Defining Reference Information for Restoring Ecologically Rare Tallgrass Oak Savannas in the Midwestern United States

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ABSTRACT

Reference information is commonly used in ecological restorations to guide management decisions and assess progress toward achieving goals. However, for extremely rare or degraded ecosystems, obtaining reliable reference information may be a daunting task. This article explores the limitations and potentials for identifying reference information for ecologically rare tallgrass oak savanna ecosystems, using a case study from central Iowa. Preliminary results suggest that restoration goals related to certain ecosystem parameters, such as vegetation structure, may be achieved relatively quickly, whereas other parameters, such as species composition, require longer timescales. The importance of developing additional reference information through experimental and adaptive management approaches is emphasized.

Keywords: historic range of variation, tallgrass oak savanna, reference information, restoration

Ecological restoration is a subset of ecosystem management that focuses on repairing ecological damage and, generally, implies restoring a degraded habitat to historical (i.e., pre-European settlement) conditions (Jordan III et al. 1987). Recently, the identification and explicit use of reference information for the design and monitoring of ecological restorations has received increasing attention and debate (Egan and Howell 2001). Reference information is defined as the ecosystem's range of spatial and temporal ecological variation and can be derived from historical and extant sources at both the local site and the landscape levels (White and Walker 1997, Egan and Howell 2001). These potential sources of reference information are organized into a useful conceptual framework by White and Walker (1997), in which the advantages and limitations of each are identified (Table 1). Despite the value of determining reference information from such a broad spatial and temporal context, in practice it can be difficult or impossible to obtain accurate and relevant reference information.

In this article, we use White and Walker's (1997) conceptual framework as a basis for assessing reference information for the restoration of a tallgrass oak savanna in the Midwestern United States. In particular, we assess the constraints that arise when reference information from various sources is either unavailable or highly limited. Tallgrass oak savanna is considered one of the rarest ecosystems in North America (Nuzzo 1986) and therefore provides an ideal study system for testing the practical limits and potentials for using reference information from multiple sources as a guide for establishing restoration goals and evaluating success. We also discuss how incorporating research as part of the restoration process may lead to the development of new sources of reference information, thereby strengthening our basis for making management decisions and assessing progress toward goals.

Description of the Tallgrass Oak Savanna and the Study Site

Tallgrass oak savanna is a subset of a much broader savanna community type that occurs across temperate and tropical regions and is characterized by scattered, open-grown, fire-tolerant trees (primarily oak species) with a dense herbaceous understory (Anderson 1998). At the time of European settlement, an estimated 11–13 million hectares of tallgrass oak savanna existed within portions of Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio (Nuzzo 1986).

Reference information for restoration of tallgrass oak savanna is limited for several reasons. Most prominent is the lack of high-quality extant communities: only 0.02% of original oak savanna remains today, and most of this occurs as small fragmented remnants (Nuzzo 1986). Patterns of tallgrass oak savanna are controlled by complex inter-

Table 1. Synopsis of the benefits (+) and limitations (−) of reference information from each of the four potential sources.

		Contemporary		Historic
Local				
	+	Site equivalent Climate equivalent	+	Site equivalent
	−	Snapshot view needs to be supplemented with long-term data Human impacts/degraded state lead to lack of suitable sites	−	Poor spatial resolution Data possibly qualitative and/or biased Biases in historic record more likely to be evident at small spatial scales Unknown past climatic and historic effects
Regional				
	+	Community and ecosystem processes directly measured Ability to experiment and test hypothesis	+	Direct picture of past states, variation, and human impact
	−	Spatial variation in context, environmental conditions Human impacts/degraded state lead to lack of suitable sites	−	Both spatial and temporal uncertainties apply Data possibly qualitative and/or biased Unknown past climatic and historic effects

Source: Adapted from White and Walker (1997).

actions between climate, topography, and fire (Anderson 1998), making it difficult to obtain reliable reference information at the local level. In addition, the Midwest is an agriculturally dominated landscape in which native plant communities are highly fragmented and isolated—a radical change from historical conditions.

