FINAL PERFORMANCE REPORT

Federal Aid Grant No. F14AF01228 (T-83-1)

Distribution, Population Estimate, and Response to Prescribed Fire in the Rattlesnake-Master Borer Moth at the Nature Conservancy's Tallgrass Prairie Preserve in Osage County, Oklahoma

Oklahoma Department of Wildlife Conservation

Grant Period: January 1, 2015 - December 31, 2017

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Principal Investigator: Dr. Daniel Howard**,** University of New Hampshire

A. ABSTRACT

The purpose of this project was to assess the presence of the Rattlesnake-Master Borer Moth (*Papaipema eryngii*), a federal candidate species, on the Tallgrass Prairie Preserve owned by The Nature Conservancy in Osage County, Oklahoma. Another component was to determine the abundance and distribution of its host plant, Rattlesnake Master (*Eryngium yuccifolium*). Resulting data collected from this project would provide critical insights into the patterns of abundance and biodiversity of night-flying insects in a grassland ecosystem impacted by prescribed burning, grazing by bison and cattle, and impacts related to energy resource extraction. Sampling for both the host plant and the moth occurred in 2015 and 2016, with 50 sites sampled for both species. Although no *P. enryngii* were identified, 24 of the 50 sites on the preserve held high densities of the host plant *E. yuccifolium*.

B. INTRODUCTION

Documenting abundance, distribution, and ecological interactions can provide the first data necessary for understanding and developing conservation strategies for species that are not well understood. The rattlesnake-master borer moth (*Papaipema eryngii*) (see App. 1, Fig. 1) is part of the family Noctuidae, comprising the owlet moths (USFWS 2013). The genus *Papaipema* contains 53 species, all of which are located in North America. The nocturnal univoltine life history of *P. eryngii* contributes to the difficulty of its study according to the U. S. Fish and Wildlife Service (2013). Adult moths emerge between September and October with female oviposition occurring in mid- October. The eggs are oviposited near *Eryngium yuccifolium* (rattlesnake-master, Fig. 2), and when the larvae emerge they feed exclusively on this plant. Following overwintering, the larvae emerge between May and June. First instar larvae feed on *E. yuccifolium* leaves, and the second instars burrow into the stem and continue to the root of the plant where they remain until they pupate in mid to late August. The boring activities of the larvae typically leave the rattlesnake-master plant unable to produce flowers, and can reduce the fitness of or be fatal to the plant (USFWS 2013).

The adult flight period of the rattlesnake-master borer moth is brief and the species' feeding habits are relatively unknown. They have underdeveloped mouthparts and a large amount of stored fat, so it is suggested that adult moths do not allocate energy resources to foraging, and likely rely on dew or sap for moisture intake (USFWS 2013). Adult moths are relatively sedentary and are thought to have a small home range; however, this is dependent upon the availability of the rattlesnake-master plant. Moths are thought to travel 3-6 kilometers if an area has low abundance of the required host plant (USFWS 2013).

Rattlesnake-master borer moths occupy large undisturbed areas of prairie and woodland. It is estimated that the moth's host plant occurs at low abundances (<1%) in relict and restored prairies. Rattlesnake master has a potentially large range, but the loss of the tallgrass prairies has been detrimental to remaining populations with estimated declines of 82-92% across its historic range (USFWS 2013). Extant tallgrass prairie only occurs in 1% of this ecosystem's former extent (OCWCS 2005), and thus, the recent reduction in abundance and distribution of the moth is presumed to be associated with the loss of prairie habitat and host plant abundance.

While the tallgrass prairie is a declining and threatened habitat because of agricultural expansion, suppression of fires, and invasion of trees, this ecosystem once spanned 150 million acres across 14 North American states (OCWCS 2005). The last remaining continuous tallgrass prairie habitat exists in the Flint Hills of Oklahoma and Kansas (OCWCS 2005). This remnant prairie region contains habitat for many native species, and because of the large undisturbed tall grasses, oak savannahs, and deciduous forests, the Oklahoma tallgrass prairie likely sustains isolated populations of the rattlesnake-master borer moth. While little historical data exist for this species, presence/absence surveys within the remaining tallgrass prairie ecosystem are needed to identify and monitor remaining populations and address conservation management needs (USFWS 2013).

The Nature Conservancy's Tallgrass Prairie Preserve (TPP) in Osage County, Oklahoma is a contiguous 40,000 acre tract of native undisturbed and restored tallgrass prairie ecosystem. The long-term management of the TPP incorporates natural and anthropogenic disturbances that mimic historic prairie function, and includes bison and ungulate grazing and prescribed burning to promote botanical biomass structure and nutrient cycling. The patch-bum fire regime is designed to mimic a three-year fire return to control woody invasion and maintain a landcover ratio of approximately 80% grassland and 20% forest. *E. yuccifolium* is known to occur across the preserve in tallgrass, woodland, and savanna patches (Bob Hamilton personal obs.), but no formal survey for the plant or for the moth have been conducted by scientists working at the site.

In order to develop comprehensive conservation strategies for the rattlesnake-master borer moth, this project will investigate the following questions:

1) What is the abundance and distribution of *Papaipema eryngii* and its host plant, *Eryngium yuccifolium*, across the extent of the Tallgrass Prairie Preserve, the largest remaining tract of native tallgrass prairie in the Flint Hills?

2) How is the population structure of *Papaipema eryngii* and its host plant *Eryngium yuccifolium* influenced by prescribed burning seasonality?

3) What is the population of this candidate species at the focal study site?

