Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Monitoring the Ecological Response to Restoration Treatments in the Missouri Pine-Oak Woodlands Restoration Project of the Mark Twain National Forest

Authors: Mike Leahy[1], Kyle Steele[2], Elizabeth Yohe[3], Brian Davidson[2], Jason Stevens[4] and Greg Nowacki[4]

SUMMARY

The Missouri Pine-Oak Woodlands Restoration Project (MOPWR) on the Mark Twain National Forest (MTNF) is one of 31 projects across the country supported by the U.S. Forest Service Collaborative Forest Landscape Restoration Program (CFLRP). The Project aims to restore mixed shortleaf pine (*Pinus echinata*)-oak (*Quercus* spp.) woodlands that historically dominated this landscape. A number of ecological monitoring projects have occurred in MOPWR, including birds, vegetation, and a small amount of pollinator surveys. Based on these monitoring projects, in particular the Community Health Index (CHI), treatments of fire and fire + thinning are moving stands towards more functional ecosystems – as well as actively providing benefits for certain focal species. However, there is uncertainty as to whether it is possible to move stands to reference conditions. The goal of functional but not reference condition natural communities may be a more realistic target for the MOPWR landscape.

The Southern Tier Oak Restoration Initiative (STORI) is a partnership coordinated by the Eastern Region of the U.S. Forest Service. The partnership includes the southern tier National Forests in the Eastern Region and their state partners. The goal of the partnership is to produce needed ecosystem mapping, monitoring, and ecological departure guidance in support of oak natural community management in the Central Hardwood Region.

Cover Photo: Prescribed fire in a remnant shortleaf pine-oak woodland ecological site in Shannon County, Missouri (photo by Kyle Steele).

[1] Missouri Department of Conservation
[2] U.S. Forest Service – Mark Twain National Forest
[3] University of Missouri
[4] U.S. Forest Service – Eastern Region

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INTRODUCTION

Overview of the Missouri Pine-Oak Woodlands Restoration (MOPWR) Project

The landscape of MOPWR includes the Eleven Point and Poplar Bluff Ranger Districts of the Mark Twain National Forest (MTNF) and surrounding public lands (**Figure 1**). The project area lies within a region identified by numerous agencies and entities as having some of the highest priority landscapes for ecological restoration in the Ozark Highlands. The project area includes significant public land ownership and some of the most undeveloped lands in the region.

