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ASSESSING SHRUB DISTRIBUTION AND IMPACT IN TALLGRASS PRAIRIE USING AERIAL AND GROUND-BASED MAPPING

by

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ABSTRACT

Woody plant invasion of native tallgrass prairie can result in degradation of the herbaceous community and eventual replacement by woody communities. Methods are needed to assess shrub distribution and potential impacts in prairie ecosystems. This study examined distribution and effects of the shrub smooth sumac (*Rhus glabra* L.) in the Rockefeller Native Prairie, a small prairie remnant in northeastern Kansas. We assessed distribution using ground-based measurements and aerial imagery, established a baseline for monitoring, and quantified both sumac and herbaceous biomass as a function of sumac stem density. Photo- and ground-based maps, each showing four categories of sumac density, indicate that sumac grows in approximately 35% of the prairie. We tested the hypothesis that increasing sumac abundance is associated with decreasing herbaceous biomass. We found that herbaceous biomass is negatively correlated with sumac abundance, expressed as either density or biomass. Our sampling design allowed us to show that this inverse relationship holds for mapped sumac density classes, thus allowing us to infer impacts within mapped units throughout the prairie.

INTRODUCTION

Tallgrass prairie once covered large areas of the eastern North American Great Plains region. As a result of human activity during the last century the vast majority of native prairie has been destroyed or severely degraded. Extant tracts of high quality native prairie are invaluable natural resources that should he protected. Before European colonization, fire and native grazers were essential for inhibiting woody invasion of prairie ecosystems (Collins and Wallace 1990, Wells 1968, 1970). Now, with the elimination of widespread fires and native grazers, timely management is necessary to prevent trees and shrubs from invading, particularly in eastern prairies where moisture is relatively abundant. Ecological succession to woody species is well documented in northeastern Kansas (Fitch 1965. Fitch and Hall 1978). This study focuses on smooth sumac (*Rhus glabra* L.), a 3-5 m tall native shrub, which if uncontrolled, has been known to replace the herbaceous flora of native prairies (Weaver 1954). Smooth sumac forms dense thickets, spreading from underground rootsuckers, and is common along borders of fields and prairies throughout much of North America (McGregor 1986).

Herein we examine the extent and impact of smooth sumac in a small native prairie in northeastern Kansas. Our study has three objectives. The first objective is to determine the current extent of shrub invasion at the prairie. To assess this we conducted quantitative field sampling and constructed a ground-based map of the occurrence and density of sumac at the site. Our second objective is to determine the feasibility of establishing a remote sensing-based monitoring program for this prairie that might have wider applicability. We analyzed false color infrared photography of the site, constructed a photo-based map of shrub invasion, and compared it to the ground-based map. This study serves as a pilot for using remote sensing to monitor sumac abundance and distribution in the future. The last objective of the study is to determine the impact of sumac invasion on herbaceous vegetation within the native prairie. To address this question we examined the effect of different sumac densities on herbaceous biomass. It is beyond the scope of this study to elucidate the mechanism whereby sumac might inhibit the native prairie vegetation. However, as a beginning, we characterize canopy development (leaf area index) and consider how competition for light resources aboveground relates to belowground competitive processes, for example competition for nutrients and water.

METHODS

Study Site

Field work was conducted at the Rockefeller Native Prairie (RNP), part of the Kansas Ecological Reserves (managed by the Experimental and Applied Ecology Program at the University of Kansas, Lawrence, KS). The prairie is located 12 km north of Lawrence in Jefferson County. This 4-hectare remnant of the native tallgrass prairie has a diverse plant community representative of the original prairie (Kindscher 1991). Rare plants include Mead's milkweed (*Asclepias meadii* Torr.) and the Western prairie fringed orchid (*Platanthera praeclara* Sheviak & Bowles). The prairie is believed to have been mowed and burned annually from the 1870s until 1956, though it was never plowed (Fitch and Hall 1978). Since then it has been burned in the spring at intervals ranging from 1 to 3 years to control woody vegetation (Fitch and Kettle 1988). Recent management of the prairie has involved mid-April prescribed burns in 1985, 1986, 1988, 1990, and 1992. In addition, dense patches of sumac were mowed in August, 1987. Despite active management, abundant populations of smooth sumac grow on the RNP. It is the general consensus of biologists familiar with the prairie that sumac has become more abundant on the site in recent years. Because of concern that sumac increase may lead to decline in native herbaceous species, early to mid-summer cutting of sumac will be conducted, in addition to biennial prescribed burns.