The study site, located on the southwestern edge of Saylorville Lake, a flood-control reservoir on the Des Moines River in central Iowa, supports a relatively intact overstory of scattered, open-grown oak trees (primarily *Quercus alba*, with a minor component of *Quercus rubra* and *Quercus velutina*) characteristic of historical tallgrass oak savanna. The topography is highly dissected, comprising a series of ridges and valleys with an east-west orientation. The land was logged and heavily grazed after European settlement in the late 1800s but has remained unmanaged since being purchased by the US Army Corps of Engineers, between 1965 and 1975 (see Karnitz [2005] for detailed site description). The existing condition of this remnant savanna resembles relatively dense woodland because of management practices that precluded disturbance and the subsequent encroachment of shade-tolerant tree species (e.g., *Ulmus* spp., *Ostrya virginiana*; Figure 1A). In the following section, we analyze the historical and contemporary reference information at both local and regional scales available for this tallgrass savanna restoration site. Historical information was obtained from both historical records and scientific literature. Contemporary information—ideally obtained from relatively intact habitat occurring under similar biophysical and climatic conditions as the restoration site—was for our site primarily derived from alternative sources, as described in the following section. After presenting the reference information, we discuss the goals, experimental design, and preliminary results for the restoration of this degraded oak savanna as they relate to our current knowledge of reference conditions and the potential for improving this knowledge in the future.

Historical Reference Information

Historical Regional. General Land Office (GLO) surveys conducted at the time of European settlement, 1845–1850, give general descriptions of the landscape and dominant tree species (Whitney and DeCant 2001). Every one-half mile (~805 m) along section lines, GLO surveyors marked the two closest trees as witness trees and recorded the angle and distance to the tree as well as the diameter at breast height (dbh) and species of the tree. Analysis of the 38 survey points located in nearby areas with similar topography, landscape position, and soils to our study site indicated that that the dominant overstory tree species were *Q. alba*, occurring at 55% of the points; *Quercus macrocarpa*, occurring at 53% of the points; *Q. velutina*, occurring at 32% of the points; and *Q. rubra* and *Ulmus* spp, both occurring at 21%. However, surveyor techniques and the coarse resolution of the survey make direct calculations of tree densities and average tree size impossible (Nelson 1997). In addition, these data were taken only once and can not account for temporal variation in tree species composition caused by changing climate, fire intervals, and periods of drought—all factors that greatly influenced the occurrence of savanna (Anderson 1998). Paleotechniques, such as lake sediment core analysis and dendrochronology, which could increase the temporal resolution of the reference information, are not viable approaches because there are no permanent ponds in the region or trees that predate European settlement. Thus, regional GLO records compiled across similar sites conveyed landscape-level information on the variation in canopy tree composition, allowing inferences about the likely structure of the ecosystem, while precluding more precise estimates of tree density and size.

Figure 1. Low-intensity tree-removal research area (A) before and (B) after tree removal treatment. Note the dense canopy of *O. virginia* that was removed during treatment implementation. (Photo credit: L.A. Brudvig; photos taken during Jan. 2003.).

Historical regional information about the understory layer is even more problematic, because surveyor notes from this region did not include specific information about species composition. However, early settlers described oak savannas as having a dense herbaceous understory (White 1994), providing a qualitative reference of the understory appearance. This qualitative information is limited in value because the current pre- and postrestoration data that we wish to compare it with are quantitative, making interpretations ambiguous. Consequently, the notoriously scarce historical information about species composition in temperate oak savanna ecosystems (see Delong and Hooper [1996]) also applies to this site.

Historical Local. Limited information was available about the historical conditions of our study site. A GLO survey taken less than 0.5 km from our site described a broken topography with timber consisting of *Q. macrocarpa* and *Q. alba*, thereby suggesting that our study area was historically under savanna vegetation during the time of European settlement. However, initial dendrochronological analysis indicated that the oldest tree at the site was a 145-year-old white oak, which postdates European settlement, thereby greatly limiting our ability to derive quantitative information about historical conditions from the existing vegetation. Oak trees present on the landscape today could have arisen after European settlement by resprouting from former savanna trees that were released after land abandonment. Others have also pointed to the widespread post-European settlement establishment of oaks in plant communities considered to represent degraded savannas (Abrams 1996, Anderson 1998). Consequently, historical analysis using dendrochronology does not provide sufficient data to either confirm or dispute the GLO description. A more useful approach may be to obtain core samples from the rootstocks and use dendrochronological methods to determine the temporal origin of these oak trees.

Contemporary Reference Information

Contemporary Regional. For our restoration site, contemporary reference information at the regional scale was inferred from three primary sources: (1) soils; (2) characteristics of the overstory trees, particularly canopy cover; and (3) species composition of the understory flora.