Given the known presence of the host plant, we hypothesized that *P. eryngii* would be found in local abundance and exhibit a heterogeneous distribution at the site in parallel with distribution of the plant distribution. We also postulated that the management practice of prescribed burning, while potentially deleterious in the short term, would be related to moth abundance in the long-term given the ecological relationship between the host plant and its fire-dependent prairie habitat. This study will meet the intent of the Oklahoma Comprehensive Wildlife Conservation Strategy with respect to the first identified conservation issue associated within the plan's Tallgrass Prairie region: addressing the "Incomplete data concerning species of greatest conservation need and habitat, an impediment for effective conservation planning and implementation" (Oklahoma CWCS, Tallgrass Prairie Region, pg. 53). The second identified conservation issue also applies in that this species and it host plant are threatened by "Habitat loss and fragmentation from land management practices" (Oklahoma CWCS, Tallgrass Prairie Region, pg. 54).

C. OBJECTIVES:

1) Document the distribution and abundance of *Papaipema eryngii* and its host plant *Eryngium yuccifolium* at the Tallgrass Prairie Preserve.

2) Examine the species' response to fire, a natural disturbance in its native habitat.

3) Produce a population estimate for the species based on Bayesian modeling algorithms that can aid in determining the biological sustainability of the population.

D. APPROACH

Study Area

The study will occur at The Nature Conservancy's Tallgrass Prairie Preserve (36°49'N, 96°23'W) in Osage County, Oklahoma, USA during the period of 1 Jan. 2015- 31 Dec. 2016. The site was purchased by The Nature Conservancy in 1989, having been utilized for cattle grazing during the previous century as a part of the 98,000 acre Chapman-Barnard Ranch. The Preserve's holdings currently include approximately 40,000 acres of tallgrass and mixed-grass prairie, along with riparian gallery forests; approximately 80% of the preserve is grassland habitat, with the remaining 20% consisting of Crosstimbers forest with *Quercus stellata* and *Q. marilandica* the predominant tree species. Prescribed fire was reintroduced as a restoration tool soon after the site was purchased by TNC, with burn sites selected annually through a lottery mechanism. Fire frequency is currently set at a three-year return interval in an effort to replicate pre-settlement fire disturbance dynamics, and prescribed burns are distributed with a seasonal spring-summer-fall frequency of 40%-20%-40%. This management strategy produces a patchwork of burn histories across the preserve, with approximately one-third of the preserve disturbed by fire each year. Anecdotal sightings of *Papaipema eryngii* have been documented at the site, and this candidate species' host plant *Eryngium yuccifolium* is known to occur in local abundance.

Field Methods

Year 1

We conducted field surveys to determine the abundance and distribution of *Papaipema eryngii* and its host plant *Eryngium yuccifolium* at the Tallgrass Prairie Preserve. Night surveys were conducted using automated Bioquip UV light traps at fifty sampling sites (see App. 1, Fig. 3) across the preserve during September and October of 2015, with each site sampled for three consecutive nights. All insects collected in the traps were vouchered for calculations of family-level biodiversity and dry biomass. Parallel botanical surveys for the moth's host plant *Eryngium yuccifolium* occurred along line transects that originated at the sampling site and extended for 100 m in each cardinal direction (400 m total). Sampling sites were produced by generating a regular grid of sample points using the Hawth's Analysis Tools, ver. 3.27 sampling function extension in ArcGIS 10.1.2 software (ESRI, Redlands, CA, USA). Points were spaced 1850 meters apart, and layered over the preserve boundary, with points falling on or within the boundary retained as sample sites (see App. 1, Fig. 4). This trap density (0.031 traps ha-1) was selected as a reasonable tradeoff between sampling effort and predicted moth encounter probabilities based upon what is known regarding nightly movement patterns of *Papaipema eryngii*.

Year 2

Since we identified no confirmed *Papaipema eryngii* at any of the fifty sampling sites, we concentrated night collecting in six regions (four sites each; total = twenty-four sample sites) of known high abundance of the host plant as confirmed in the fall of 2015. In both years, sites varied with respect to post-burn interval, from unburned to sites not burned for over five years.

Data Analyses

To understand the spatial distribution of *Papaipema eryngii* and its host plant *Eryngium Yuccifolium,* we employed spatial analytical tools in a Geographic Information System (GIS) platform (ESRI ArcGIS ver. 10.1.2), supplemented with non-spatial statistical techniques. First, we mapped host plant prevalence, and then examined night-flying insect biodiversity and abundance patterns across the site for distributional homogeneity using the Moran's I spatial autocorrelation test statistic (Mitchell 2005). To determine if identified clusters exhibited high or low values of abundance, we examined data using the Getis-Ord General G test statistic. To identify specific sample locations across the landscape with clusters of significantly high or low values of moth or plant abundances, the Getis-Ord Gi* test statistic was used. To identify the areas of highest abundance at the study site, we interpolated abundance data using an IDW technique in the GIS using a 2.0 S.D. parameter (Watson and Philip 1985), and then created percent volume contours for the 50, and 95 percent probability density distributions. To test for an association between insect biodiversity and habitat variables on the landscape, we first calculated the Shannon Index of Diversity for each site, using family level collection detail.