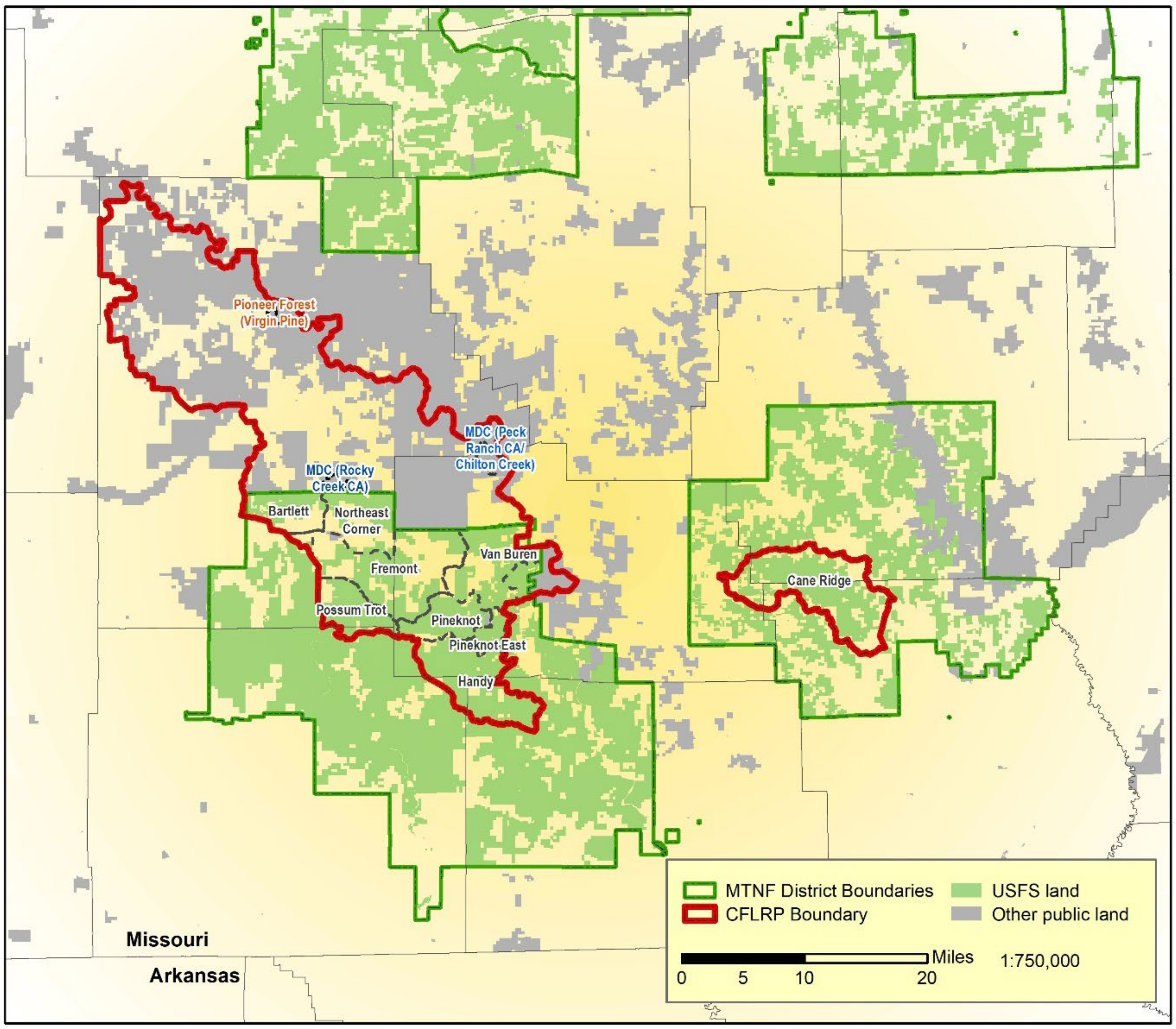

Figure 1. Missouri Pine-Oak Woodlands Restoration Project boundary and associated project areas on the Eleven Point and Poplar Bluff Ranger Districts of the Mark Twain National Forest, L-A-D Foundation, and Missouri Department of Conservation.

For the last 2,000+ years up until the early 1800s, this area was dominated by mixed shortleaf pine-oak and oak-pine woodland ecosystems (Nanavati and Grimm 2019). Prior to fire suppression in the 1930s, the region had widespread occurrence of relatively frequent, low severity fire regimes (Stambaugh and Guyette 2008). Based on analyses of General Land Office (GLO) surveys, in the mid-1800s shortleaf pine occurred on more than six million acres of the southern Missouri Ozarks, supporting extirpated species such as the red-cockaded woodpecker (*Dryobaetes borealis*; Nelson 2010) and brown-headed nuthatch (*Sitta pusilla*; recently reintroduced).

Most of the MOPWR project area is within the Current River Hills Ecological Subsection, but also includes a portion of the Black River Ozark Border. Both Subsections are similar in relation to soils, geology, topography, and historical ecological conditions. Landtype Associations (LTAs) of the project area range from gently rolling dissected karst plains - historically covered by open woodlands heavily dominated by shortleaf pine - to steep and rugged river hills and breaks landscapes consisting of oak-pine mixed woodlands and forests (**Figure 2).**