The RNP is an upland prairie located on a relatively level ridge with gentle side slopes. The prairie soil is predominantly Oska silty clay loam and Grundy silty clay loam with a small amount of Pawnee soils (Dickey et al. 1977). Oska soils are fine, montmorillonitic, mesic Typic Argiudolls and Grundy soils are fine, montmorillonitic, mesic Aquic Argiudolls. The regional soil map by Dickey et al. (1977) is relatively coarse, and we do not know its accuracy within the RNP. However, if it is accurate, then the Oska soils would appear to be relatively more invaded by sumac than the Grundy soils. This could be due to various factors, including the proximity of wooded invasion along the Oska soils. In any event, we assume that there are no significant differences in productivity associated with these soils that would significantly affect the outcome of our study.

The 133-year (1857-1990) mean of annual precipitation at Lawrence, KS is 93.0 cm (36.6 inches) with an average of 69% of the annual precipitation occurring during the growing season, April – September (Atmospheric Science Laboratory, University of Kansas, United States Centennial Cooperative Weather Station, Lawrence, KS, 1857-1990). Annual precipitation records from a site 1.5 km northeast of the prairie (G.L. Pittman, unpublished) were compared to the 133-year mean to characterize rainfall for our study. Annual precipitation values for 1988-1991 and for the period January through October 1992, expressed as a percentage of the annual mean, were as follows: 94% (1992), 76% (1991), 107% (1990), 84% (1989), and 59% (1988).

Ground-Based Mapping and Sampling Design

A ground-based map was prepared of the RNP to show areas characterized by four sumac density classes (None, Low, Medium, and High). Distinct density classes were readily and consistently apparent based on visual comparison. Stem counts along transects showed that these density classes correspond roughly to the following ranges: Low 1-3, Medium 4-5, and High >5 stems/rn^2. Field mapping was aided by use of an existing grid system consisting of posts placed at approximately 8 to 30 m intervals.

Randomly-located sample plots were established for measurement of sumac stem density, height, and leaf area index, and associated herbaceous biomass. A total of 18 sample plots were distributed within each of the four sumac density classes (total 72 plots). All sample plots were separated by at least 2.0 m and located in areas where the April prescribed burn had left no living aboveground stems. Each plot consisted of nested set of three quadrats, with a 0.1 m^2 biomass sample quadrat (0.2 m x 0.5 m) centered within 1.0 and 3.0 m^2 circular quadrats (0.56 and 0.98 m radius, respectively) for sampling sumac stem density and height. Two sizes of circular quadrats were used to determine the appropriate sampling scale. Because results from the 1.0 and 3.0 m^2 quadrats were not significantly different (based on pairwise t-tests, $p<0.05$), we only report results from the 3.0 m^2 quadrats.

Aerial Photography Interpretation

A photo-based map of sumac densities was constructed using false color infrared aerial imagery of the RNP taken on October 7, 1989. Additional aerial imagery had been planned for 1992 to allow a direct comparison with ground-based measurements; however, technical problems precluded acquisition of this imagery before sumac had dropped its leaves. In the 1989 photographs, areas of different shrub densities are apparent as various intensities of yellow. Outlines of these areas were manually traced on a mylar overlay and transferred to a base map (Universal Transverse Mercator projection), using a Kargl reflecting projector (Riebe-Kelsey Instruments, Inc.). This map was then digitized using ARC\INFO version 6.1 GIS software (Environmental Systems Research Institute) on a UNIX workstation (SUN SPARCstation 2). While smooth sumac is by far the main woody species within the RNP, a few small, isolated patches of dwarf sumac (*Rhus copallina* L.) and blackberry (*Rubus* spp.) also occur and may have been interpreted as smooth sumac in the photo-based map. The 1992 ground-level map prepared for this study was transferred to the base map and digitized using the same methodology. A summary of sumac density class coverage was prepared for each map.

