Coarse-level monitoring protocol for assessing baseline condition and restoration progress in oak woodlands

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Bureau of Natural Heritage Conservation
P.O. Box 7921
Madison, WI 53707
April 2023 *(with minor updates in November 2023)*

PUB-NH-747 2023

Acknowledgments

The authors would like to thank Peter Duerkop, Rich Henderson, Stephen Packard, Pat Trochlell, Ken Wade, Divine Word Seminary, and Kettle Moraine Land Trust for their assistance with property access, discussion in the field, and survey assistance. Numerous private landowners also graciously allowed access to their property for the purposes of collecting data and testing metrics. We are also grateful for support from The Prairie Enthusiasts (TPE), The Nature Conservancy (TNC), the John J. Brander and Christine E. Rundblad Research Fellowship Program at the Milwaukee Public Museum, and Wisconsin DNR, especially Diane Brusoe, Drew Feldkirchner, Owen Boyle, Tara Bergeson, and Hadeer Saleh.

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Suggested citation: Carter, D., Miner, B., Staffen, A., O'Connor, R. and Zine, M. 2023. Coarse-level monitoring protocol for assessing baseline condition and restoration progress in oak woodlands. The Prairie Enthusiasts, The Nature Conservancy, and Wisconsin Department of Natural Resources. WDNR PUB NH-747. Madison, WI.

Cover Photo: Privately owned oak woodland in Iowa County, Wisconsin. Photo by Dan Carter.

Preface

The vocabulary we use for timbered lands is not adequately descriptive. Our stewardship should strive towards the most vibrant and diverse expression of any one place, and to do so requires that the steward become student of the local ecological system. Wisconsin's oak systems are expressions of deep relationships between people and land. We can only expect them to continue if those relationships are rekindled and endure. Recognize that oak forests, oak woodland, and oak opening are constructs, and let the land be your guide. An assessment tool is a scaffold and should not be taken as a boilerplate solution. It is there to help the user identify and pursue useful lines of inquiry in their reading of the land. Many alternative shared characteristics of oak systems exist. Our aim is that a good number of those will be captured by metrics we have chosen. First and as a practical matter, recognize that the non-arboreal dimensions of oak systems are critically important—perhaps even more important—than the trees themselves.

When to use this protocol

Coarse-level monitoring is useful for habitat managers interested in assessing baseline conditions and restoration progress. The coarse level metrics used in the approach can also be used to track ecological integrity over time in response to management or lack thereof. The metrics are based on key ecological attributes and broken into quantified ranking bins ranging from A-D. They are easily estimated in the field without the use of plots. A general understanding of natural communities and associated plants are required to complete the monitoring, but extensive botanical expertise is not needed. This rapid, coarse-level approach is not intended to replace other, more intensive plot-based methods that seek to answer specific management or research questions, but it may serve as a useful way to monitor sites when time or botanical expertise is lacking.

Course level metrics have been developed for oak woodlands, oak openings and oak and pine barrens. However, communities can grade into one another, and historical land use and degradation can make it difficult to determine the historical plant community. Characteristic features of each community are noted below. Use the monitoring protocol that best matches your site and management goals.

Description and characteristics of oak woodland

In general, oak woodlands tend to be dominated by members of white oak group, especially white oak, sometimes also with bur oak, and locally in southwestern Wisconsin, chinquapin oak. Red oak, black oak and shagbark hickory may also be present and can sometimes account for 50% relative cover or more of the tree layer. Canopy closure can vary widely, but in the best quality sites is between 41-65%. **"Canopy closure" is the proportion of shrub and ground layer that is covered in shade or shade flecks at noon on a sunny day.** Closure is not measured by the degree to which crowns are touching, although crowns in oak woodlands are often touching through much or all of the canopy.

The groundlayer in oak woodlands is often dominated by a matrix of sedges like Pennsylvania sedge and savanna running sedge (*Carex siccata*), sometimes also with a variety of other graminoids that thrive under dappled light conditions. Forbs overlap significantly with oak openings and oak forest, but some of the best indicators include wide-leaved panic grass (*Dichanthelium latifolium*), upland boneset (*Eupatorium sessilifolium*), prairie alumroot (*Heuchera richardsonii*), two-flowered Cynthia (*Krigia biflora*), veiny pea (*Lathyrus venosus*), pale vetchling (*Lathyrus ochroleucus*), blunt-leaved sandwort (*Moehringia lateriflora*), wood betony (*Pedicularis canadensis*), eastern shooting-star, yellow-pimpernel (*Taenidia integerrima*), Culver's-root (*Veronicastrum virginicum*), and Carolina vetch (*Vicia caroliniana*). See the oak woodlands coarse-level metrics indicator species checklist under Metric 2 below and on the field worksheet for a more complete list.

Oak woodlands can occur in a variety of landscape settings, usually in sites that allowed them to persist with frequent fire but not so severe as to convert to prairie or oak opening. Examples include cooler slope aspects adjacent to prairies and oak openings, knolls and ridgetops surrounded by mesic to dry-mesic forest, and upland islands surrounded by wetlands in southeast Wisconsin.