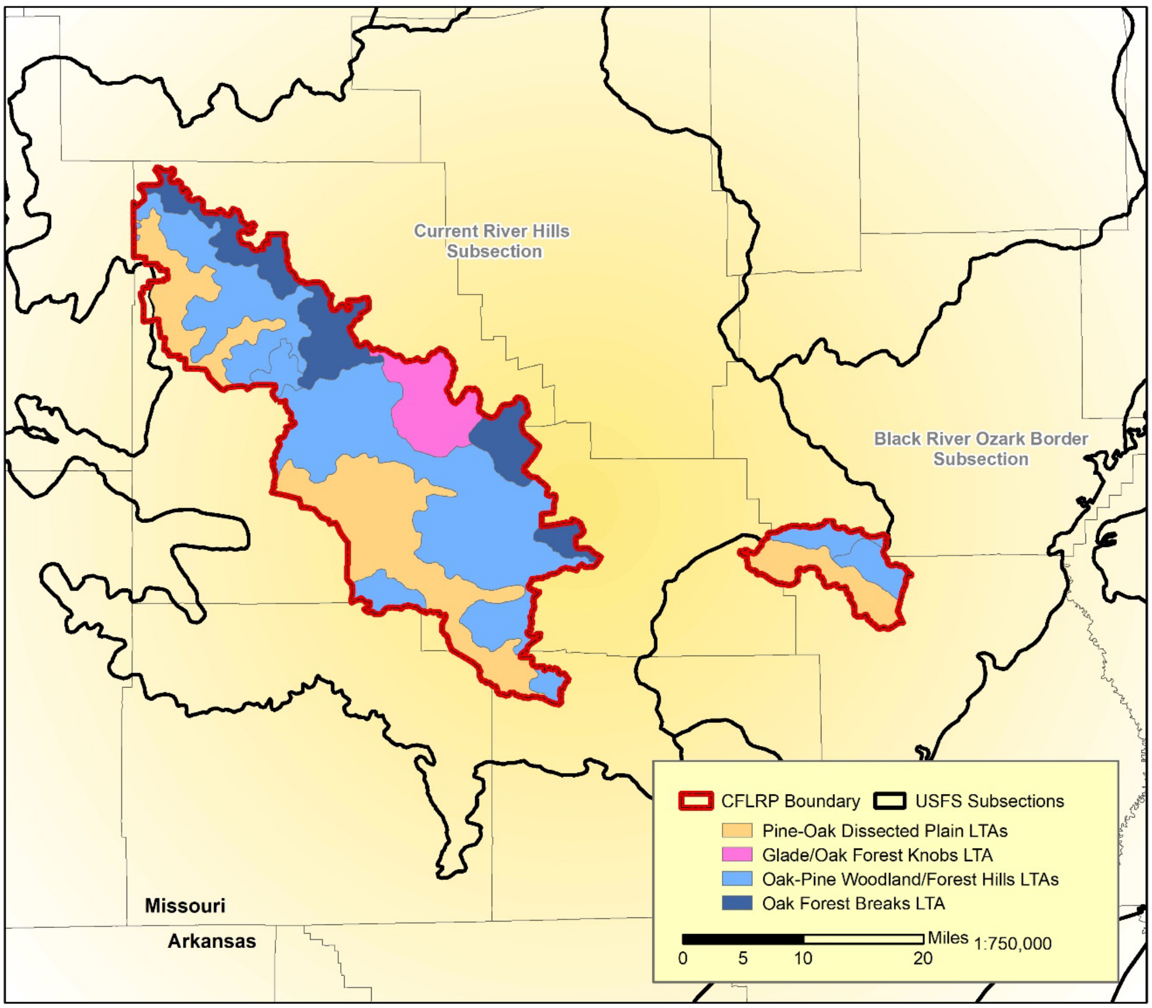

Figure 2. Ecological context of the Missouri Pine-Oak Woodlands Restoration Project within the Ozark Highlands Section, including the Current River Hills and Black River Ozark Border Subsections (Nigh and Schroeder 2002). Landtype Associations are shown grouped by LTA-type from gently rolling to steep and rugged, and separated by igneous versus sedimentary geology.

Natural communities of the project area are variable. Areas receiving management mostly include dry and dry-mesic chert woodlands as described by Nelson (2010). Sites defining this natural community type include an array of “low base” woodland ecological sites, which indicate parent materials of a highly acidic and often rocky nature consisting of low amounts of base cations. All of these promote proliferation of the pine-oak ecosystem. Soils of gently rolling terrain are loamy mantled and relatively rock free, and while they are extremely acidic, the increased water holding capacity provides relatively high site productivity (Nigh and Schroeder 2002).

The MOPWR project began in 2012 and includes the following MTNF vegetation management areas: Bartlett, Cane Ridge, Fremont, Handy, Northeast Corner, Pineknot, Pineknot East, Possum Trot, and Van Buren (**Figure 1**). The total project area is 444,088 acres and includes 127,008 acres of U.S Forest Service land. Between 2012 and 2021, the project completed 23,571 acres of commercial timber harvest, 36,053 acres of non-commercial mechanical treatment, 153,850 acres of prescribed fire, and has a cumulative treatment footprint of 138,224 acres. A total of 59,624 acres have received both mechanical overstory treatments, at least two prescribed fires, and are considered structurally restored to open or closed woodland conditions. Prior to MOPWR, an additional 7,568 acres received thinning in the Pineknot, Cane Ridge, and Northeast Corner vegetation management areas. These areas are also considered structurally restored and have received multiple prescribed fire treatments.