Soils. Anderson (1987) describes oak savanna soils as having characteristics intermediate between prairie and forest soils, with a reduction in O and A horizon thickness (relative to prairie) and development of weak E and Bt horizons. The Lester soil series, which represents one of the dominant soil types at our study site, closely matches this characterization, lending support to the historical presence of savanna vegetation at this site.

Overstory Trees and Canopy Cover. Many ecologists have attempted to describe savanna ecosystems according to percent canopy cover; however, no consensus has been reached and values for savanna canopy cover vary widely, from a low of 10% to a high of 80% (Curtis 1959, Nuzzo 1986, Cochrane and Iltis 2000). A relatively conservative range of 10–40% canopy cover proposed by The Nature Conservancy represents a widely accepted and practically useful guide for savanna restoration and was considered appropriate as an initial guideline for our restoration site.

Species Composition of Understory Flora. The composition of the ground layer flora in oak savanna has been widely debated (Leach and Givnish 1999). Reference information for understory composition is difficult to obtain because intact, high-quality savannas are rare and most remnants are severely degraded. Moreover, species lists from distant remnants, generally, are inadequate because species distributions and habitat affinities vary regionally (DeLong and Hooper 1996). An alternative approach is to characterize herbaceous species based on their tolerance of mixed-light conditions, as presumably such microclimate conditions would have prevailed in historical oak savannas. Using this approach, DeLong and Hooper (1996) identified 287 potential savanna understory species for Iowa, based on existing knowledge about species' resource requirements and habitat affinities. The Delong and Hooper (1996) list has two significant limitations: first, it was derived from a fairly subjective process, and, second, the criteria for selection includes a wide range of shade tolerances, and therefore the list is very broad and is not exclusively applicable to savanna habitat.

A second approach to identifying contemporary reference information about understory species for savanna restorations is the use of coefficients of conservatism. Conservative species are defined as species with a high affinity to relatively intact native habitat, which in Iowa includes the spectrum from prairie to savanna to forest. Conversely, generalist species can persist in areas impacted by modern human disturbance and in human-created habitats. The most conservative species are assigned a value of 10, and the most general are assigned a zero (Swink and Wilhelm 1994). Applying these criteria, Swink and Wilhelm (1994) developed coefficients of conservatism for plant species common to the Chicago region, which was later adapted to the 1,984 species common to the Iowa flora (http://www.public.iastate.edu/~herbarium/coeffici.HTML). In the Swink and Wilhelm (1994) system, nonnative species are not assigned a coefficient of conservatism; however, we feel that it is important to include nonnative species during floristic assessments. For this reason, and because nonnative species often are associated with disturbed habitats, we assigned nonnative species a value of zero. Despite the aforementioned limitations described, both coefficients of conservatism and the list of potential Iowa savanna species are tools with which we can measure responses to the restoration process, as well as preliminary guidelines for selecting understory species for active restoration.

Contemporary Local. No contemporary local information was available because our restoration site and all nearby areas were severely degraded by cattle grazing and fire suppression as inadequate as a reference of intact oak savanna conditions. Although the overstory canopy of the study site supports scattered open-grown white oak trees, these trees do not predate European settlement and thus grew under postsettlement conditions. Similarly, the understory and midstory developed under fire-suppressed conditions and are dominated by a dense stand of shade-tolerant species that are not representative of savanna vegetation. Thus, lack of extant high-quality savanna remnants available precluded the possibility of measuring population, community, and ecosystem processes directly.

The Savanna Restoration Experiment: Goals and Study Design

The available reference information, although clearly deficient in many respects, provided an important baseline for setting the restoration goal for this site: to move the current overgrown woodland condition toward the historical savanna condition, as characterized by overstory canopy trees dominated by oak, relatively sparse canopy cover (10–40%) and a dense herbaceous understory. Removal of nonoak trees was considered an important first step in this

Table 2. Summary of the reference information, baseline data, and posttreatment data used to evaluate the oak savanna restoration case study.