Oak woodlands can be differentiated from oak openings by having a higher degree of canopy closure, more dappled light, and more a continuous canopy. In contrast, oak openings tend to have a more open canopy with less continuous canopy and significant areas of full sun. Oak woodlands tend to have a groundlayer that thrives in dappled light and usually lack many of the prairie species present in oak openings. Mature trees in oak woodlands also usually lack the short boles and wide-spreading lower limb architecture found in oak openings, but instead have somewhat intermediate growth forms between oak opening and the tall, straight, forest-grown trees found in more closed-canopy forests.

Oak woodlands can be differentiated from oak barrens by their canopy usually dominated by white oak and locally bur oak, often with red oak, black oak, and shagbark hickory also present. In contrast, oak barrens are usually dominated by black or Hill’s oak, sometimes with pines co-dominant. Oak woodlands also tend to occur on sandy loam to clay loam soils, whereas oak barrens usually occur on sand.

Closed canopy oak woodlands degraded by fire suppression or grazing can be difficult to differentiate from southern dry and dry-mesic forests. The best approach is to look for woodland indicators that may still persist in more shaded habitats, often especially along trails and edges, such as upland boneset, Culver’s root, eastern shooting-star, wide-leaved panic grass, prairie alumroot, orange false-dandelion, veiny pea, pale vetchling, blunt-leaved sandwort, wood betony, and Carolina vetch. Oak woodlands also tend to have trees with moderately spreading limbs, rather than narrow crowns entirely lacking the spreading upper limbs found among trees that originated in a mostly closed-canopy oak forest.

While we acknowledge that both conceptual and spatial boundaries between community types are somewhat arbitrary, they are still useful in helping managers determine the most appropriate management goals based on current species composition, historical conditions, desired future condition, and feasibility. Users of this protocol should also recognize that the metrics are sufficiently flexible to cover a diverse suite of ecological parameters across a wide range of quality. No single metric (e.g., canopy closure) dominates the overall score and good-quality sites will usually be recognized as such even if there is uncertainty over individual metrics or even whether a site should be evaluated as an oak opening or an oak woodland.

Introduction

Oak woodland is the more canopied subtype of the Midwest oak savanna, and a globally rare community that has long been a conservation focus, especially in recent decades. Like other savannas, oak woodlands have been degraded through past grazing, severely altered fire regimes, logging, invasive species, excessive deer browse, and fragmentation. However, present-day distinction between oak openings and oak woodlands can be difficult, particularly where past land use and fire exclusion have shifted oak openings and associated natural community types towards forest. Curtis (1959) did not separate oak woodlands in Wisconsin from oak openings or oak-dominated forests, so oak woodlands straddle Curtis' concepts of oak opening and dry and dry-mesic forests. The contemporary condition of historical prairie--oak opening--oak woodland--forest mosaics is often homogeneous forest structure, with some persisting clues as to past condition. Many species, including rare species, are moderately to significantly associated with both oak openings and oak woodlands (e.g., red-headed woodpecker, *Melanerpes erythrocephalus*; kittentails, *Besseya bullii*) or with both dry to dry-mesic forest types and oak woodlands (e.g., woodland vole, *Microtus pinetorum*; heart-leaved skullcap, *Scutellaria ovata*). This further complicates discernment of oak woodland from oak opening and dry to dry-mesic forest conservation targets. It may be for these reasons that oak savanna restoration efforts sometimes fail to recognize historical oak woodlands and instead pursue oak opening targets, which can lead to mediocre outcomes. Nonetheless, significant resources have been invested in restoring and maintaining oak woodlands by public agencies and private organizations.

As interest in managing oak woodlands has increased, so has the need to identify sites with the highest restoration potential, as well as the need to assess restoration progress over time. Monitoring is often problematic for managers with limited time or those with limited botanical expertise, and is often limited to photo points or cursory, qualitative visual inspections that are inconsistent and non-repeatable. On a subset of sites, species-specific monitoring is conducted. While species-level surveys and habitat suitability monitoring can be valuable, more comprehensive community-level monitoring of ecological integrity encompassing the full range of oak opening sites is needed, especially for sites that are ecologically significant but are not known to support rare species. In addition, using consistent measures of community structure and composition in oak woodland sites across multiple ownerships and ecological landscapes would provide a valuable index of their conservation status.

Background on Coarse-level Metrics

We designed a monitoring approach for oak woodland based on ecological integrity. Ecological integrity is a concept used extensively by NatureServe and is grounded in the best scientific understanding of high-functioning ecosystems, taking into account ecological processes, vegetation composition and structure, and anthropogenic degradation (Parrish et al. 2003, Faber-

Langendoen et al. 2016). Metrics were developed in two phases: We initially drafted the field worksheet based on literature review and field observations of the authors, who have collectively visited and managed hundreds of sites across the state. We then field-tested the metrics with oak savanna experts and managers at sites representing a range of ecological integrity, from disturbed to high quality reference sites. We collected data at these sites to review and refine metrics and to revise the worksheet to improve ease of use.

A key principle of ecological integrity assessments (EIA) is the ability to implement monitoring at multiple scales depending on level of detail desired, expertise, and available resources. Typically, these are designated as Level 1 (remote sensing), Level 2 (moderate detail), and Level 3 (most detailed). We designed oak woodland EIA protocols and field worksheets for Level 2 (accommodates time-constrained practitioners and/or those with limited botanical expertise).