The overall restoration goal of the project is to “restore fire-adapted pine and pine-oak bluestem woodlands that will be more resilient to anticipated climate changes” (MTNF 2011). Specific objectives focus on utilizing mechanical thinning, prescribed fire, and non-native invasive species (NNIS) control to approximate the range of historical conditions for pine-oak woodlands, as defined by the MTNF Land and Resource Management Plan (MTNF 2005). The current landscape condition is characterized predominantly by Fire Regime Condition Class (FRCC) 3 which indicates fuel and vegetation conditions are uncharacteristic of historical conditions (Barrett et al. 2010). This project strives to move the vegetation toward FRCC 2 and 1 fuel characteristics, defined as either moderately departed or characteristic of historical conditions, respectively. The recreation of historical fuel and vegetation structural conditions by utilizing prescribed fire and mechanical thinning should increase native biodiversity and result in sites moving towards more natural conditions.

This report examines the different ecological monitoring tools utilized in assessing whether MOPWR has met its objectives, with a particular focus on the CHI rapid assessment approach.

Monitoring ecological integrity

CFLRP monitoring guidance

In 2020, the U.S. Forest Service provided guidance to National Forests on monitoring criteria for CFLRP projects (USFS 2023). This Common Monitoring Strategy recommended using Terrestrial Ecological Unit Inventory (TEUI; Winthers et al. 2005) as a framework to define and describe the landscape, as well as providing a set of core monitoring questions and metrics.

Based on the options provided by the national monitoring guidance, MTNF staff and partners chose to quantify the current terrestrial condition by using project-wide plot sampling information extrapolated to make inferences about the broader landscape (see 1d, page 6 in DeMeo et al. 2020).

The core CFLRP monitoring questions and indicators following the 2020 guidance this report seeks to answer include:

- "*What is the effect of the treatments on moving the Forest landscape toward a more sustainable condition that includes scale and intensity of historical disturbances?*" Our report focuses on Indicator 1 (the ecological departure metric) using the extrapolation from plots option.
- "*What are the specific effects of restoration treatments on focal species and species at risk across the CFLRP Project Area?*" Our report focuses on Indicator 2 (ecological indicator for habitat), using Habitat Suitability Indices for focal species and species at risk.

Additional questions posed by MTNF staff and partners include:

- How are treatments maintaining or improving ecological integrity of shortleaf pine and pine-oak natural communities, including the scale and intensity of both historical and future disturbances?
- How have treatments helped to create a landscape that can adapt to climate change?
- Are there any future management implications as a result of recent restoration activities?
- Are restoration treatments moving stands into Desired Future Conditions (DFCs) for pine-oak woodlands as described in MTNF Land and Resource Management Plan (MTNF 2005)?

To answer these questions, we used the CHI rapid ecological monitoring approach piloted in the MOPWR project in 2020, in conjunction with other ecological monitoring efforts.

Previous MOPWR monitoring efforts

- **Birds**: Monitoring of focal bird species within MOPWR started in 2013. Focal species included those of regional or range-wide concern, such as red-headed woodpecker (*Melanerpes erythrocephalus*; Central Hardwoods Joint Venture 2012). These data resulted in two publications, which showed that nesting-success of six focal bird species and the densities of eight focal bird species were positively related to the MOPWR restoration efforts (Roach et al. 2018, 2019). These publications address the core CFLRP monitoring question related to focal species (ecological indicator for habitat in DeMeo 2020).
- **Vegetation**: In the Pineknot and Cane Ridge vegetation management areas on MTNF, 131 permanent vegetation monitoring plots were established as a part of a partnership with The Nature Conservancy and NatureCITE. One hundred plots were established in

the Pineknot area in 2000 and sampled again in 2001, 2005, 2010 and 2014. Thirty-one plots were later established in the Cane Ridge area in 2009 and sampled again in 2012 and 2015. Each plot covered 0.33 acres and included 50 0.25 m^2 quadrats, as well as traditional forest overstory data. These data were compiled into two internal MTNF reports (Hadle and Thomas 2019 a, b), which outline baseline vegetation conditions of the plots using a floristic quality assessment (FQA) approach (Spyreas 2019).