We evaluated overall abundance of night-flying insects, including *Papaipema* spp., by measuring the dry weight (g) of material collected at each site. We then characterized each sampling location in respect to five key habitat variables. These variables included: grazing regime (cattle-bison-ungrazed), soil type, months post-burn, distance from nearest road, and distance from nearest oil/natural gas development. Road distance, and oil/natural gas distance was determined through analyses of both geo-referenced aerial images (1.0 meter resolution) and ground-truthing. Soil type was determined from a geo-referenced Natural Resources Conservation Service soil survey map (USDA 2008). Grazing and prescribed burn records were procured from The Nature Conservancy in the form of detailed burn maps in the ESRI Arcview shapefile format. To identify landscape features associated with biodiversity and abundance, all variables were entered as terms into a mixed stepwise regression model with abundance as the response variable (Darlington 1968, 1990). For model building, we were assigned a 0.25 significance probability as a threshold for a regressor term to be considered as a forward step and entered into the model, and a 0.25 significance probability for a term to be considered a backward step and removed from the model. In addition to using adjusted R-squared values in model selection, we evaluated values from both the Mallows Cp criterion (Draper and Smith 1981) and the Akaike's Information Criterion. Model selection then was thus informed by an unweighted combination of the highest R-squared value, the lowest AIC value, and a Cp value that most closely matched the number of variables in the candidate model. Terms retained in these stepwise analyses were subsequently entered into a standard least square regression model with effect leverage emphasis to complete model construction. Statistical analyses were conducted in JMP ver. 12.1 (SAS Institute Inc., Cary, North Carolina, USA).

E. RESULTS AND DISCUSSION

Results

Light-trap collections for *Papaipema eryngii* and transect surveys for its host plant *Eryngium yuccifolium* conducted at fifty sites in September and October 2015 resulted in no confirmed rattlesnake master borer moth adults collected in the traps, and no sign of larval bore holes in random samples of host plant stems (see App., Table 1). *E. yuccifolium* was distributed randomly across the preserve (Fig. 4). Several *Papaipema* congeners were identified in traps, including *P. nebris* and *P. baptisiae*. During the collecting effort in 2015 we documented new county moth records at the field study site: *Agrius cingulatus*, *Enyo lugubris* (state record) both in the family Sphingidae; *Anomis erosa*, *Catocala cara*, *Argyrogramma verruca*, *Allagrapha*, *aerea*, and *Anicla illapsa* all in the family Noctuidae. We found that both insect biodiversity (Fig. 8: Moran's I index = 0.40, $Z = 3.99$, $P < 0.01$) and insect biomass (Fig. 9: Moran's I index = 0.39, $Z = 3.82$, $P < 0.01$) exhibited spatial autocorrelation and were significantly clustered on the preserve landscape.

Additional post hoc analysis found that high, rather than low values for both variables exhibited significant spatial clustering (biodiversity: Getis-Ord General G, $Z = 2.38$, $P = 0.02$; biomass: Getis-Ord General G, $Z = 3.21$, $P < 0.01$). Using a Generalized Linear Model testing a normal distribution with identity link using a maximum likelihood estimation method, with insect biodiversity as the response variable and soil type, post-burn interval (mos.), grazing regime (cattle, bison, ungrazed), distance to roads (m) and distance to oil and/or gas development (m) as the predictor variables, we found that only soil type predicted nocturnal insect biodiversity at the site (Whole model test, Chisquare = 39.91, df = 19, P 0.003), with the following three soil types having a significant effect in the model: Catoosa-Shidler-Lula complex, Shidler Silty-Clay Loam, Steedman- Lucien complex. Likewise, insect biomass was also related to soil type alone (Whole model test, Chi-square = 31.62, df = 19, P = 0.035), but the model only identified a single soil in this association: Agra silt loam (Fig. 10).

With no *Papaipema eryngii* identified through systematic sampling in 2015, in 2016 we focused all sampling at twenty-four sites in six regions of the preserve known to hold high densities of host plant (Fig. 5), and included more extensive surveys of host plant stems for potential larval bore holes. When locating signs of putative larval activity, we collected the whole plant including roots, to search the subsurface root structure for feeding larvae. As in 2015, we collected no adult *P. eryngii* during the 72 trap-nights, and observed only a few suspicious stem bore holes that upon dissection of the root did not turn out to represent *P. eryngii* larvae. We did identify several *Papaipema* congeners and new moth county record: *Eumorpha pandorus* and *Cirrhophanus triangulifera* (Figs. 6 & 7). The results of this study were presented by the authors at the 2017 Annual Conference of the Entomological Society of America, held in Denver, Colorado 5-8 November 2017.

Discussion

While aggregations of the host plant of *Papaipema eryngii* were identified extensively across the study site during both years of the study (Fig. 5), no confirmed adult moths were identified in the UV traps. Similarly, no larvae were detected in any host plants observed and dissected. It is not unusual with species exhibiting rapid declines to be absent at sites with otherwise suitable habitat (Andrén 1997), as range contraction may occur through mechanisms other than habitat availability (Lawton 1993, Channell and Lomolino 2000). Consistent with this understanding, the results of this study lead to the conclusion that *Papaipema eryngii* is not currently found at the study site in abundances detectable using the collecting techniques employed.

Despite the results, the Tallgrass Prairie Preserve remains a biological hotspot for other invertebrate species of conservation concern in Oklahoma. During night-trapping for *Papaipema eryngii,* several federally-endangered American burying beetles (*Nicrophorus americanus,* ABB) were found near the traps, presumably attracted to the lights. Based off of results gathered from separate and ongoing longitudinal studies by the P.I., ABBs are known to occur on the study site in medium-to-high densities. However, their presence near the traps in the fall was considered unusual and may be indicative of high abundances and mild nightly temperatures. Another rare insect species that occurs on the Tallgrass Prairie Preserve is the Prairie Mole Cricket (*Gryllotalpa major*), a Tier I species of greatest conservation need.

Findings from this two-year project highlight the importance of the Tallgrass Prairie Preserve in supporting high insect biodiversity and invertebrate biomass.

F. SIGNIFICANT DEVIATIONS

There were no significant deviations to the project and all of the project's objectives were met.