Coarse-level monitoring (also called coarse-level metrics) focuses on key ecological attributes, or metrics, that are biologically important for plant and animal species and that can be influenced by management. First developed and used by The Nature Conservancy (TNC) along with the Huron-Manistee National Forests (HMNF) in Michigan, coarse-level metrics have shown to provide a relatively quick and inexpensive means to track the progress of restoration and maintenance in oak and pine barrens (Keough et al. 2011). More recently, coarse level metrics have also been developed for oak and pine barrens (O'Connor et al. 2019), and for southern sedge meadow and wet-mesic prairie (O'Connor 2020) in Wisconsin.

Evaluation of these metrics requires basic understanding of oak woodland ecosystems and the prairie-savanna-forest mosaics of which they are part, but it does not require extensive botanical expertise. The metrics are designed so that land managers and stewards can evaluate restoration success and determine the next restoration or management step(s) needed, without relying on external botanists or ecological consultants (Keough et al. 2011).

Thirteen metrics have been selected for coarse-level monitoring of oak woodland based on key ecological attributes. Each metric is evaluated independently, with observers recording their observation, a corresponding letter grade (A, B, C, D), and a numerical score. Metrics are grouped into three categories: oak woodland composition, general composition, and vegetation structure. A summary and explanation of the rationale for each metric is below.

OAK WOODLAND COMPOSITION

1) Total percent cover of native graminoids

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
11-65%	6-10% or 66-80%	1-5% or 81-95%	<1% or >95%

While the cover of grasses, sedges, and rushes can vary quite widely, even healthy woodlands with relatively low graminoid cover tend to have graminoids fairly evenly interspersed among the other herbaceous vegetation. Abundant species at the best sites include Pennsylvania sedge (*Carex pennsylvanica*), running savanna sedge (*Carex* *siccata*), poverty oatgrass (*Danthonia spicata*), and common wood rush (*Luzula multiflora*). High quality or restorable sites may have other graminoids as well, including those that are often occur on heavier soils such as eastern star sedge (*Carex radiata*).

Please note that the B, C and D categories have split rankings that encompass both a low and high range of cover values. Both too low and too high cover of native graminoids are signs that herbaceous vegetation has been degraded by past land use or fire exclusion in an oak woodland. Graminoids are important sources of fine fuels to carry fire, and their fine roots build and maintain soil organic matter, but high graminoid cover with few woodland forbs can result from overgrazing or severe deer browse. On the other end of the spectrum, too little graminoid cover can make it difficult to carry fire.

2) Number of native indicator species (see checklist)

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
20+	14-19	6-13	0-5

The authors began with a long list of candidate species that was informed by other lists developed for oak woodlands or more broadly for savannas and other oak-dominated communities in Wisconsin (Curtis 1959, Pruka 1995, Bader 2001), the authors' own experience, and consideration of importance of indicator against ease of identification and geography of natural occurrence within Wisconsin. The authors further compiled data on the occurrence of candidate indicator species from species inventories, floristic quality assessments, and other visits to historical oak woodland sites of variable quality to inform the list.

Indicator species selected exhibited most of the following traits:

1) They are present at good-quality remnant sites,
2) They discriminate between high and low-quality sites,
3) They are not extremely rare or geographically restricted, and
4) They are readily identifiable during the recommended monitoring period of mid-June through July.

Please note that some species on the list in the same genus may be difficult to differentiate from one another at certain times of year such as horse gentians (*Triosteum aurantiacum* and *T. perfoliatum*). If an observer is confident at least one indicator species in a genus is present, they should check one of the boxes and count it in their total but note their uncertainty on the field worksheet. This caveat allows for botanists who are confident in identifying similar species in a genus to get credit for all indicators present, but for non-experts to still have the option of maximizing their indicator species richness without confusing future surveyors who might otherwise question their species identification.

There are species that occur in oak woodlands that were not chosen as indicators for a variety of reasons. For example, some do not discriminate between high and low quality sites such as spreading dogbane (*Apocynum androsaemifolium*). For other species, their high abundance seems to be associated with past grazing or mesification, such as hog-peanut (*Amphicarpaea bracteata*). Finally, others occur among too broad a range of natural community types to be useful indicators of any one particular habitat, such as wild sarsaparilla (*Aralia nudicaulis*) and wild geranium (*Geranium maculatum*).

While survey area is correlated with species richness, even small sites can have excellent flora, and these ranges should work for sites greater than about one acre in size. For example, the most indicator-rich oak woodland in our data was at Army Lake in Walworth County, which had an assessment area smaller than one acre (Figure 2). This site was protected from grazing by surrounding waters of Army Lake and peatlands. Several similar woodland remnants exist elsewhere in Walworth County in vicinity of Army Lake, Lake Beulah, and Lulu Lake, and another in the Village of Summit, Waukesha County. Despite some of these occurring on fine textured, relatively mesic soils, they are quite similar to remnant woodlands in the Driftless Area and the Central Sands on sandy soils. For example, velvetleaf blueberry (*Vaccinium myrtilloides*) often occurs on these sites, despite their mesic soils.

Figure 2: Remnant oak woodland on fine-textured soil at Army Lake that supports more than 20 oak woodland composition indicators in an assessment area of less than one acre. Photo by Dan Carter.