In the Pineknot area, species richness (both native and non-native) at the site level increased significantly between 2000 and 2014 (Hadle and Thomas 2019a). In their report, they prioritized using mean coefficient of conservatism (Total Mean C) defined as the average conservatism value assigned to plant species in an area (Spyreas 2019). This has long been documented as being a strong measure of the floristic quality of a site (Taft et al. 2006). At the site level, they found Total Mean C was highest in 2005 but declined thereafter, although results were not statistically significant. It's important to note that this project was not set up as a true experimental design. Many of the plots had different ecological conditions prior to the analysis and comparisons across the four treatment regimes - no treatment, burn only, thin only, and burn + thin - were problematic in terms of evaluating FQA. The authors analyzed Mean C at the plot level versus treatment level and found that 60 % of plots in any of the treatments exhibited consistent declines in Mean C, and 40 % were stable or improving. Analyses of plant physiognomic groups and dominant species were not specifically conducted, but the authors noted that such information could be of value. In the Cane Ridge area, there were likewise nonconclusive results for similar reasons (Hadle and Thomas 2019b). The authors concluded that plot-by-plot comparison through time would be needed.

These results show that, while the focal bird community is responding positively to restoration treatments, it is not clear that floristic quality trends using FQA are tracking towards desired conditions.

Natural community health index (CHI) approach

While monitoring is a critical component of strategic habitat conservation, due to the time-consuming and costly nature of such methods, plot-level monitoring often does not occur. Detailed vegetation monitoring also requires a high degree of botanical skill, a skill which is in increasingly shorter supply. For these reasons, the CHI rapid assessment and monitoring method was developed by the Missouri Department of Conservation (MDC), MTNF, and U.S. Forest Service Eastern Region. This method has many parallels to Ecological Integrity Assessments, as developed by NatureServe® (Faber-Langendoen et al. 2016). In Missouri, the concept was originally initiated to better quantify natural community grade rankings applied to records in the Missouri Natural Heritage Database. Work in Missouri to develop CHIs began in earnest in 2014. Nelson (2010) provided the terrestrial natural community classification system that forms the basis of CHI types, as did the more recent developments in Missouri's ecological classification system and TEUI work – identifying ecological sites - being led by the Natural Resources Conservation Service and MTNF (Wallace and Young 2021). The creation of new CHI surveys has been a direct application of TEUI, improving the ability to build ecosystem-specific protocols and providing maps of where on the landscape individual CHI protocols should be utilized.

An effective CHI assesses the following five major components of ecological integrity, each of which is weighted differently in the resultant index/scores (Leahy and Buchanan 2022):

1) Landscape context and community patch size (10% total score)
2) Ground flora composition - including diversity, evenness and abundance (55% total score)
3) Woody structure and composition of functional/physiognomic groups (35% total score)
4) Wildlife composition (not included in total score)
5) Negative disturbance or stressors affecting the site (reduces score)

The development of ecosystem specific metrics and scores is based on existing literature, expert knowledge, peer review, and field testing. Vegetation composition and structure compose the bulk of the CHI score. This is because the vegetative community influences most ecosystem functions and provides habitat for other taxonomic groups, while being the primary vector of energy flow through an ecosystem (Kimmins 1997, Grossman et al. 1998, Fryxell et al. 2014). In addition, strong correlations exist between vegetation and soils, and plants are the most easily and practically measured components of natural communities (Binkley and Fisher 2020, White and Madany 1978). Vegetation is the basis of ecosystem structure and function, integrates spatially and temporally variable natural and management-induced disturbances, and vegetation and higher trophic-level diversity are correlated to some degree (Oliver and Larson 1990, Panzer and Schwartz 1998; Wilhelm and Rericha 2017).