G. PREPARED BY: Dr. Daniel Howard
University of New Hampshire

H. DATE: December 18, 2017

I. APPROVED BY: Alan Peoples

Wildlife Division Administration
Oklahoma Department of Wildlife Conservation

Andrea K Crews

Andrea Crews, Federal Aid Coordinator
Oklahoma Department of Wildlife Conservation

APPENDIX I.

Table 1: Results of night-collecting efforts at the Nature Conservancy's Tallgrass Prairie Preserve in August and September 2015.

Site	Latitude	Longitude	Date (3rd night)	Grazing Type	Post-Burn (3 mo)	Insect Orders	Insect Families	Insect Biodiversity (Shannon)	Insect Biomass (g)	Papaipema eryngii (Y/N)	Papaipema spp.
1	36.89672	-96.42001	9/20/2015	Cattle	6.00	9	28	0.2685	12.56	N	*P.nebris (x4)*
2	36.89697	-96.40061	9/20/2015	Cattle	29.00	9	51	0.1177	7.06	N	None
3	36.88141	-96.42075	9/20/2015	Bison	6.00	9	64	0.1273	16.56	N	None
4	36.88117	-96.40123	9/20/2015	Cattle	6.00	8	34	0.1459	8.99	N	*P. nebris (x2)*
5	36.86496	-96.42252	9/16/2015	Cattle	18.00	7	26	0.1548	4.64	N	None
6	36.86451	-96.40179	9/20/2015	Cattle	18.00	9	37	0.3460	15.44	N	None
7	36.86406	-96.38106	10/10/2015	Cattle	6.00	9	43	0.1063	1.63	N	None
8	36.86360	-96.36032	10/10/2015	Cattle	7.00	9	48	0.1580	2.04	N	None
9	36.86313	-96.33959	9/16/2015	Cattle	6.00	9	23	0.1405	4.87	N	None
10	36.84919	-96.46454	9/29/2015	Bison	42.00	9	23	0.2282	0.99	N	None
11	36.84875	-96.44381	9/29/2015	Bison	1.50	8	38	0.2949	1.71	N	None
12	36.84830	-96.42308	9/29/2015	Bison	5.00	7	50	0.1710	1.95	N	*P. baptisiae (x1)*
13	36.84785	-96.40235	10/6/2015	Bison	7.00	7	15	0.1220	0.58	N	None
14	36.84740	-96.38163	10/10/2015	Cattle	42.00	9	38	0.1194	2.34	N	None
15	36.84694	-96.36090	10/10/2015	Cattle	42.00	9	29	0.2081	3.82	N	None
16	36.84648	-96.34017	10/10/2015	Cattle	42.00	8	35	0.1355	2.47	N	*P. nebris (x2)*
17	36.83253	-96.46509	9/29/2015	Bison	42.00	9	26	0.2259	2.29	N	*P.nebris (x2)*
18	36.83209	-96.44437	9/29/2015	Bison	18.00	9	25	0.1747	2.28	N	*P. baptisiae (x1), P. nebris (x1)*
19	36.83164	-96.42364	10/13/2015	Bison	18.00	10	44	0.1017	1.64	N	None
20	36.83119	-96.40292	10/6/2015	Bison	0.50	9	46	0.1719	3.18	N	None
21	36.83074	-96.38219	10/6/2015	Cattle	62.00	8	19	0.2224	1.06	N	None
22	36.83028	-96.36147	10/6/2015	Cattle	7.00	9	17	0.1806	1.76	N	None
23	36.82982	-96.34075	9/26/2015	Cattle	55.00	12	45	0.0765	2.34	N	None
24	36.82546	-96.48184	9/23/2015	Bison	18.00	11	48	0.0851	10.37	N	*P. nebris* (x 7); *P. baptisiae* x4
25	36.81587	-96.46564	9/23/2015	Bison	5.00	10	55	0.0747	13.97	N	None
26	36.81543	-96.44492	9/23/2015	Bison	12.50	11	54	0.1143	9.47	N	*P.nebris* (x5)
27	36.81498	-96.42420	10/13/2015	Bison	18.50	8	22	0.1022	0.53	N	None
28	36.81453	-96.40348	10/13/2015	Bison	18.50	9	37	0.3953	1.88	N	None

29	36.81408	-96.38276	10/6/2015	Bison	55.0	7	23	0.1771	0.78	N	None
30	36.81362	-96.36204	9/26/2015	Bison	6.50	9	34	0.1049	1.62	N	None
31	36.81316	-96.34132	9/26/2015	Bison	17.50	9	49	0.0960	7.01	N	None
32	36.79832	-96.42476	9/23/2015	Bison	0.70	8	35	0.1239	1.64	N	*P. nebris* (x1)
33	36.79787	-96.40404	10/13/2015	Bison	1.50	8	37	0.1472	2.02	N	None
34	36.79743	-96.38333	10/13/2015	Bison	13.00	9	34	0.1343	2.58	N	None
35	36.79696	-96.36261	9/26/2015	Bison	17.50	9	41	.0751	1.02	N	None
36	36.79650	-96.34190	9/26/2015	Bison	17.80	10	45	0.0719	2.55	N	None
37	36.78166	-96.42532	9/23/2015	Bison	0.80	7	39	0.3277	3.52	N	None
38	36.78121	-96.40461	10/16/2015	Bison	18.70	6	26	0.2137	1.97	N	None
39	36.78076	-96.38390	9/16/2015	Bison	12.00	8	27	0.1767	6.62	N	*P. nebris* (x2)
40	36.78030	-96.36318	10/16/2015	Bison	63.50	6	14	0.5129	0.78	N	None
41	36.76455	-96.40517	10/16/2015	Bison	18.70	8	27	0.2660	0.41	N	None
42	36.76410	-96.38446	9/16/2015	Bison	0.50	9	28	0.2477	6.96	N	*P. nebris* (x1)
43	36.76364	-96.36376	10/16/2015	Bison	54.00	6	21	0.5629	0.78	N	None
44	36.77040	-96.34504	10/16/2015	Bison	6.50	5	13	0.3338	1.29	N	*P. baptisiae* (x2)
45	36.74744	-96.38503	10/14/2015	Cattle	6.50	8	36	0.0886	2.42	N	*P. baptisiae* (x37); *P. nebris* (x2)
46	36.74698	-96.36433	10/3/2015	Bison	6.00	8	21	0.4437	1.03	N	*P. baptisiae* (x2); *P. nebris* (x1)
47	36.74652	-96.34362	10/3/2015	Cattle	5.90	6	12	0.4626	0.74	N	None
48	36.73276	-96.38394	10/3/2015	Cattle	6.00	10	32	0.1099	1.23	N	*P. baptisiae* (x1); P. nebris (x4)
49	36.73304	-96.34297	10/3/2015	Cattle	5.90	7	17	0.7852	1.22	N	None
50	36.71899	-96.34557	10/3/2015	Cattle	6.00	7	21	0.3549	0.44	N	None