3) Total percent cover of native indicators of degradation (see checklist)

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
0-20%	21-30%	31-60%	>60%

These species tend to be abundant at sites that experienced a period of excessive shade, excessive litter accumulation, and / or past grazing. Most are known to be weedy and have low coefficients of conservatism (Bernthal 2003). A few others like woodland sunflowers and clonal goldenrods have been documented by restoration practitioners to be aggressive and outcompete smaller-statured species over time. Many of these species will undoubtedly occur in relatively low abundance at good-quality sites, which is expected. Percent cover bins were established to differentiate between high and low integrity sites and to trigger management action to decrease their abundance when needed.

4) Number of parasitic or myco-heterotrophic plants (see checklist)

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
3+	2	1	0

Parasitic, partially parasitic plants and myco-heterotrophic plants are indicators of intact ecological interactions. The best sites tend to have several species in this category, and at least one hemi-parasitic species in abundance (e.g., false toadflax, *Comandra umbellata*; wood betony, *Pedicularis canadensis*), often woven throughout the ground layer. In addition to indicating higher levels of ecological complexity and maturity, parasitic and partially parasitic plants also often serve a function of reducing the stature and dominance of otherwise aggressive species (e.g. dense grasses or sunflowers). This can enhance opportunities for germination and growth of annuals and short-statured species. Myco-heterotrophic plants [e.g., ghost pipes (*Monotropa* spp.), coral-root orchids (*Corallorhiza* spp.), etc.] are included here, because their presence indicates the presence of suitable mycelium.

GENERAL COMPOSITION

5) Total percent cover of non-native species

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
<1%	1-5%	C: 6-15% C-: 16-30%	>30%

Natural communities should be comprised predominantly of native species. Increasing cover of non-native species indicates declining ecological integrity. High levels of non-native species are often associated with past land use history, especially grazing [e.g., multiflora rose (*Rosa multiflora*)], fire exclusion, and a degraded local landscape [e.g., bird-dispersed shrubs such as buckthorn (*Rhamnus cathartica*) and exotic bush honeysuckles (*Lonicera* spp.)]. In addition, non-native invasives suppress and outcompete native species under disturbed conditions, change nutrient dynamics, can impede prescribed fire application by producing poor fuel that retains more moisture and decomposes faster, and do not support fauna that specialize on savanna plant species, among other negative impacts. Due to the need to parse the “fair” category into higher and lower integrity bins, a C-minus category is added for this metric, which should be assigned a numerical score of 1.5.

6) Abundance of white oak group seedlings and saplings up to 20 ft. tall

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
Common-Occasional	Uncommon-Rare (score as B)		Absent

There should be some capacity for oak regeneration in a healthy woodland. Depending on recent fire history, small oaks may be present as seedlings, saplings, or grubs. Even where black oak (*Quercus velutina*) is abundant on xeric and/or sandy soils, at least some component of white oak (*Q. alba*) or bur oak (*Q. macrocarpa*) is typically present. White oak group species are particularly desirable due to their relative resistance to oak wilt fungus (*Ceratocystis fagacearum*), fire tolerance, wildlife value, and longevity.

Due to the time-consuming nature of most quantitative measures for oak regeneration (density, frequency, etc.), qualitative ranks were selected for this protocol instead:

- **Common to Occasional** (score as A): Occurring regularly in good numbers throughout more than half of assessment area (common) or appearing irregularly, but in more than one portion of assessment area in moderate numbers (occasional).

- **Uncommon to Rare** (score as B): Appearing either irregularly in low numbers or very sparsely throughout assessment area. (Note that 'B' and 'C' ranks are merged into a single 'B' option.)

- **Absent** (score as D): None observed.

7) The ratio of the percent cover of white oak group (white, bur, chinkapin, swamp white) to red oak group (black, red, Hill's) and shagbark hickory > 20 ft. tall

Ranking Guidance for each metric			
A	**B**	**C**	**D**
(Excellent)	(Good)	(Fair)	(Poor)
>1:1	1:1 to 1:3	<1:3 to 1:9	<1:9

Most oak woodlands will be dominated by the white oak group. While some woodlands on drier soils or landscape positions will have more black or Hill's oak (*Quercus velutina* or *Quercus ellipsoidalis*) than species in the white oak group, members of the white oak group should still have a significant presence. On more mesic sites, there may be higher proportions of red oak and shagbark hickory.

Note that this metric is expressed in terms of ratios. For users more comfortable with comparing relative percent cover, the following table is provided.

	A	**B**	**C**	**D**
	(Excellent)	(Good)	(Fair)	(Poor)
Ratio of white oak group to red oak group and shagbark hickory	>1:1	1:1 to 1:3	<1:3 to 1:9	<1:9
Translated to relative percent cover white oak group	>50%	25% to 50%	10% to <25%	<10%
Translated to relative percent cover red oak group and shagbark hickory	≤50%	>50% to 75%	>75% to 90%	>90%

8) The ratio of oak and shagbark hickory percent cover to that of all other trees > 20 ft. tall

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
>9:1	4:1 to 9:1	2:1 to <4:1	<2:1

Trees other than oaks and shagbark hickory are typically minor components in oak woodlands. Species such as elms (*Ulmus* spp.), boxelder (*Acer negundo*), basswood (*Tilia americana*), black locust (*Robinia pseudoacacia*) and black walnut (*Juglans nigra*) cast excessive shade and produce litter that is less flammable and alters nutrient cycling by its faster decomposition relative to oak. An abundance of such trees is often an indication of fire exclusion and deleterious land use.