Site attribute	Reference information	Baseline data from control sites	Post—low-intensity tree removal	Post—high-intensity tree removal	Evaluation
Overstory tree composition	Dominance of white oak, burr oak, and black oak	American elm, honey locust, and shagbark hickory	Shagbark hickory, black oak, and northern red oak	Northern red oak and black oak	Shift toward oak dominance
Canopy cover %	10–40%	84%	45%	16%	Addresses low and high bounds of range
Understory structure	Dense herbaceous understory	7.6% cover for understory vegetation	26.2% cover for understory vegetation	38.8% cover for understory vegetation	Significant increase in understory vegetation cover
Understory species composition	Species present on the Delong and Hooper (1996) savanna list	Control 1: 42 species total 6 on savanna list; Control 2: 74 species total 18 on savanna list	116 species total 29 on savanna list 87 off savanna list	119 species total 31 on savanna list 88 off savanna list	Proportion of savanna species not different between treatments
Species quality	High proportion of species are conservative for native habitats	Control 1: 39 species total 14 conservative; Control 2: 48 species total 14 conservative	114 species total 50 conservative	118 species total 48 conservative	Proportion of conservative species not different between treatments

Baseline data are derived from control sites, which did not receive tree removal treatments.

process, followed by reestablishment of the fire regime.

The study design included three consecutive, parallel ridge tops. Prerestoration conditions were assessed in 2002. All herbaceous and woody vegetation less than 50 cm in height was measured in 1 × 1 m quadrats, at 10-m intervals along 200-m transects within each treatment and control area. In each quadrat, percent cover of woody and herbaceous vegetation and species composition was recorded. Species composition was supplemented with four additional 10 × 10 m sampling quadrats located every 50 m along each transect. Three hemispherical photographs were taken at each 10-m sampling point, and percent canopy cover was analyzed using the software package Hemiview 2.1 (Delta-T Devices, Ltd., Cambridge, UK).

Two different tree-removal treatments were conducted in the winter of 2003: (1) low intensity—removal of all non-nut–bearing trees (i.e., oak, hickory, and walnut)—and (2) high intensity—removal of all nonoak trees. In both treatments, woody vegetation taller than 150 cm was cut manually with a chainsaw and burned in slash piles off-site (Figure 1, A and B). Treatments were conducted on one ridge, and the other two ridges were left as controls. The control and treatment areas averaged 2.5 ha in size. Posttreatment sampling of the vegetation was conducted during the 2003 growing season using the same methods described previously. We applied the two regional sources of reference information described previously to assess changes in understory flora: the list of potential savanna species in Iowa (Delong and Hooper 1996) and the list of coefficients of conservatism adapted for the Iowa flora (with values of 4–10 considered to represent conservative species).

Data were analyzed using one-way analysis of variance with treatments (tree removal versus controls) as the independent variable and vegetation measurements as the dependent variables. Changes in understory species composition were analyzed using contingency tables. All statistical analyses were conducted in SAS (release 8.01, 1999–2000; The SAS System, SAS Institute, Inc., Cary, NC, US).

Results and Discussion

Some responses to restoration treatments may be relatively immediate. In this study, pretreatment canopy cover for both treatment and control areas varied between 83 and 84.5%. Low-intensity and high-intensity tree removal resulted in canopy covers of 45 and 16%, respectively, which are near The Nature Conservancy's proposed standard range (Table 2). The restoration treatment also shifted the overstory species composition toward the reference condition by increasing the dominance of oak trees. Before tree removal, no differences in percent cover of the understory vegetation were recorded between treatment and control areas ($P = 0.4345$). However, after tree removal, percent understory vegetation cover was significantly greater in treatment areas than control areas ($P < 0.0001$; Table 2). Treatment areas tended to have a higher number of potential savanna species than the control areas; however, treatment areas also had more species overall, and therefore the proportion of these species did not increase ($\chi^2 = 2.5$, degrees of freedom [df] = 3, $P = 0.47$; Tables 2 and 3). Similarly, treatment areas had a greater number of conservative species than control areas; however, because treatment areas also had a greater number of generalist species (values of 0–3), treatments did not increase the proportion of conservative species ($\chi^2 = 3.3$, df = 3, $P = 0.34$; Tables 2 and 4). Thus, there was little indication that the treatments affected understory species composition, and no such change was expected so early in our study.

Most restoration processes occur over longer temporal scales. Restoring the savanna understory conditions will require a longer process, including long-term management by prescribed fire, which has been shown to increase native understory savanna species abundance (Tester 1996). Regional data suggest that oak savanna fire return intervals were historically on the order of 3–5 years (Guyette and Cutter 1991), which provides a starting point for establishing a historical fire return interval. In addition to the importance of reintroducing fire, the successful restoration of the savanna understory flora also may be contingent on and sequential to ensuring appropriate prop-

Table 3. Contingency tables for number of conservative (CC ≥ 4) versus generalist species.