Fig. 1 - An adult Rattlesnake Master-borer Moth, *Papaipema eryngii.*
(Photo credit: Mississippi State University Entomological Museum).

Fig. 2 - Rattlesnake Master-borer Moth, *Papaipema eryngii* host plant, *Eryngium yuccifolium.*
Photo credit: Bill Summers. USDA NRCS.

Fig. 3 – Field technicians deploying automated night collecting traps at one of fifty sampling sites at The Nature Conservancy's Tallgrass Prairie Preserve in Osage County, Oklahoma (Photo credit: D.R. Howard).

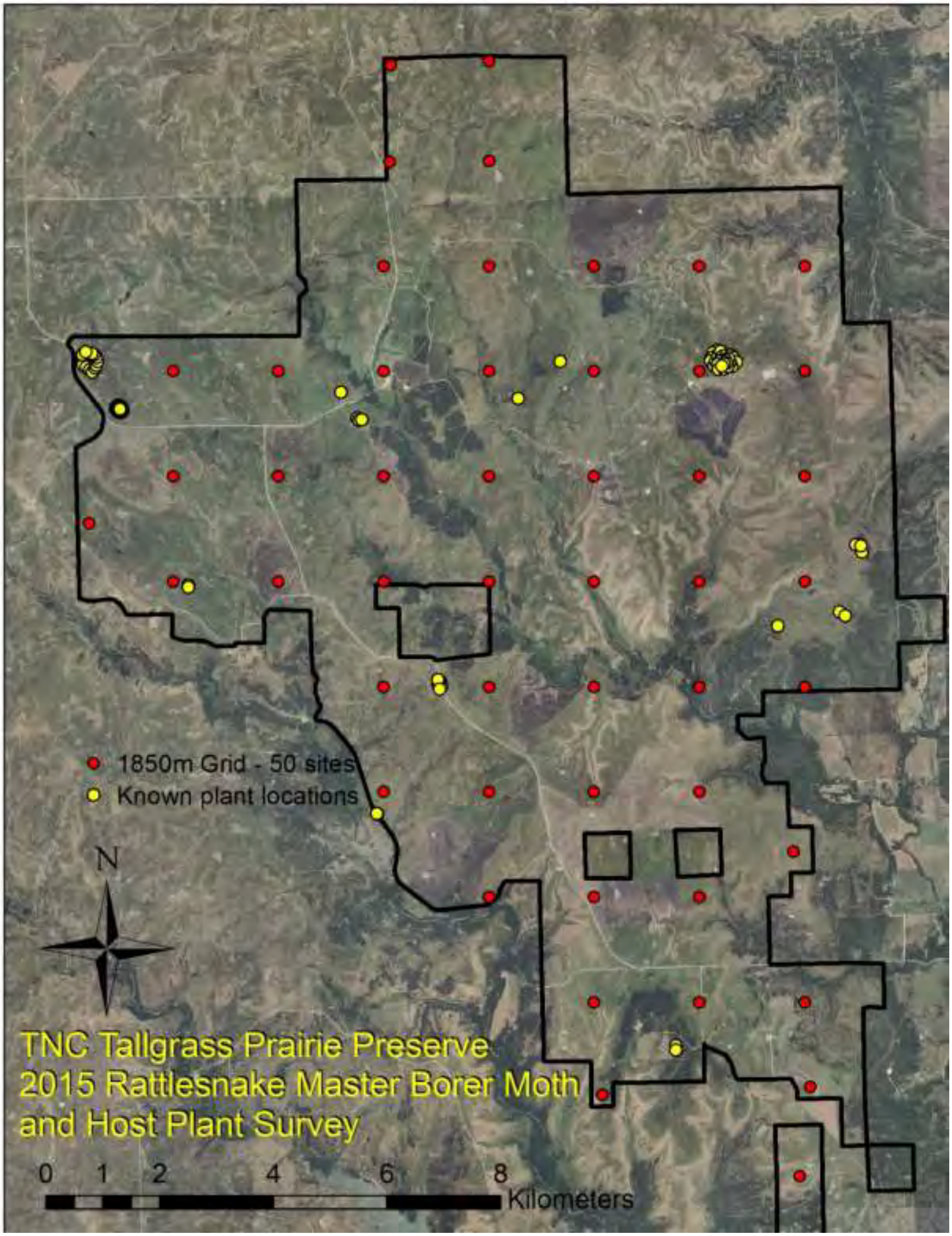

Fig. 4: Locations of *Papaipema eryngii* host plant *Eryngium yuccifolium* resulting from surveys conducted at fifty sites in September and October 2015 and locations identified opportunistically.