Note that this metric is expressed in terms of ratios. For users more comfortable with comparing relative percent cover, the following table is provided.

	A	B	C	D
	(Excellent)	(Good)	(Fair)	(Poor)
Ratio of oak and shagbark hickory to all other trees	>9:1	4:1 to 9:1	2:1 to <4:1	<2:1
Translated to relative percent cover oak and shagbark hickory	>90%	80% to 90%	67% to <80%	<67%
Translated to relative percent cover of other tree species (e.g., basswood, black locust, black walnut, boxelder, hackberry, elm, maple, etc.)	≤10%	>10% to <20%	20% to 33%	>33%

VEGETATION STRUCTURE

9) Total % cover of native herbaceous plants above two feet high

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
0-10%	11-20%	21-40%	>40%

The best sites or portions of sites tend to have relatively short herbaceous vegetation. Notably, shorter vegetation in oak woodland is also often more species diverse. Thus, this metric also provides a surrogate for diversity, heterogeneity, and ecological complexity. Taller species are usually present, but their total cover in high-integrity sites is quite low. Sites that have abundant taller species are often dominated by aggressive rhizomatous or annual species such as Canada goldenrod, woodland sunflower, and jewelweed. In addition to suppressing smaller statured plants through competition, many of these taller species are also documented or suspected to be allelopathic. While there will be some correlation between this metric and Metric 3, Native Indicators of Degradation, both are included as they measure different attributes of ecological integrity.

We selected a cut-off for short statured vegetation of approximately knee height or slightly above, an easy threshold for most observers to use in the field. In field trials this metric tended to hold true throughout the middle and later growing season. It is recommended that monitoring be conducted no earlier than mid-June.

10) Total % cover of low/medium height woody plants (<6 ft tall)

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
0-15%	16-25%	26-35%	>35%

This includes all native and non-native small trees, shrubs and vines. Excess cover of woody shrubs increases competition for sunlight, much as an overly dense tree canopy or subcanopy. Depending on the type of woodland and recent fire history, low/medium height woody plants may be minimal, although low growing species like low bush honeysuckle (*Diervilla lonicera*), snowberry (*Symphoricarpos albus* or *S. occidentalis*), blueberry (*Vaccinium* spp.), huckleberry (*Gaylussacia baccata*), New Jersey tea (*Ceanothus americanus*), and lead plant (*Amorpha canescens*, usually south aspects) may be present. Also, depending on browse and fire history, some shrubs and trees capable of taller stature may fall into this category, including American hazelnut (*Corylus americana*), round-leaved dogwood (*Cornus rugosa*), Juneberry (*Amelanchier* spp.), *Viburnum* spp., and oak grubs (*Quercus* spp.).

11) Total % cover of all small trees and tall shrubs (6-20 feet tall)

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
1-10%	<1% or 11-20%	21-30%	>30%

In oak woodlands with high integrity small trees and tall shrubs should be relatively sparse. Similar to the upper tree canopy, this mid-canopy structural layer has the potential to cast excessive shade on low shrubs and the herbaceous groundlayer. While some small oak trees are desirable to replace canopy oaks over time, relatively few are needed for adequate regeneration in woodlands. Unlike a closed canopy forest, one of the primary characteristics of an oak woodland is having a relatively open understory that allows a significant amount of dappled light to reach the herbaceous layer. Note that the B category is split, containing both a range that is higher than ideal (11-20%) and a range that is lower than ideal (<1%). This captures the fact that a least a few small trees are desirable for canopy replacement over time.

12) Total % canopy closure of trees (>20 feet tall)

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
41-65%	31-40%; 66-80% (score as B)		<31% or >80%

An excellent quality oak woodland should have a tree canopy closure of 41-65%. This can be measured using mobile applications such as CanopyApp (University of New Hampshire 2018), CanopyCapture (Patel 2018), or Canopy Cover Free (Easlon 2018). This can also be expressed as the inverse of the amount of sky patches that can be observed through the canopy, or light flecks falling on the groundlayer, assuming small tree and shrub cover is minimal. This is technically termed canopy *closure* (Jennings et al. 1999).

Two ways to conceptualize canopy closure:

- The inverse of the amount of sky patches that can be observed through the canopy.
- The proportion of shrub and ground layer that is covered in shade or shade flecks at noon on a sunny day.

In contrast, canopy *cover* is classically defined as the extent to which crowns are touching, or what percent of points on the ground have a tree canopy directly above them (Jennings et al. 1999). In that classic definition, small gaps of sky between branches and leaves would be counted as canopy, as would be seen from above on an aerial photo. Notably, this classic definition of canopy cover is correlated with stand volume and basal area but bears little relationship to light availability at the ground level (Jennings et al. 1999). Canopy closure is a therefore a better measure for oak woodland monitoring, as it is directly relates to the light regime and microclimate and thus to site suitability for herbaceous plants (Jennings et al. 1999).

Our ranges of A and B quality (31-80%) is based on analysis of good- and excellent-quality sites using standardized mobile device-based measurements. These ranges differ from those outlined by others, but much of the confusion appears to stem from how to best measure and describe canopy, with various authors using the technical definition of closure (despite sometimes still calling it cover) and others using the classical definition of cover, described above.

