequency ($F = 12.13$, $P = 0.00$), but were not affected by site area ($F = 1.58$, $P = 0.23$). Unburned sites (38.22 ± 1.72; Tukey's test, $P < 0.05$) yielded significantly higher $\text{AQI}_{w/outN}$ values than sites burned more than twice (21.77 ± 2.36) and once (30.19 ± 2.17), but were not significantly greater than sites burned twice (34.23 ± 2.82).

We also detected declines in conservative (i.e., remnant-dependent and fire-sensitive), moderately-conservative, and adventives auchenorrhynchan species richness based on timing (Fig. 4) and frequency (Fig. 5) of burns, with conservative species being the most affected by these practices. For example, conservative auchenorrhynchan species, such as *Flexamia* spp., *Laevicephalus* spp., *Bruchomorpha* spp., and *Polyamia* spp. declined on recently burned sites compared to unburned sites and sites burned 3–5 years ago. We also observed increases in species and abundance of adventives species, such as *Draeculacephala* spp., *Empoasca* spp. and *Erythroneura* spp. (Typhlocybinae leafhopper species) in recently burned and frequently burned sites (Appendix). In contrast, these adventives species were absent or were represented by a few individuals on unburned sites and sites burned 3–5 years ago, and infrequently burned sites (Appendix).

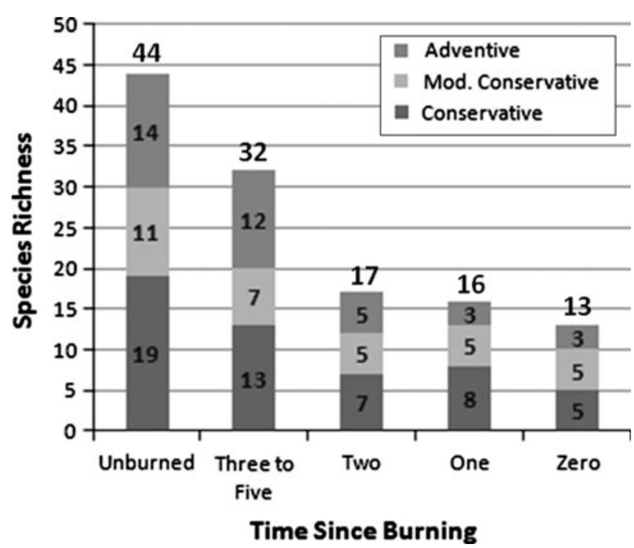

Fig. 4 Distribution of Auchenorrhyncha species richness based on their coefficient of conservation (CC) values in responses to time since a prescribed burned from 19 hill prairies in Illinois. The *numbers* above the columns are the total number of auchenorrhynchan species for each time since burn treatment. The *numbers* within each of the columns are the total number of highly conservative (CC from 11 to 18), moderately-conservative (CC from 6 to 10), and adventives (CC from 0 to 5) auchenorrhychan species found for each burn treatment

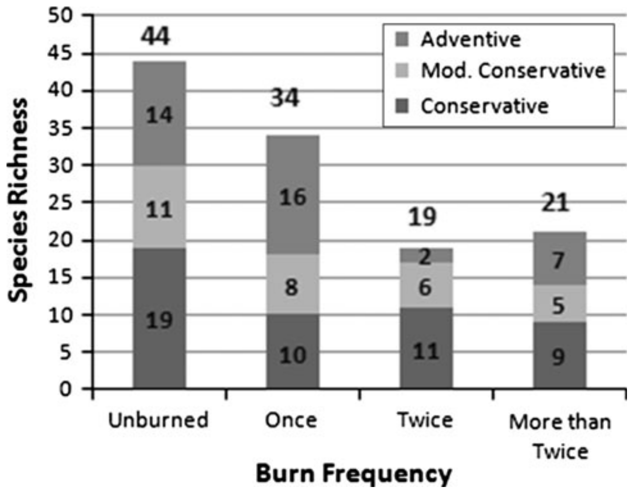

Fig. 5 Distribution of Auchenorrhyncha species richness based on their coefficient of conservation (CC) values in responses to frequency of prescribed burns from 19 hill prairies in Illinois. The *numbers* above the columns are the total number of auchenorrhynchan species for each burn frequency treatment. The *numbers* within each of the columns are the total number of highly conservative (CC from 11 to 18), moderately-conservative (CC from 6 to 10), and adventives (CC from 0 to 5) auchenorrhychan species found for each frequency treatment