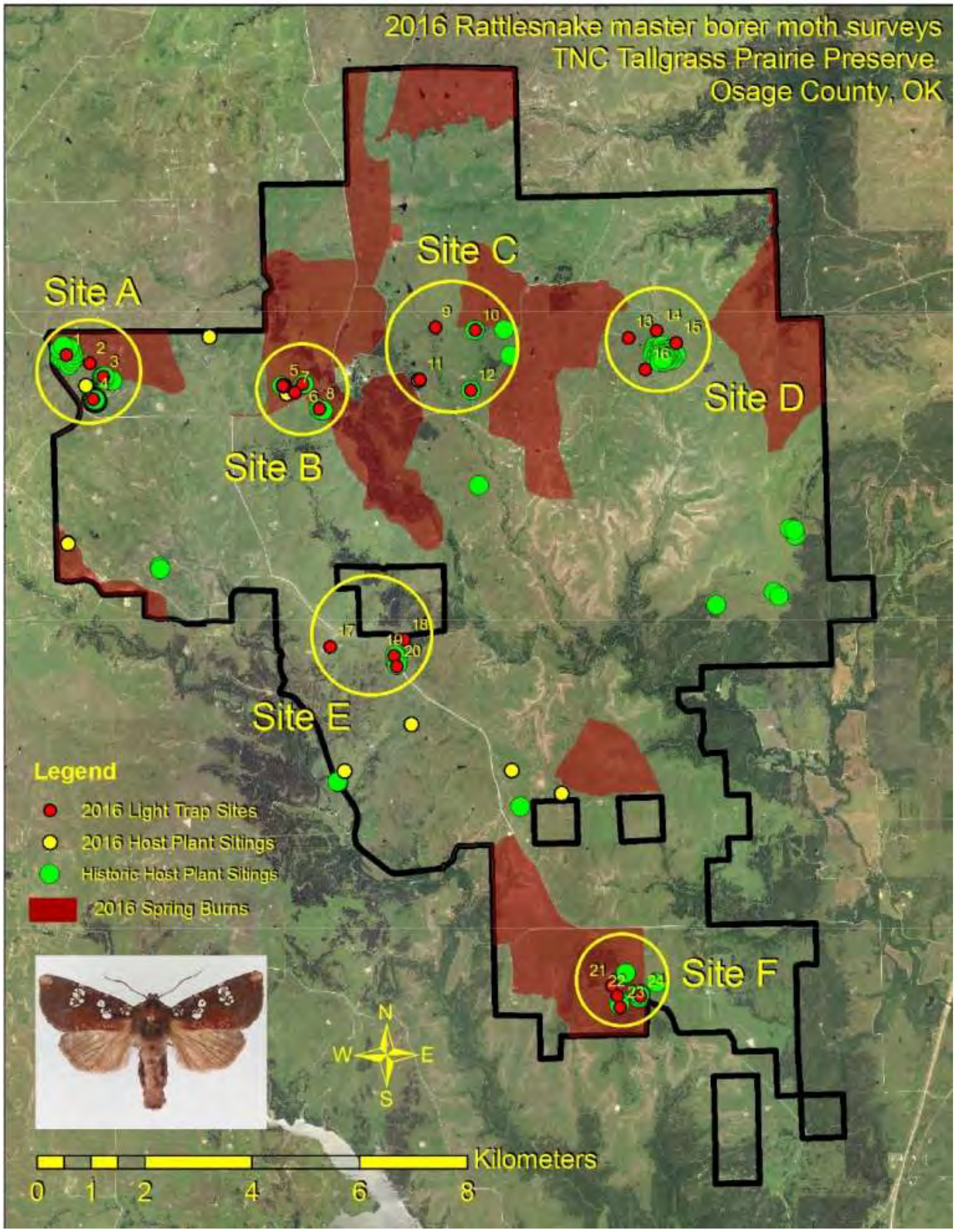

Fig. 5 – Map of the sampling scheme for the 2016 *Papaipema eryngii* survey at the Tallgrass Prairie Preserve in Osage County, Oklahoma. The six regions (4 sites per region) were collocated at sites where high densities of the host plant *Eryngium yuccifolium* were identified during the 2015 survey.

Fig. 6 – *Eumorpha pandorus*, a new county record moth species collected during the project survey at the TNC study site in Osage County. Inset shows the known distribution of the species (Photo credit: Chris French, map credit: Mississippi State University Entomological Museum).

Fig. 7 – *Cirrhophanus triangulifera*, a new county record moth species documented during the project survey at the TNC study site in Osage County. Inset shows the known distribution of the species (Photo credit: Jim Vargo, map credit: Mississippi State University Entomological Museum).