Curtis (1959) had no formal category for oak woodland but set a boundary of 50% canopy closure (which he called "cover") between oak opening and southern dry forest and southern dry-mesic forest. This he describes as the percent "of ground area shaded by trees at noon in midsummer". However, Clements (1928) instead used the classical definition of canopy cover and noted that in a savanna (i.e., oak opening) tree canopy "shadows do not touch." Despite the differences in terminology and descriptions of how to measure canopy, both authors make clear in their discussion they are primarily concerned with light availability in the groundlayer, which is best correlated with closure, as described above.

Epstein (2017) provides a range of 50-100% canopy cover for oak woodland. It is assumed that this range refers to the classical definition of cover, that is, whether or not crowns (or shadows) touch, not how much dappled light reaches the ground or what percentage of sky patches are visible through the canopy.

Confusion of how to measure and describe canopy has clearly persisted for nearly a century. By standardizing the measurement of canopy using apps and by clearly defining the concept of "canopy closure," we hope to standardize monitoring and management guidance for practitioners now and into the future.

13) Leaf litter accumulation, expressed as impedance of low-statured plants

Ranking Guidance for each metric			
A	B	C	D
(Excellent)	(Good)	(Fair)	(Poor)
Low	Low to moderate	Moderate to high	High OR Site heavily wormed

The best areas where healthy vegetation has managed to persist seem to be where leaf litter build-up is minimal, and that condition is not due to the activity of invasive earthworms. The primary mechanisms that prevent excess litter accumulation are regular fire and/or the interaction of wind and topography. For example, prevailing winds frequently blow leaves free from topographic knobs and exposed slopes, leaving smaller statured vegetation able to photosynthesize and reproduce. Areas with excessive leaf litter accumulation tend to have higher cover of degradation indicators and taller herbaceous vegetation. Tall, long-rhizomatous or stoloniferous herbaceous species (e.g., woodland sunflower, Virginia creeper, etc.) may have an advantage in this setting. Excessive leaf litter accumulation may also lead to higher fire intensity and duration than desired when dry. In the absence of continuous graminoid cover, sufficient leaf litter allows fire to carry across the site.

General Methods

1. **Ensure that oak woodland is the most appropriate management target.** Choose to use this assessment based on evidence gathered about a site's history and future potential. Remaining indicator species, late 1930's aerial photography (available online through the *Wisconsin Historic Aerial Imagery Finder*), and original public land survey notes from 1832-1866 (available online through the *Wisconsin Public Land Survey Records*) are very useful and accessible resources for Wisconsin. Most remnant woodlands will appear to have closed canopies (shadows from trees often make small gaps look dark) or closely spaced trees with small gaps growing season mid-1900s aerial photography. Sites or portions of sites at which the 1930s canopy is intermittent with larger intervening spaces between individual tree crowns may be better assessed as oak opening or oak barrens unless there is reason to suspect the opening was transient due to timber harvest. While not included in this protocol, observers should also consider oak limb architecture to better understand whether oak woodland was historically present. In woodlands oak crowns are narrower and trunks/boles generally taller than in oak openings, but some relatively small diameter lower limbs are often retained (see Figure 1). In woodlands, the limbs of middle and upper portions of the trees are typically more spreading than they are in forest. Dead lower limbs and their scars are evidence of higher light conditions in the past. Timber harvest can erase evidence from old trees, but opportunities for oak woodland restoration may still be discerned from herbaceous indicator species. Historical vegetation maps (Finley 1976) are not recommended for use at the site scale, because of their coarse resolution and because the source data (*Wisconsin Public Land Survey Records*) is readily available and contains more detail than could be incorporated into larger scale maps. If an original land survey transect does not pass through the focal site, read notes from those nearby, especially those that pass over similar topography and soils.

2. **Divide the site into assessment areas (AAs) that are useful for both management and monitoring purposes** (Figure 2). Assessment areas may be based on natural ecosystem boundaries, existing management units, or prescribed burn units. Degraded areas, such as a ditched or plowed area, or dense clumps of invasive species, may be split into separate AAs. Ideal size for AAs is from 2-3 up to about 40 acres. In larger areas, it may be challenging to accurately complete the coarse-level protocol, and numbers for area-dependent metrics may be inflated (e.g., number of indicator species). Assessments of areas smaller than two acres may score lower on area-dependent metrics, though metrics would still be able to show changes relative to baseline conditions.

   It is recommended that a goal (or desired future condition) for the AAs be clearly articulated. Examples of desired future condition include oak opening, oak barrens, and oak woodland, though explicit inclusion of site nuance is useful for posterity (e.g., a non-oak canopy element there is good reason to maintain). The metrics described here may be applied differently, or not at all, in units having a goal other than oak woodland.