The abundance, diversity, and evenness of matrix as well as high-conservation value (termed "conservative") ground flora species are weighted heavily, contributing to the majority of possible points. We utilize the concepts of FQA to develop lists of indicator species for each of those groups. Using this system, all plant species in an area are ranked on a 10-point scale based on their fidelity to intact ecological systems (Taft et al. 2006). The first group of species – matrix species – are those with ranking values of 4 to 6: these make up the backbone of a functional natural community of a given type, such as bristly sunflower (*Helianthus hirsutus*; Spyreas 2019). A full complement of these matrix species should be in place in all reasonably intact, remnant natural communities. The second group of species are those with ranking values of 7 to 10: those that are truly remnant-dependent conservative species and indicate a higher level of ecological function, such as anise-scented goldenrod (*Solidago odora*; Spyreas 2019). The conservative group of species are weighted more heavily in CHI scoring. Plant species with ranking values of 1 to 3 - termed ruderal - were not included in assessment due to their ability to grow on sites of varying ecological conditions. In addition to listing species with indicator value to a particular ecological type, priority is given to those that are relatively easy to recognize vegetatively without extensive keying and identifiable throughout large portions of the growing season. This also allows the CHI to be conducted by a larger cadre of biologists (with appropriate experience or training). Finally, a fourth group of species is added to the list which includes all NNIS thought to be present in the area. Presence of these species produce negative scores. The list of species included in CHI protocol supporting this effort can be found in **Appendix A**.

The presence of a diverse suite of both matrix and conservative species has shown connections to ecological function and health. Sites that harbor conservative plant assemblages have often been shown to support specialized insect fauna (Hahn and Orrock 2014, LaRose et al. 2019, Panzer and Schwartz 1998). In tallgrass prairies, certain plant taxa are critically important for native bee communities, which are a key pollinator group in North America (Harmon-Threatt and Hendrix 2015). On the other side of this, the presence of invasive or non-native plant species can disrupt ecosystem function. These species have been shown to increase decomposition rates in an area, increase soil nitrogen, and their roots can alter soil structure to increase filtration (Weidenhamer and Callaway 2010). Therefore, it is important for a site have limited NNIS and to contain healthy numbers of both matrix and conservative species for maintained ecological heath.

METHODS

Field work was conducted during the summer field seasons of 2020, 2021, and 2022. The primary goal of this effort was to field test various stages of the Ozark Pine-Oak Woodland CHI protocol development. Between each field season minor additions or changes to the protocol were made until a final version was fully vetted (**Table 1**). Sites were selected to test a range of conditions, including land ownership, variation in ecological sites, unmanaged vs. unmanaged, long term vs. early restoration, etc. Prior to field work, sampling units were delineated in the office using geographic information systems (GIS) software. Sampling units were based on natural community type first and management history second.

Key spatial data used included ecological site maps, topography, geology, aerial imagery, and stand management data. The size of sampling units ranged between 40 and 80 acres. Any CHI questions that could be answered in the office were completed prior to field work, such as Landscape Context and Woodland Community Patch Size. Assessment point locations were designated in representative areas of the sampling unit. Random point generator tools in GIS were tested but provided unsatisfactory coverage of the units; instead assessment points were selected to cover a range of landform conditions, and to provide complete coverage within the unit. The number of assessment points per sampling unit was based on MDC and U.S. Forest Service forest inventory protocols for inventories in mature, homogenous stands (roughly one plot per ten acres with a minimum of four plots; USFS 2015). Once sampling units and assessment point locations were delineated, work in the field commenced. Once in the field, a goal was to spend no more than 90 seconds per acre per sample unit; thus, the time within a given sampling unit varied depending on acreage. Data were primarily collected on paper forms but eventually transitioned to use of a customized ESRI® Survey 123 application - currently in development. Crew size ranged from a minimum of two to a maximum of four, with the ideal number of individuals conducting a survey being three, as this avoids sampling consistency errors.

While in the sampling unit, staff navigated to assessment points in a meandering fashion with their preferred global positioning system (GPS) technology. Initiation of the meander transects for ground flora started ten ft inside unit boundary to avoid edge effects of roads. As staff navigated to each assessment point, indicator and NNIS ground flora species were tallied from a predetermined list within three timed increments. The timed increments were variable depending on size of the sampling unit and difficulty traversing the unit (e.g., excessively rocky and/or steep). For most woodland units, the total sampling time per transect was a function of sampling

Table 1. Breakdown of highest possible CHI scores achievable in each point category, effectively representing the desired conditions for Shortleaf Pine-Oak woodlands in the Ozarks.