Discussion

Overall effects

The objective of this study was to determine the effects of prescribed burning on prairie Auchenorryncha integrity and diversity. The results from this study showed that unburned sites supported the greatest number of species, had the highest Auchenorrhyncha integrity, and area did not influence hill prairie Auchenorrhyncha integrity and diversity. These data support our hypothesis that unburned sites will have higher Auchenorrhyncha diversity and integrity than sites under constant fire management. Furthermore, these results are consistent with other studies that demonstrate the importance of fire in influencing the dynamics of prairie insect community assemblages and that prairie Auchenorrhyncha respond negatively to fire (Whitcomb et al. 1988; Hamilton 1995; Reed 1997; Harper et al. 2000; Panzer 2002, 2003; Hamilton and Whitcomb 2010). However, a recent study by Henderson (2010) found no strong fire effects on leafhopper communities, but similar to our study no area effect on prairie-specialist leafhoppers was found.

Time since burn treatments

Unburned sites supported more conservative species as time since a burn increased (Figs. 2, 4, Appendix). For instance, unburned sites harbored 44 (68%) out of the total 65 species encountered from all 19 sites used in the statistical analysis and 19 of these 44 species (43%) were dependent on prairies and intolerant to fire. Some of these species include *Bruchomorpha jocosa*, *B. tristis*, *Flexamia pectinata*, *F. prairiana*, *Laevicephalus minimus*, and *Polyamia dilata*. Similar compositions of conservative auchenorrhynchan species were observed on other unburned prairies in Kansas (Blocker et al. 1972), Illinois (Harper et al. 2000; Panzer 2002; Hamilton 1995), and in the upper Midwest (Hamilton 1995, 2005). Other studies based on different insect taxa have found a similar pattern. For example, Swengel (1996) found a disproportionate number of prairie-remnant dependent butterflies on unburned prairies. The greater number of prairie-associated Auchenorrhyncha found on unburned sites could be the result of more structural complexity (i.e., more niches). Haysom and Coulson (1998) observed species richness of Lepidoptera associated with heather (*Calluna*) increased with more years since last fire, as a consequence of greater height and structural diversity of this plant.

Also at unburned sites, 11 out of the 44 (25%) species were moderately conservative, including *Acinopterus acuminatus*, *Cuerna costalis*, *Delphacodes rotundata*, and *Stirellus bicolor*. These species are common on native grasslands (DeLong 1948) and can occur on undisturbed and moderately disturbed prairies (Panzer 2002). These sites also harbored 14 adventive species (32%), which were represented by typhlocybine species, treehoppers, and spittlebugs. These species are common on relatively disturbed grasslands (Whitcomb et al. 1988; Hamilton 1995; Harper et al. 2000).

As time since a burn changed from unburned to 3–5 years the number of species decreased from 44 to 32, with 13 (41%) of these species being highly conservative, 7 (22%) moderately conservative, and 12 (38%) adventives. Conservative species absent from these sites but present on unburned sites were *B. jocosa*, *Delphacodes trimaculata*, *Flexamia sandersi*, *Laevicephalus unicoloratus*, *Phylloscelis pallescens*, and *Scolops perdix*. Not only were these conservative species absent, but declines in abundance of many conservative species were also found (Appendix). These declines in abundance and species richness may be attributed to ecological characteristics of conservative Auchenorrhyncha, which have been reported to be highly sensitive to fire. Some of these characteristics include poor dispersal ability (i.e., short wings), and host-plant and habitat specificity. For example, Panzer (2002) found that fires dramatically reduced population sizes of immobile, stem boring *Papaipema* larvae; Dana (1991) observed that host and habitat specific prairie skippers were negatively affected by frequently burned prairies; and Harper et al. (2000), Panzer (2002), and Hamilton and Whitcomb (2010) found that host specific leafhoppers and their relatives exhibited substantial population declines immediately after a prescribed burn. Grubb Hollow prairie, a site burned 3–5 years ago, also yielded *Philaenus spumarius*, a spittlebug introduced from Europe (Hamilton 1983), which was absent on unburned sites.