Characterization of Canopy Development

Differences in canopy development were characterized at each sample plot by measurements of leaf area index (LAI), using a Licor LAI-2000 Plant Canopy Analyzer. LAI readings were taken at ground level in all sample areas and at half of the average sumac stem height for each sample plot where sumac was present. LAI readings were recorded on August 3-5, 1992 under evenly overcast sky conditions throughout the sampling period. The canopy was assumed to be maximally developed on these dates.

Stem Density and Biomass Sampling

Sumac stem density and biomass were estimated using stem counts and stem heights measured for both the 1.0 and 3.0 m^2 quadrats. Sumac biomass was calculated from height using regressions of height and dry weight. Leaf and stem biomass for sumac was obtained from a sample of 48 sumac plants across the full range of heights in the RNP. Stems and leaves were separated, dried at 90° C for 96 hr (extra drying time required due to thickness of stems), and weighed to the nearest 0.01 g. Separate regressions were obtained for leaf, stem, and total sumac biomass (total sumac biomass: $y = 166.47 x – 79.00$, $r^2=0.71$; leaf sumac biomass: $y = 107.30 x – 48.09$, $r^2 = 0.70$; stem sumac biomass: $y = 59.20 x – 30.91$, $r^2 = 0.73$, where y is biomass in g, and x is height in m). These regressions were used to estimate sumac biomass based on the stem height and density measurements. Total herbaceous and shrub biomass for each sumac density class was calculated for the RNP based on coverage.

Herbaceous biomass was sampled on August 4 – 6, 1992, to determine effects of sumac abundance on herbaceous productivity. Before biomass sampling, LAI was recorded for each plot. Then all herbaceous growth was removed from each of the 0.1 m^2 biomass quadrats,