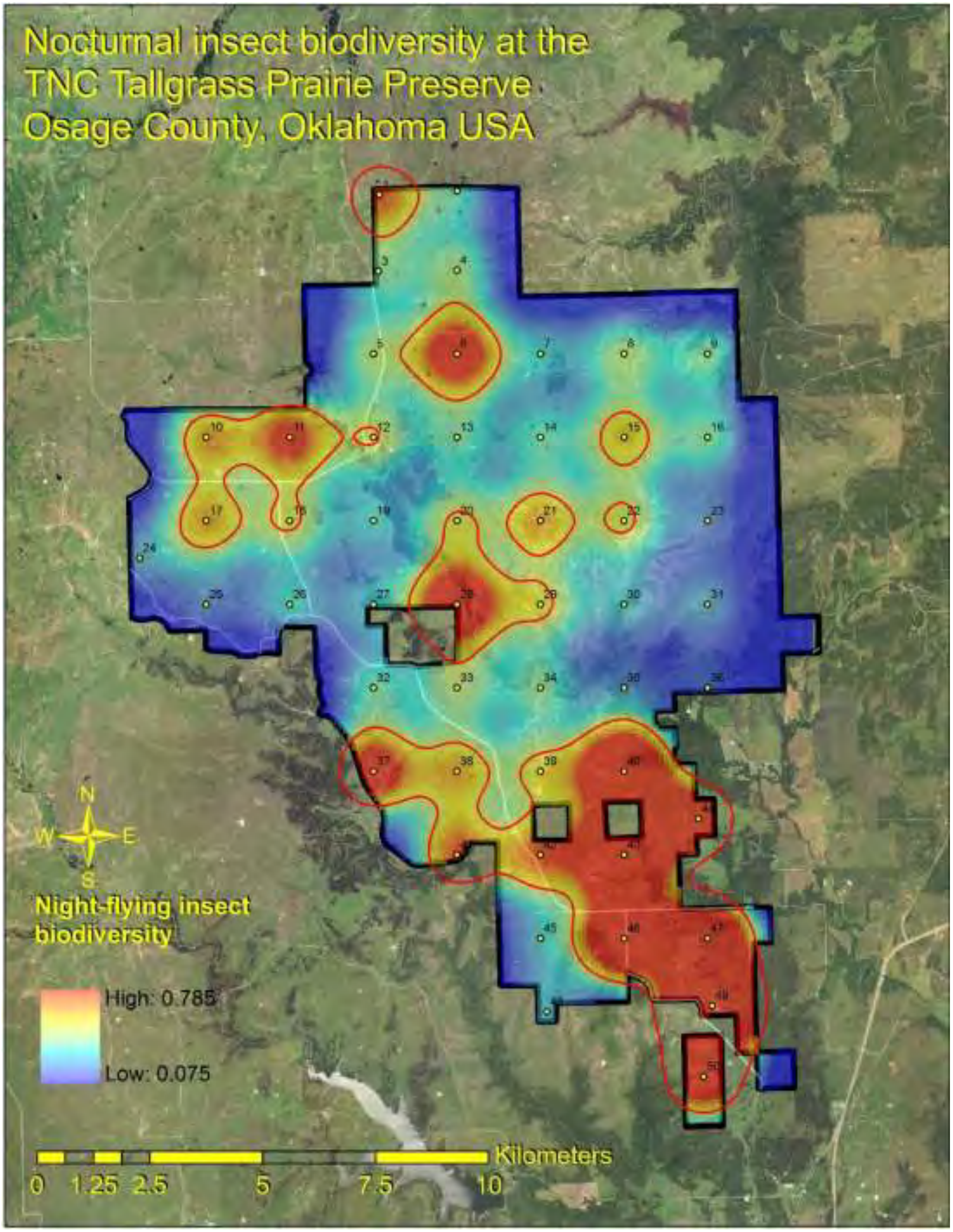

Fig. 8 – Map of the interpolation of insect biodiversity (Shannon index) at The Nature Conservancy's Tallgrass Prairie Preserve in Osage County, Oklahoma derived from samples collected during light traps at fifty sites during August and September 2015.