As time since burning progressed from 3–5 to 2 years, the number of species continued to decrease to 17 species, with 7 (41%) conservative species, 5 (29%) moderately conservative, and 5 (29%) adventives species. Of these conservative species, *F. pectinata* and *F. prairiana* were the most abundant, but not as abundant as on unburned sites and sites burned 3–5 years ago. Other conservative species, such as *B. dorsata*, *P. dilata*, and *Fitchiella robertsonii* were found on only one site. Moderately conservative species include *Cuerna costalis*, *Gyponana ortha*, and *Stirellus bicolor*. Some adventives species include *Draeculacephala* species, *Neocoelidia tumidifro*ns, and *Empoasca* species. These results are in sharp contrast to other studies (Swengel 1996; Panzer 2002) were most prairie insects showed rapid recovery within 2 years of a burn.

Sites burned 1 year previously yielded slightly fewer species (16) than those burned 2 years ago (17). Moreover, the number of conservative species found on sites burned 1 year previously increased by only one species, moderately conservative species stayed the same with 5 species, and adventives species decreased from 5 to 3 species. Abundance also declined for many conservative auchenorrhynchan species with the exception of *F. pectinata* and *F. prairiana* (Appendix). However, population size of these species only increased at one site. These results are consistent with other studies that documented a steady decline in conservative prairie skippers (Swengel 1996), leaf beetles (Reed 1997), and leafhoppers following a burn conducted the previous growing season (Harper et al. 2000; Johnson et al. 2008). However, Tooker and Hanks (2004) observed that populations of *Silphium* spp. (Asteraceae) stem-boring Hymenoptera and Coleoptera dramatically rebounded the year following prairie burns, suggesting that prairie Auchenorrhyncha may be more sensitive to fire than these endophytic prairie insects.

Sites recently burned (0 year) yielded a similar species composition of Auchenorrhyncha compared to sites burned 1 year ago. On these sites, the number of species decreased to 13, with 5 (38%) conservative species, 5 (38%) moderately conservative species, and 3 (23%) adventives species (Fig. 3). Many of the conservative species present on these sites, such as *B. dorsata*, *Flexamia pectinata*, and *L. unicoloratus* were represented by only 1 individual (Appendix), suggesting that these insects are fire-intolerant. Other studies have reported similar declines of these species in Illinois (Harper et al. 2000; Panzer 2002) and in Kansas (Cancelado and Yonke 1970).

Burn frequency treatments

Unburned sites harbored more auchenorrhynchan species compared to frequently burned sites, with 44 species, 19 (43%) of which are conservative, 11 (25%) are moderately conservative, and 14 (32%) are adventives (Figs. 3, 5). Other studies have reported reduced species richness as prescribed burning increased in frequency. Evans (1984, 1988) and Wright and Samways (1999) demonstrate that unburned grasslands harbored more remnant-dependent species than frequently burned grasslands, and Morris (1975) showed that increased burning can reduce grassland insect species richness.

Sites burned once yielded fewer species than unburned sites, with 34 species, 10 (29%) of which were conservative, 8 (24%) were moderately conservative, and 16 (47%) were adventives. Sites burned twice supported fewer species than sites burned once, 19 species, 11 of which were conservative (58%), 6 (32%) species were moderately conservative, and two species (10%) were adventives. Although, species richness decreased from 34 on sites burned once to 19 species on sites burned twice, the number of conservative species on sites burned twice remained about the same. Similar numbers of conservative species on sites burned twice may be the result of wide periods of time between burns (i.e., 3–5 years), thus allowing enough time for conservative prairie Auchenorrhyncha to re-colonize these prairies. A similar trend was observed by Harper et al. (2000), which showed that conservative leafhoppers required more than 2 years to recover from a prairie burn. As prescribed burning increased in frequency from twice to more than twice, the number of species increased to 21 species. Nine (43%) of these species were conservative, 5 (24%) species were moderately conservative species, and 7 (33%) species were adventives. These data are consistent with other studies that have reported more conservative Auchenorrhyncha on prairie remnants that have been managed by fire at wide intervals, between 3 and 5 years (Hamilton 1995; Hamilton and Whitcomb 2010). This pattern has also been well documented for butterflies that favor open prairie (Swengel 1998).