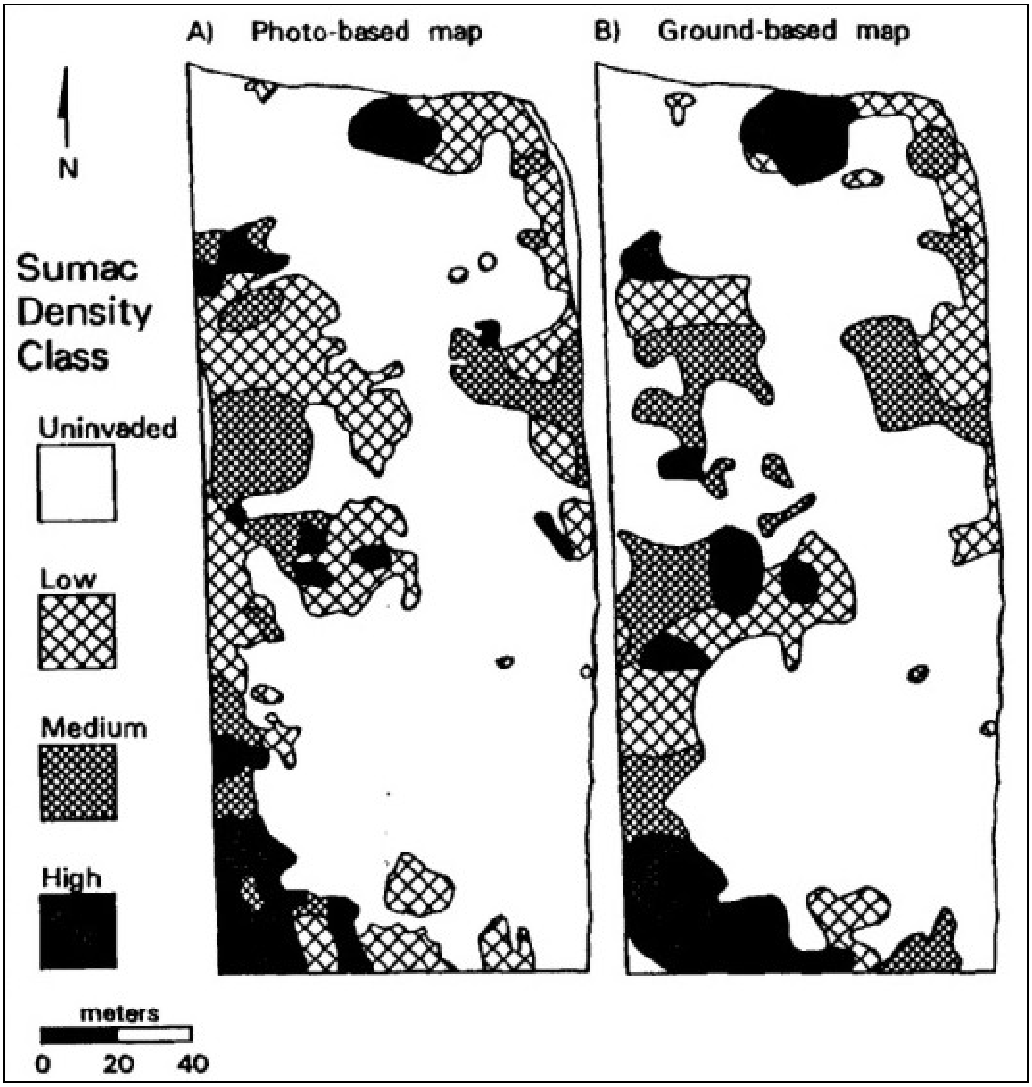

Figure 1. Smooth sumac distribution in the Rockefeller Native Prairie, Kansas: A) photo-based map interpreted from false color infrared photography taken October 7, 1989; and B) ground-based map from field measurements during June-September 1992.

separated into grass and forb components, and dried for 48 hr at 90° C. Finally, total herbaceous biomass for both grasses and forbs was calculated on a dry weight basis.

RESULTS AND DISCUSSION

Photo- and ground-based maps of sumac distribution both indicate sumac covers approximately 35% of the RNP (Figure 1, Table I). The photo-based map shows a higher percentage of sumac in the Low density class than the ground-based map (19% compared to 13%, respectively), with the ground-based map indicating slightly greater amounts in Medium and High density classes (Figure 1, Table 1). Overall, there is good correspondence between the two maps. Discrepancies in some patch locations are probably attributable to inaccuracies in the RNP grid, which has not been surveyed. In addition, we do not know what changes have occurred over the three year period between photo- and ground-based measurements. Taken at face value, the two maps appear to show that overall extent of

Table 1. Absolute coverage and relative coverage of sumac in photo- and ground- based maps. Sumac density classes are explained in the text.

	Sumac Density Class				
	None	Low	Medium	High	Total Sumac
Photo-based map					
Absolute coverage (m^2)	24,744	7,169	3,445	2,860	13,474
Relative coverage (%)	64.7	18.8	9.0	7.5	35.3
Ground-based map					
Absolute coverage (m^2)	24,759	4,863	4,489	4,107	13,459
Relative coverage (%)	64.8	12.7	11.8	10.7	35.2

sumac has not increased, but density within invaded areas has increased over the three years. However, because we were not able to acquire imagery at the same time as when the ground-based map was produced, we can not make a direct comparison between the two maps, and further analysis of the maps must await acquisition and analysis of additional imagery. Aerial imagery is planned for 1993. Thus, the current pilot study establishes a baseline for comparison.

Our sampling design allowed us to test the hypothesis that increasing sumac abundance is associated with decreasing herbaceous biomass. Relations between sumac stem density and herbaceous biomass and between sumac biomass and herbaceous biomass were initially examined using all individual data points. Herbaceous biomass (forbs and grasses pooled) declined significantly with increasing sumac stem density and with sumac biomass (Pearson's r, $p<0.05$, Figure 2). Thus, sumac abundance, expressed as either density or biomass, is negatively correlated with herbaceous biomass. By including all data points, we avoided problems resulting from choice of "artificial" density classes.