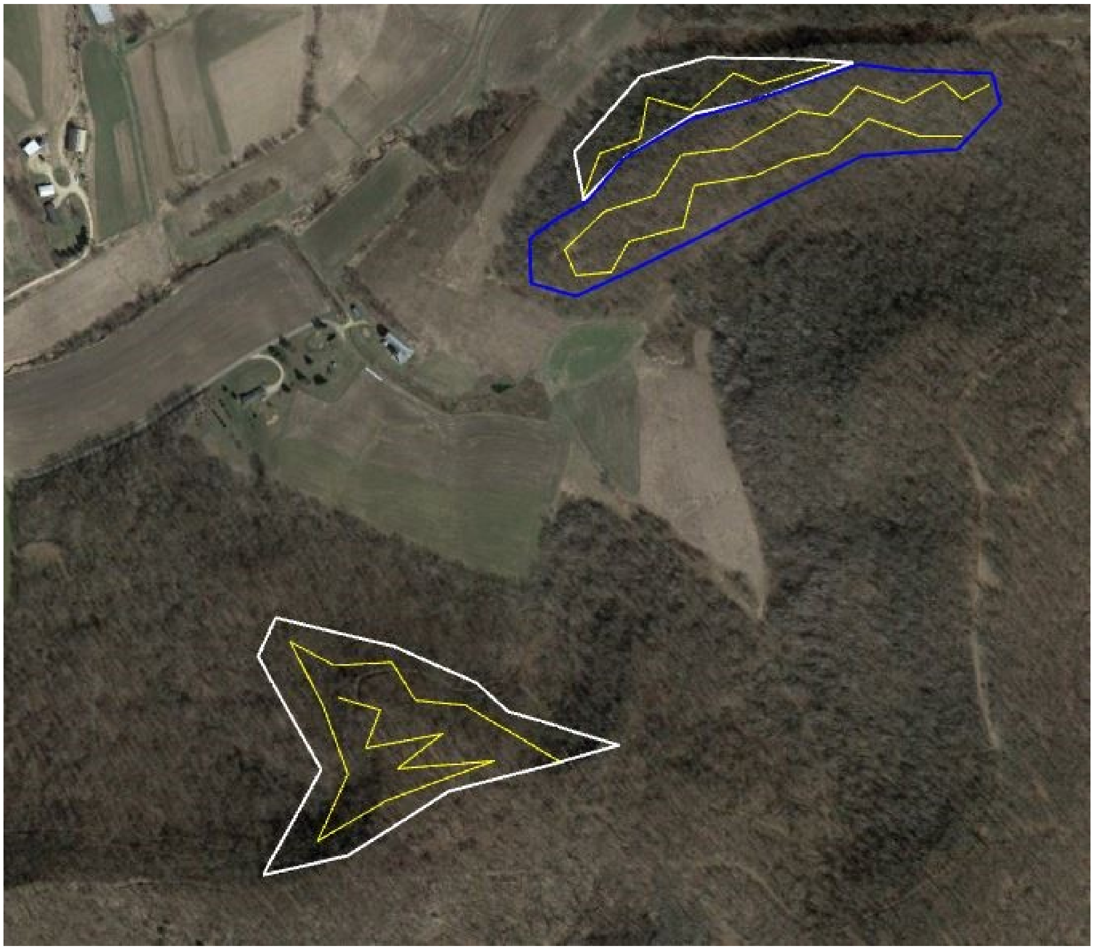

Figure 2. Hypothetical assessment areas (remnant oak woodlands in white, remnant oak opening in blue) and survey routes (yellow zig-zag) at a private property in the Driftless Area. These areas were deduced despite infill of forest canopy from indicator species still present, late 1930's aerial photography, and original land survey notes.

3. **Ensure adequate coverage.** To ensure AAs are adequately covered in surveys, meander through the AA being careful to equally cover all available habitat, including variations in canopy cover, brushiness, topography, and aspect. To facilitate adequate coverage in the field and avoid observer bias, survey routes may be established a priori that zig-zag across the entire AA (Figure 2). For large AAs, surveyors have the option of recording interim observations (see Step 6 below).

4. **Enhance accuracy of measurements with multiple surveyors.** It is recommended that the assessments be performed by at least two people familiar with oak woodland ecology. This is particularly helpful for metrics that require estimates of percent cover, which are subjective and may thus vary among surveyors. While illustrations of various degrees of percent cover are provided on the field worksheet as a guide, the effect of individual bias may be reduced by having surveyors make independent assessments of percent cover and average the values at the end of the survey. Mobile apps such as "CanopyApp" (University of New Hampshire 2018), "CanopyCover" (Patel 2018), or "Canopy Cover Free" (Easlon 2016) are helpful, particularly for estimating tree canopy cover in AAs

with a partially closed canopy. We found that even where canopies of trees were generally touching or closed and appear closed in growing season aerial photography, canopy cover measured with CanopyApp could be below 50% where canopies were comprised exclusively of oak due to many smaller gaps through the canopies of individual trees.

5. **Follow protocol for assigning letter ranks.** For each metric in the AA, write the corresponding estimate to the nearest whole percent in the column "Your Obs", then assign a letter rank (A, B, C, D) for that metric using guidelines provided on the form (Attachment A - Oak Woodland Monitoring Form). Note that there are unique descriptions of A- through D- ranks for each individual metric. Convert the letter rank into a numerical score using a grade-point style conversion (i.e., A=4, B=3, C=2, D=1).