Additional considerations

Although the original Auchenorrhyncha fauna of most of these sites was unknown, these sites are comparable because they supported similar plant species composition, such as grasses and forbs (personal observations 2006), and thus may support similar grass- and forb-feeding Auchenorrhyncha. Given this similarity in plant species composition, changes in prairie Auchenorrhyncha fauna can be attributed to differences in burn management rather than plants. In addition, this study showed that Auchenorrhyncha integrity and diversity seemed to recover after 3 years following a prescribed burn. However, land managers need to be aware that several conservative auchenorrhynchan species, such as *Bruchomorpha jocosa*, *Delphacodes trimaculata*, *Flexamia sandersi*, *Laevicephalus minimus*, *L. unicolor*atus, *Phylloscelis pallescens*, *Poblicia fuliginosa*, and *Scolops perdix* (Appendix) were absent from sites that had been burned in 3 years or less, suggesting that additional time between burns is needed in preserving most fire sensitive auchenorrhynchan species

Conclusions

Fire is an important natural component in the maintenance of grassland diversity and integrity. However, frequent burning by land managers in an effort to reduce the invasion of exotic plant species, trees, and shrubs may have dire consequences on the invertebrate community. In order for land managers to maintain the prairie Auchenorrhyncha community and conserve vascular plants, this study recommends infrequent rotational burning with a minimum of 3–5 years; although additional studies are needed to determine the appropriate number of years between each burn.

Overall, tallgrass hill prairie preserves should be managed with a minimum of 3–5 years rotational burns. This management practice may be adequate in conserving most of the prairie Auchenorrhyncha, reduce the number of adventives Auchenorrhyncha that may become numerically dominant following a burn (Harper et al. 2000), and conserve prairie vegetation. However, monitoring with the Auchenorrhyncha Quality Index and the Floristic Quality Index (Taft et al. 1997) is needed to evaluate the success of these management practices. Additional studies should be conducted within other tallgrass prairies (e.g., wet-mesic, sand, glacial-drift hill prairies) to test the generality of the results obtained here.

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Appendix

See Table 2.

Table 2 Comprehensive list of Auchenorrhynchan species for the study

Species	CC	Gunterman	Bland	Walnut Grove	Housen	OstermanB	OstermanA	Principia	Grubb Hollow	Fults	Jennings
Acanalonia bivittata	5.5	0	0	1	1	0	6	0	1	0	0
Acinopterus acuminatus	7.25	0	6	0	0	0	0	0	0	0	0
Agalliota constricta	3	0	0	0	0	0	0	0	1	0	0
Aphrophora quadrinotata	6.25	0	1	0	0	0	0	0	0	0	0
Balclutha neglecta	1.5	0	3	0	0	0	0	0	0	0	0
Bruchomorpha dorsata	12.25	0	14	3	7	8	9	2	18	1	5
Bruchomorpha jocosa	16	5	2	1	0	0	0	0	0	0	0
Bruchomorpha tristis	16	0	3	0	0	0	0	0	0	0	0
Campylenchia latipes	6.25	0	0	0	1	0	9	0	0	0	0
Catonia pumila	4.5	0	0	0	0	0	0	0	1	0	0
Ceratagallia agricola	4.75	1	217	0	2	0	3	0	2	0	0
Chlorotettix galbanatus	7.25	0	0	0	0	0	6	0	1	0	0
Chlorotettix spatulatus	10	1	0	0	0	2	0	0	0	0	0
Cuerna alpina	7.25	0	0	0	0	0	0	0	0	0	0
Cuerna costalis	7.25	2	0	0	0	0	0	0	0	0	6
Delphacodes puella	5.5	0	0	0	0	0	0	0	1	0	0
Delphacodes rotundata	9.75	0	4	0	0	0	3	0	2	0	0
Delphacodes trimaculata	14	0	3	0	0	0	0	0	0	0	0
Draeculacephala antica	3.75	0	0	0	0	0	0	0	0	0	0
Draeculacephala constricta	3.75	0	1	0	0	0	0	0	1	1	0