Section		Submetric		Optimal Point Category	Points
1	**Landscape Context** (10% of score)	1a	Percent of surrounding landscape in native cover type	>76 percent	5
		1b	Size of community type	>550 acres	5
2	**Ground Flora Species Transects** (54% of score)	2a	Number of identifiable matrix plant species	46 species possible	14
		2b	Occurrence of matrix plant species present	>80 "hits" combined across three meander transects	4
		2c	Estimated frequency of occurrence of characteristic matrix plant species across site	Very frequent (seen in >66 percent of area)	2
		2d	Number of identifiable conservative plant species	25 species possible	20
		2e	Occurrence of conservative plant species present	>27 "hits" combined across three meander transects	5
		2f	Estimated frequency of occurrence of characteristic conservative plant species across site	Very frequent (seen in >66 percent of area)	5
3	**Structure & Overstory Composition** (36% of score)	3a	Percent native graminoid (grasses, sedges) cover	25-50 percent	6
		3b	Percent native forb cover (flowering plants; not bracken fern)	50-75 percent	6
		3c	Percent total cover seedlings (woody stems < 4.5 ft tall)	5-25 percent (negative points for >50 percent)	3
		3d	Percent total cover saplings (woody stems > 4.5 ft tall)	5-25 percent (negative points for >50 percent)	2
		3e	Percent cover of Sumac and Blackberry species (seedlings + saplings)	1-5 percent (negative points for >25 percent)	2
		3f	Percent canopy closure of woody vegetation > 4.5 ft tall	25-75 percent	1
		3g	Percent stand stocking	30-75 percent	3
		3h	Percent of desired overstory species (> 5 in DBH): shortleaf pine	51-75 percent	3
		3i	Percent of desired overstory species: white oak group	26-75 percent	2
		3j	Snag abundance per acre (in classes 2-5 decomposition)	4-6 snags/acre	0.5
		3k	Large trees per acre of desired species (> 18 in DBH): excluding red oak group	Over 4 trees/acre	5
		3l	Proportion of trees in prism plots with crown dieback in classes 2-5	0 (negative points for any percentage)	0
		3m	Desired tree regeneration (< 4.5 ft tall): shortleaf pine seedlings	5-25 percent	0.5
		3n	Desired tree recruitment (> 4.5 ft tall): shortleaf pine saplings	5-25 percent	2
		3o	Desired tree regeneration (< 4.5 ft tall): white oak group seedlings	5-25 percent	1

Table 2. *Continued*

Section	Submetric		Optimal Point Category	Points
	3p	Desired tree recruitment (> 4.5 ft tall): white oak group saplings	5-25 percent	1
	3q	Average litter throughout unit	<1 inch (negative points for >4 in)	1
	3r	Duff frequency throughout unit based on visual observations at assessment point (Oi/Oa horizons)	Abundant (seen in >66 percent of area; negative points for not present)	1
4 **Disturbance Factors** (0% or negative score)	4a	Number of non-native invasive plant species present	None (otherwise -0.25 points per species)	0
	4b	Occurrence of non-native invasive plant species present	<5 "hits" combined across three meander transects (otherwise negative points)	0
	4c	Estimated frequency of occurrence of non-native invasive plant species across site	Anything greater than "not present" results in negative points	0
	4d	Evidence of negative animal impacts: feral hog damage	"yes" results in -1 point	0
	4e	Evidence of recent off-road vehicles or other human caused soil disturbance	"yes" results in -1 point	0
5 **Wildlife Species** (optional, not included)	5a	Presence of priority woodland bird species	>16 species (17 total species on list)	5
	5b	Presence of priority woodland herptile species	>3 species (14 total species on list)	5

unit size, which can be calculated using the rule-of-thumb of 45 seconds per acre of sampling unit, divided by three transects (for example a 50-acre unit requires 37.5 minutes to sample, or 12.5 minutes per transect: 50 x 45 seconds /60 seconds per minute / 3 transects = 12.5 minutes per transect). Along a meander transect, staff called out "hits" to the recorder for each species encountered on the list. The person recording time was prepared to "pause" the clock once the crew arrived at an assessment point, during times of especially difficult terrain, to traverse through ecological site inclusions, key out plant species, or for work breaks. Following a lapse in meander transect time the crew moved a minimum of 10 ft to ensure they were in a new transect area and began the process again; indicator species were resampled within each timed interval. During this navigation process, staff were instructed to look for the presence of negative disturbances, such as unauthorized off-road vehicle use, excessive logging damage, and feral hog sign.