6. **Optional: For larger AAs, it may be helpful to record interim observations at various points within the AA.** Similarly, if a survey route has been pre-established, it may be beneficial to evaluate metrics at multiple points along the survey route. In these instances, record interim estimates for metrics of percent cover on page 2 of the form. Do not record interim observations for indicator species or spatial heterogeneity, which should be integrated across the entire AA. At each interim stop, note the approximate proportional area of the AA covered by the stop. This is especially important if some stops offer longer sight lines, while others are limited (e.g., five interim stops with one stop covering 60% of an AA, and four stops each covering 10% of the AA). If each interim observation covers approximately the same proportion of the AA, divide by the number of stops (e.g., five interim stops each covering an equal area for a proportional area for each stop of 20%). Upon completion of the survey, calculate the weighted average for each percent cover metric in the AA, based on the proportional area of each stop. Write the weighted average in the "Your Obs" column on the front of the form, and follow Step 5 to translate the observation to an A-D rank and numerical score for each metric.

7. **Consider tips for recording indicator species.** For the metric for number of indicator species, use the indicator species checklist form and check off each species observed during the survey. Most of the species were selected to be identifiable in late June, though some observers may capture most indicators throughout the growing season. Common wood rush and running savanna sedge are notable exceptions, but were included because they are present, if not abundant, at the majority of the best sites. When looking for indicator species, move slowly and explore ecological gradients of light, aspect, soil type, etc. thoroughly. Keep a running tally of species for the entire AA; do not track zig-zag segments separately. Upon completion of the survey, count the total number of indicator species observed in the AA and enter it on the main form, and follow the procedure in Step 5 to translate that into a letter grade and numerical score.

8. **Calculate subtotal scores for Oak Woodland Composition, General Composition, and Structure.**

    a. For the **Oak Woodland Composition** subtotal, calculate the average of the four numerical scores for the Oak Woodland Composition metrics. To facilitate calculation of the overall composite score for the site, multiply the Oak Woodland composition subtotal score by 0.60 and enter it in the weighted average field in the rightmost column. The higher weight given to this subtotal reflects the importance of the herbaceous and shrub vegetation.

    b. For **General Composition** subtotal, calculate the average of the four numerical scores for the General Composition metrics. To facilitate calculation of the overall composite score for the site, multiply the General composition subtotal score by 0.2 and enter it in the weighted average field in the rightmost column.

    c. For **Structure** subtotal, calculate the average of the five numerical scores for the Structure metrics. If the Tree canopy metric is D (1), write D (1) for the overall structure subtotal. Sites with a very closed canopy may be other forest types or have lower restoration potential due to prolonged shading, and completely open sites likely are not oak woodland or have been severely degraded by clearing. Review of historical aerial photography and original land survey notes can be helpful for these interpretations. To facilitate calculation of the overall composite score for the site, multiply the Structure subtotal score by 0.2 and enter it in the weighted average field in the rightmost column.

9. **Calculate a composite rank** for the entire management unit by adding all of the weighted subtotal scores in the rightmost column and translate the total to a letter rank using the Composite Rank Guide (provided below and on the form).

A	>3.8-4
A-	3.5-3.79
B	3-3.49
B-	2.5-2.99
C	2-2.49
C-	1.5-1.99
D	<1.49

10. **Compile data for multiple assessment areas.** In some cases, a site may be composed of more than one assessment area, or an assessment area may not be uniform and may be subdivided for estimates (e.g., multiple oak woodland AAs in Figure 2). To determine values for each metric for the entire community, or for multiple communities across the entire site, calculate a weighted estimate for each assessment area:

    a. First, calculate the area of each assessment area and determine the proportional area of each assessment area over the whole site.

   b. Second, calculate the weighted value for each metric in each assessment area by multiplying the estimated values by the proportional area.

   c. Lastly, determine the sum of all weighted values for each metric across all assessment areas.

11. **Illustrate locations of specific management concerns on a map.** Reference concerns in the notes section of the form and include recommendations for those areas of management concern.

Guidelines for Field Estimates

1. Conduct field monitoring from mid-June through August when herbaceous species are easiest to identify. Less experienced botanists will find this easiest from mid-June to July. Prior to mid-June herbaceous vegetation height cannot be properly assessed.

2. Ensure all areas within an AA are visible and accessible to observers on the ground. Exclude features that may be inaccessible or separate inaccessible features into different AAs (e.g., blufftops surrounded by cliffs, areas split by rivers or streams that cannot easily be crossed, etc.).

3. The vegetation patterns of savannas are intrinsically uneven due to variable degrees of shade and woody cover, and patchy distribution of various species, thus it is important to evaluate each metric thoroughly across the entire assessment area. For example, total percent cover of native graminoids in open areas should be averaged with those that occur underneath shrubs or trees. Likewise, tree canopy cover should be averaged across a few estimates or measurements throughout the site.

4. Monitoring before and after significant management actions may offer insights into impacts and efficacy of those actions. Consider timing post-management surveys to suit various needs, e.g., finding short-statured species during the first growing season following prescribed fire. Also consider frequency of monitoring to track change over time, whether in response to direct management, lack of management, climate change, etc.

Supplies and Equipment

- Compass
- GPS unit or digital map depicting assessment area boundaries
- Aerial photographs depicting assessment area boundaries
- Data sheets
- Clipboard
- Pencils with erasers
- Field guide to Wisconsin wildflowers, (can be a simple, introductory guide if most indicator species are included). Grass, sedge, and rush indicators will not be in wildflower field guides.

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