Table 2 continued

Species	CC	Gunterman	Bland	Walnut Grove	Housen	OstermanB	OstermanA	Principia	Grubb Hollow	Fults	Jennings
Doratura gammaroides	12.5	0	0	0	0	0	0	0	0	3	0
Empoasca bifircata	3.25	0	3	0	0	0	0	0	0	0	0
Empoasca recurvata	3.25	0	12	0	0	0	0	0	0	0	0
Endria inimica	4	0	0	0	0	0	0	0	0	0	0
Erasmanuera vulnerata	2.5	0	0	0	1	0	0	0	2	0	0
Erythroneura octonotata	2.5	0	0	1	0	0	0	0	0	0	0
Exitianus exitiosus	4	0	0	0	0	0	3	0	0	0	0
Fitchiella robertsonii	16	0	0	0	0	0	0	0	0	0	0
Flexamia pectinata	13.25	39	0	8	2	88	74	63	66	8	39
Flexamia prairiana	11.75	38	10	4	33	42	129	20	14	41	25
Flexamia sandersi	12.25	0	27	0	0	0	0	0	0	0	0
Graphocephala hieroglyphica	4.75	0	0	0	0	0	0	0	4	0	0
Gyponana ortha	6.25	0	0	0	0	0	0	0	0	0	0
Kansendria kansiensis	9.5	0	0	0	0	0	0	0	0	0	0
Laevicephalus melsheimeri	12	0	0	0	0	0	0	0	0	0	0
Laevicephalus minimus	12.75	0	0	36	102	9	12	0	0	0	0
Laevicephalus unicoloratus	11.25	0	0	0	0	18	0	0	0	0	0
Latalus personatus	9	0	0	0	0	0	0	0	0	0	0
Lepyronia quadrangularis	6.25	0	0	0	0	1	0	0	5	0	0
Liburniella ornata	3	1	2	0	0	0	0	0	1	0	0
Memnonia flavida	15	2	0	0	0	0	0	0	1	0	0
Neocoelidia tumidifrons	4.75	0	0	0	0	0	0	0	0	0	0
Paraphlepsius electus	13	1	6	0	1	0	0	1	0	0	0
Paraphlepsius irroratus	5.5	0	0	0	0	0	1	0	2	0	0
Paraulazices irrorata	6.25	0	1	0	0	0	0	0	0	0	0
Pendarus punctiscriptus	13	1	0	0	0	0	0	2	0	0	0
Penthimia americana	6.75	0	0	0	0	0	0	0	0	1	0
Planicephalus flavicostus	5	0	0	0	0	0	4	0	1	0	1
Philaenus spumarius	0	0	0	0	0	0	0	0	1	0	0
Phylloscelis pallescens	13.75	0	1	0	0	1	2	0	0	0	0
Phylloscelis atra	11.75	0	0	0	0	0	0	0	0	0	0
Poblicia fulginosa	11	1	0	0	0	0	0	0	0	0	0
Polyamia caperata	11.5	5	21	0	7	10	3	3	40	17	0
Polyamia compacta	14.75	0	0	4	0	1	0	8	0	2	0
Polyamia dilata	15.5	2	0	2	19	5	11	13	22	4	3
Polyamia weedi	12.25	0	0	0	0	0	0	0	2	0	0
Prairiana kansana	14	0	0	0	0	0	0	0	0	1	0
Rhynchomitra microrhina	6.25	0	0	0	0	0	0	0	0	0	0
Scolops angustatus	12	1	0	0	0	0	2	0	0	0	5
Scolops perdix	14.5	0	0	0	0	1	0	0	0	0	0
Stirellus bicolor	6	1	4	0	1	20	1	8	9	21	0
Texananus decorus	10	0	0	0	0	0	0	0	2	0	0
Tibicen canicularis	5.5	0	0	1	0	0	0	0	0	0	0
Xerophloea major	8.5	0	4	0	0	2	1	0	0	1	4
Xestocephalus pulicarius	4	1	5	0	2	0	1	1	3	0	1