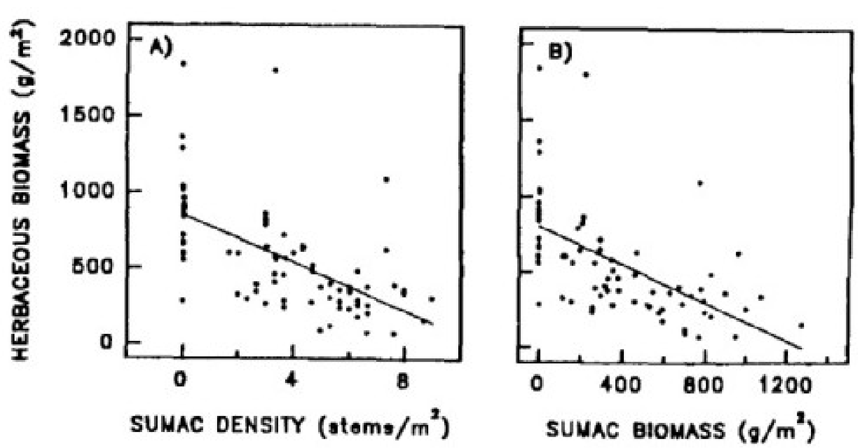

Figure 2. Herbaceous biomass relations with A) sumac density ($y = -78.97x + 853.81$, $r^2 = 0.35$); and B) sumac biomass ($y = -0.63x + 798.67$, $r^2 = 0.34$).

It is also important to know whether the inverse relationship between sumac abundance and herbaceous biomass also holds for the mapped sumac density classes. When considered within the established sumac density classes, total herbaceous vegetation (grasses and forbs pooled) is significantly reduced for the Low density class, and even further reduced for Medium and High density classes (one-way ANOVA. p<0.05, Table 2). When considered separately, forb biomass is significantly reduced at the Medium and High density classes (one-way ANOVA, p<0.05, Table 2). On the other hand, grass biomass is significantly reduced only at the High density class (one- way ANOVA, p<0.05, Table 2). By demonstrating that the basic relationship holds for sumac density classes, we can now infer the impact of sumac on herbaceous growth in the RNP based on our maps.

Table 2. Herbaceous biomass, sumac biomass, sumac density, and sumac height for each sumac density class (mean ± SE). Values within a row that share a superscript are not significantly different from each other (p <0.05, based on one-way ANOVA with mean separation using Tukey's test).

	Sumac Density Class			
	None	Low	Medium	High
Herbaceous biomass (g/m^2)				
Forbs	528.70 ± 8.52^{a}	313.81 ± 9.40^{ab}	160.29 ± 2.33^{b}	139.73 ± 2.97^{b}
Grasses	382.21 ± 5.21^{a}	284.73 ± 4.80^{ab}	262.15 ± 4.72^{ab}	173.61 ± 3.92^{b}
Total herbaceous	910.92 ± 9.12^{a}	598.54 ± 8.12^{b}	422.44 ± 4.44^{bc}	313.34 ± 5.29^{c}
Sumac biomass (g/m^2)				
Stems	0.00 ± 0.00^{a}	73.86 ± 7.82^{b}	166.91 ± 19.02^{c}	255.20 ± 16.66^{d}
Leaves	0.00 ± 0.00^{a}	159.76 ± 15.48^{b}	342.83 ± 37.42^{c}	514.09 ± 31.66^{d}
Total sumac	0.00 ± 0.00^{a}	233.53 ± 23.26^{b}	509.57 ± 56.42^{c}	769.04 ± 48.29^{d}
Sumac density (stems/m^2)	0.00 ± 0.00^{a}	3.26 ± 1.16^{b}	5.07 ± 0.40^{c}	6.48 ± 0.27^{d}
Sumac height (cm)	0.00 ± 0.00^{a}	91.21 ± 3.09^{b}	105.88 ± 2.82^{c}	118.61 ± 3.06^{d}

Aboveground biomass (productivity) estimates, including herbaceous components, sumac leaves, and sumac stems, demonstrate a shift in plant biomass from herbaceous to shrub components as sumac abundance increases (Figure 3, Table 2). Sumac stem biomass is included in these comparisons because all standing aboveground biomass was burned in the spring (1992); and therefore all stems sprouted from the ground during the current growing season. In our case, aboveground biomass is roughly equivalent to aboveground productivity. Partitioning this productivity between new productivity, translocation, and storage is not possible based on our data.