Treatment area	Conservative species	Generalist species	Total
Control 1	14	24	39
Control 2	14	34	48
Low-intensity tree removal	50	64	114
High-intensity tree removal	48	70	118
Total	126	193	310

Table 4. Number of species on DeLong and Hooper's (1996) list of potential savanna species versus those that do not occur on the list for two treatments and controls at the Saylorville Lake savanna restoration site, central Iowa.

Treatment area	Potential savanna species	Non-savanna species	Total
Control 1	6	36	42
Control 2	18	56	74
Low-intensity tree removal	29	87	116
High-intensity tree removal	31	88	119
Total	84	267	351

Table 5. Summary of the reference information used for the oak savanna case study from each of the four potential sources.

	Contemporary	Historic
Local	None available	No quantitative reference information Qualitative description of area
Regional	Canopy cover between 10 and 40% Presence of understory species from potential savanna species list for Iowa (Delong and Hooper 1996) High level of species conservatism	Overstory species composition Qualitative description of understory cover

agule availability of understory species and allowing sufficient time for soil restoration (especially where severe compaction and erosion have occurred because of past land use). Long-term goals, such as reestablishing ecosystem functions and processes, are also sequential and will not be achieved without first having reestablished the proper vegetation and soil components.

Given the lack of historical quantitative data and extant reference sites, reference information alone is insufficient for evaluating progress toward achieving the restoration goal. Another important measure will be the degree of change in the treatment areas with respect to both the starting condition (i.e., the control) and the available reference condition—e.g., by assessing shifts in understory species composition, soil characteristics and microclimate conditions over time. According to ecological restoration theory, we would expect the site to follow a trajectory away from the degraded state and toward the reference condition (Hobbs and Norton 1996). Although the finer details of this target condition are presently unknown for oak savanna, there exists significant opportunities to enhance our knowledge about what constitutes a healthy and functioning savanna ecosystem through the restoration process itself. The potential value of such reference information developed through adaptive experimentation and management represents an often-overlooked component of ecological restoration.

For example, as more precise and quantitative data are obtained for understory plant species composition and species-specific resource requirements from diverse sites, more accurate lists of conservative savanna species can be compiled, both on a local and on a regional scale. In addition, reference information regarding ecosystem processes like nutrient and water cycling can not be obtained effectively through historical or current means because these processes were not historically recorded, and contemporary degraded sites do not represent fully functioning savanna systems. Thus, restorations that successfully establish attributes identified as important for the reference condition (Egan and Howell 2001) provide initial models for quantifying ecosystem processes and establishing acceptable baseline reference information. Pooled over multiple "successful" restoration sites, a sound understanding of ecosystem processes and spatial and temporal variation can be derived for a particular habitat. Several studies suggest that ecosystem processes in restorations may recover more quickly than species composition (e.g., Aide et al. [2000], Brooks et al. [2002], Kolka et al. [2002]); thus, such process-based matrices may be especially useful as reference information for evaluating results. As new information becomes available, adjustments will need to be made to both the reference condition and the restoration process.

These preliminary results from our Saylorville tallgrass savanna restoration experiment were used to evaluate how the conceptual framework of White and Walker (1997) might be applied to an actual restoration. Although the model was clearly a useful guide in helping to define potential reference sources at the appropriate scale, we had to deviate greatly from the framework and the ideal because of the significant gaps in available information for temperate oak savanna ecosystems. We encountered many of the limitations associated with the different references described by White and Walker (1997), as well as some that they did not anticipate, most notably the almost complete lack of contemporary information at any scale.

Reference information can and, ideally, should be gleaned from multiple sources that capture a broad range of spatial and temporal variability (White and Walker 1997; Table 1). However, for extremely rare and/or highly degraded ecosystems, such as the tallgrass oak savanna presented in this case study, an incomplete and patchy historical record and a dearth of contemporary intact ecosystems may render such comprehensive assessments of reference information impossible (Table 5). These limitations do not negate the value of seeking and applying available reference information for several reasons: (1) reference information lends credibility and validity to our restoration decisions, which otherwise may be based on purely human perceptions of what the "ideal landscape" should look like; (2) reference information provides a baseline for monitoring change, as well as refining our reference data through experimentation and adaptive management; and (3) control conditions often are not sufficient for assessing restorations because of the lack of intact habitat and prevalence of highly disturbed conditions; thus, there is no ecological basis for determining target future conditions. In addition to documenting and using reference information that is readily available, some reference information will not be available from either historical or contemporary sources and should be developed through long-term data collection and interpretation that builds on ecological theory and empirical evidence.

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