Table 2 continued

Species	CC	Demint	ChalfinA	ChalfinB	Hanover	Gonterman	MSP	BGB	Olin	BGA
Acanalonia bivittata	5.5	0	0	0	0	0	0	0	0	0
Acinopterus acuminatus	7.25	0	0	0	0	0	0	0	0	0
Agalliota constricta	3	0	0	0	0	0	1	0	0	0
Aphrophora quadrinotata	6.25	0	0	0	0	0	0	0	0	0
Balclutha neglecta	1.5	0	0	0	0	0	0	0	0	0
Bruchomorpha dorsata	12.25	0	0	1	2	1	0	0	1	0
Bruchomorpha jocosa	16	0	0	0	0	0	0	0	0	0
Bruchomorpha tristis	16	0	0	0	0	0	0	0	0	0
Campylenchia latipes	6.25	0	0	0	0	0	0	0	0	0
Catonia pumila	4.5	0	0	0	0	0	0	0	0	0
Ceratagallia agricola	4.75	0	0	0	0	0	0	6	0	4
Chlorotettix galbanatus	7.25	0	0	0	0	0	0	0	0	0
Chlorotettix spatulatus	10	0	0	0	0	0	0	0	0	0
Cuerna alpina	7.25	0	0	0	0	0	0	5	0	0
Cuerna costalis	7.25	0	0	1	0	0	0	0	5	0
Delphacodes puella	5.5	0	0	0	0	0	0	0	0	0
Delphacodes rotundata	9.75	0	0	0	2	0	0	0	0	0
Delphacodes trimaculata	14	0	0	0	0	0	0	0	0	0
Draeculacephala antica	3.75	1	2	5	0	0	0	12	0	7
Draeculacephala constricta	3.75	3	0	0	0	0	0	0	4	0
Doratura gammaroides	12.5	0	0	0	0	0	0	0	0	0
Empoasca bifircata	3.25	0	0	0	0	0	0	0	0	0
Empoasca recurvata	3.25	1	0	0	0	0	0	0	0	0
Endria inimica	4	0	0	0	0	0	1	0	0	0
Erasmanuera vulnerata	2.5	0	0	0	0	0	0	0	0	0
Erythroneura octonotata	2.5	0	0	0	0	0	0	0	0	0
Exitianus exitiosus	4	0	0	0	0	0	0	0	0	0
Fitchiella robertsonii	16	1	0	0	0	0	0	0	0	0
Flexamia pectinata	13.25	29	2	8	0	132	0	1	0	1
Flexamia prairiana	11.75	10	8	9	11	18	2	0	0	0
Flexamia sandersi	12.25	0	0	0	0	0	0	0	0	0
Graphocephala hieroglyphica	4.75	0	0	0	0	0	0	0	0	0
Gyponana ortha	6.25	1	0	0	0	0	0	0	0	0
Kansendria kansiensis	9.5	0	0	0	1	0	0	0	0	0
Laevicephalus melsheimeri	12	0	0	0	0	0	0	0	1	0
Laevicephalus minimus	12.75	0	0	0	0	0	0	0	0	0
Laevicephalus unicoloratus	11.25	0	0	0	5	0	0	0	1	0
Latalus personatus	9	0	0	0	2	0	0	0	0	0
Lepyronia quadrangularis	6.25	0	0	0	0	0	0	0	0	0
Liburniella ornata	3	0	0	0	0	0	0	0	0	0
Memnonia flavida	15	0	0	1	0	0	1	0	0	0
Neocoelidia tumidifrons	4.75	0	2	0	0	0	0	0	0	0
Paraphlepsius electus	13	0	0	0	0	0	0	0	0	0
Paraphlepsius irroratus	5.5	0	0	0	0	0	0	0	0	0
Paraulazices irrorata	6.25	0	0	0	0	0	0	0	0	0
Pendarus punctiscriptus	13	0	0	0	0	0	0	0	0	0
Penthimia americana	6.75	0	0	0	0	0	0	0	0	0
Planicephalus flavicostus	5	0	0	0	0	0	0	0	0	0

Table 2 continued

Species	CC	Demint	ChalfinA	ChalfinB	Hanover	Gonterman	MSP	BGB	Olin	BGA
Philaenus spumarius	0	0	0	0	0	0	0	0	0	0
Phylloscelis pallescens	13.75	0	0	0	0	0	0	0	0	0
Phylloscelis atra	11.75	0	0	0	0	1	0	0	0	1
Poblicia fulginosa	11	0	0	0	0	0	0	0	0	0
Polyamia caperata	11.5	2	2	16	90	1	0	0	0	0
Polyamia compacta	14.75	0	0	0	0	0	0	0	0	0
Polyamia dilata	15.5	0	3	0	0	29	0	0	0	0
Polyamia weedi	12.25	0	0	0	0	0	0	0	0	0
Prairiana kansana	14	0	0	0	0	0	0	0	0	0
Rhynchomitra microrhina	6.25	4	0	0	0	0	0	1	0	1
Scolops angustatus	12	1	0	0	0	0	0	0	0	0
Scolops perdix	14.5	0	0	0	0	0	0	0	0	0
Stirellus bicolor	6	4	2	4	7	33	2	3	3	1
Texananus decorus	10	0	0	0	0	0	0	0	0	0
Tibicen canicularis	5.5	0	0	0	0	0	0	0	0	0
Xerophloea major	8.5	0	0	0	0	0	0	0	0	1
Xestocephalus pulicarius	4	0	0	0	0	0	0	0	0	0

Species name, species coefficient of conservatism (CC), and number of individuals per species (abundance) are listed for each study site

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