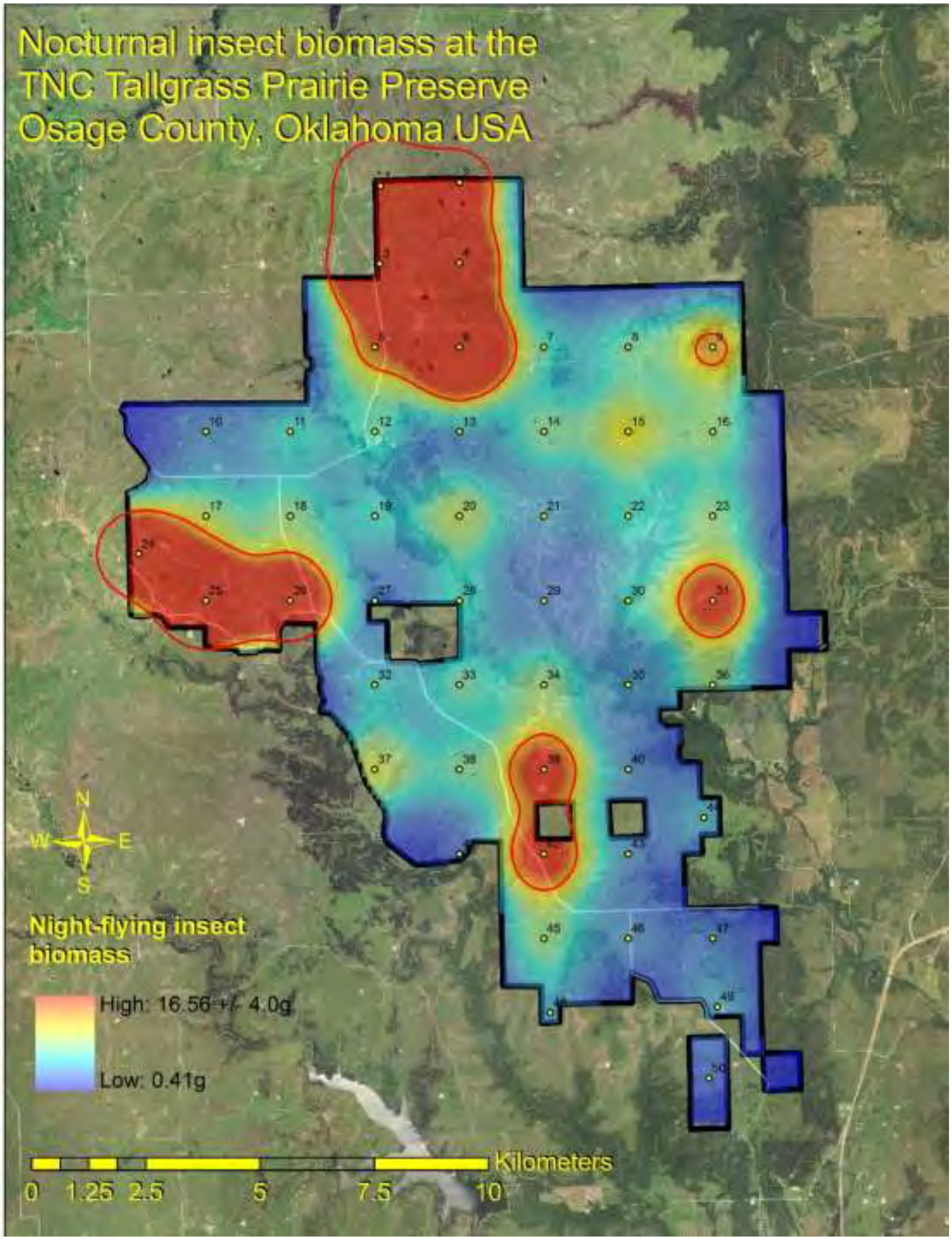

Fig. 9: Map of the interpolation of insect dry biomass (proxy for abundance) at The Nature Conservancy's Tallgrass Prairie Preserve in Osage County, Oklahoma derived from samples collected during light traps at fifty sites during August and September 2015.

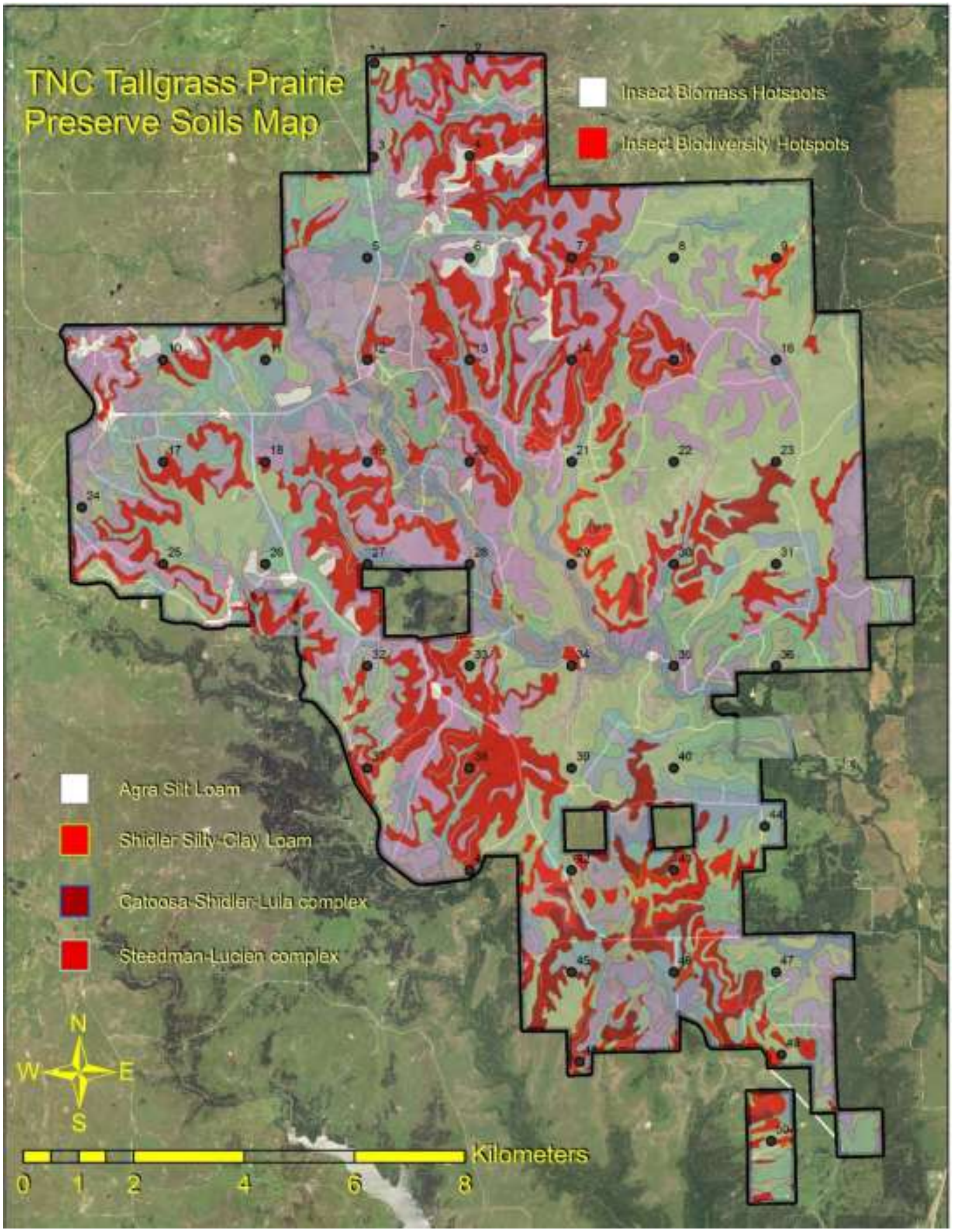

Fig. 10: Map of the primary soil types distributed across the Tallgrass Prairie Preserve study site, with soils associated with high insect biodiversity and abundance highlighted. Soil type was the strongest predictor of biodiversity and abundance of night-flying insects at the site.

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