LAI measured at ground level increases significantly whenever sumac is present (one-way ANOVA, p<0.05, Table 3); but LAI does not continue to increase with increases in sumac stem density. These results indicate that the canopy may be fully developed at LOW sumac densities, such that further increases in LAI can not occur. This suggests that increases in sumac LAI lead to roughly proportional decreases in herbaceous LAI; however, this might also result from limitations of the Licor LAT2000 in discerning differences in very closed canopies. LAJ measured at half the canopy height is not significantly different between Low and Medium sumac densities,

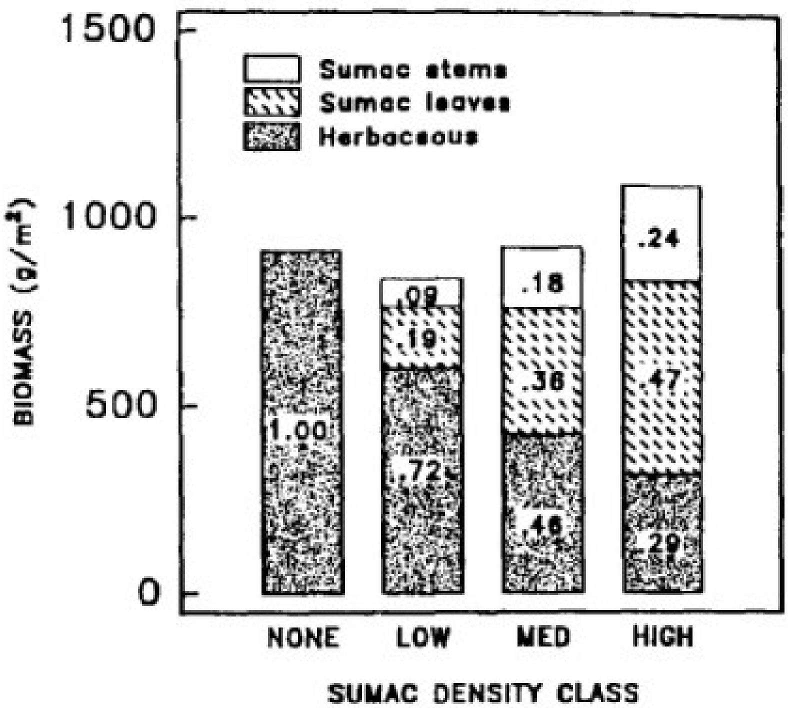

Figure 3. Total plant biomass for each sumac density class, with relative contributions of herbaceous vegetation, sumac leaves, and sumac stems. Numbers within bars are percentages of the total for each component

Table 3. Leaf area index at ground level (GL-LAI) and at one half the average sumac canopy height (ML-LAI) within different sumac density classes. Values within a row that share a superscript are not significantly different from each other (p<0.05, based on one-way ANOVA with mean separation using Tukey's test).

	Sumac Density Class			
	None	Low	Medium	High
Leaf Area Index				
GL-LAI	4.79 ± 0.17^a	5.51 ± 0.20^b	5.71 ± 0.17^b	5.83 ± 0.17^b
ML-LAI)	----	3.03 ± 0.16^a	3.10 ± 0.13^a	3.76 ± 0.22^b

but increases significantly for the High sumac density (one-way ANOVA. p<0.05, Table 3). This demonstrates that foliage becomes increasingly concentrated at greater canopy heights as the sumac density increases to high levels.

CONCLUSION

This study has produced a set of maps, using ground measurements and aerial imagery, that allow us to evaluate smooth sumac abundance in the Rockefeller Native Prairie in northeastern Kansas. These maps serve as a baseline to monitor response of sumac to management. While we are able to determine that sumac currently grows in approximately 35% of the prairie, we are not yet able to assess whether the population is expanding. We demonstrate that sumac presence results in a decline in herbaceous biomass. The combined use of remote sensing and ground measurements has provided us with a means to quantitatively assess the distribution and impact of shrub invasion in tallgrass prairie ecosystems.

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