Once at an assessment point, staff navigated as close as possible to the point using recreation-grade GPS technology. At each point, trees greater than 5 inches in diameter at breast height (DBH) were tallied with 10-factor basal area prisms; species and DBH were recorded for all "in" trees. Snags greater than 5 inches DBH within the forest inventory plot were tallied as well; species of the snag was documented if identifiable. In addition to the overstory data from the assessment points, the additional metrics were estimated within an approximate 0.1-acre circle (37.2-foot radius), following U.S. Forest Service Eastern Region TEUI vegetation sampling plot guidelines (**Table 2**). Next, at each assessment point staff collected litter and duff measurements at the following azimuths 10 ft from the plot center: 0/360°, 120°, and 240°. Recent or slightly decomposed leaf litter depth (including fibric/Oi organic soil horizon) was measured with a ruler to the nearest 0.5 inch. Duff (including hemic/Oe and sapric Oa) was recorded as present/absent.

Table 2. In addition to forest density data, the following vegetation submetrics were estimated or measured at all assessment points within a sampling unit.

Submetric	Mode of estimation/measurement
• Estimated frequency of matrix plant species • Estimated frequency of conservative plant species • Estimated frequency of NNIS	*Estimated as either: 1) sparse, occurring in 0 to 33 % of the area; 2) frequent, occurring in 33 to 66 % of the areas; or 3) abundant, occurring in greater than 66 % of the area*
• Canopy closure of woody vegetation taller than 4.5 ft	*Measured to nearest percent*
• Native graminoid cover (grasses, sedges) • Native forb cover (flowering plants; not bracken fern) • Understory cover (woody stems [trees & shrubs] < 4.5 ft tall) • Midstory cover (woody stems [trees and shrubs] > 4.5 ft tall & < 5 in DBH) • Combined blackberry (*Rubus* spp.), smooth sumac (*Rhus glabra*), and winged sumac (*R. copallinum*) cover (midstory + understory) • Shortleaf pine seedling cover < 4.5 ft tall • Shortleaf pine sapling cover > 4.5 ft & < 5 inches DBH • White oak group seedling cover < 4.5 ft tall • White oak group sapling cover > 4.5 ft & < 5 inches DBH	*Estimated using the following cover classes: 0 to 1%, 1 to 5%, 5 to 25%, 25 to 50%, 50 to 75%, 75 to 95%, and greater than 95% (Daubenmire 1959)*

Once surveys were completed, staff checked field forms or the electronic application for accuracy. For sites collected using field forms, data were later entered in the office and calculated manually. For sites collected with the electronic application, data were automatically calculated and final CHI scores were determined in the field. Although it would be impossible for a sampling unit to obtain the maximum or minimum point values, raw CHI scores could range from 0 to 100. Electronic and field form data were integrated, checked for quality control, entered into customized spreadsheets with auto-calculations, and summary statistics created.

It is important to note that while the maximum score for an individual sampling unit is 100, a score of 100 is impossible to obtain. To provide a more objective and understandable metric, sampling units were ranked and split into percentiles and then grouped into quintiles based on their overall score (i.e., the top 20 %, the lowest 20 %, etc.). This side-by-side comparison allowed for quick visualization to assess the conditions of the units relative to each other, effectively delineating modern day reference conditions for the highest scoring sampling units. Using this method, the more sites that are added to a dataset for a particular CHI protocol, the stronger the analysis becomes. Using the index in this way allows for less subjective and more understandable interpretation for both managers and ecologists. In previous reports, we categorized the raw CHI score coupled with subjective "good, fair, poor" labels. We have since moved away from this categorization method in favor of the percentile/quintile approach as providing subjective adjectives can insinuate misleading cause-and-effect relationships. Finally, while published reference or desired conditions for various natural community types provides important context, those goals may be impractical to accomplish. In contrast, the percentile/quintile method establishes a current reference related to actual, achievable desired conditions.

To examine the relationship between CHI variables, we used Pearson's correlation coefficient, denoted by *r*, which identifies the strength of the relationship between any two factors. When an increase in one factor is associated with an increase in the other, the correlation is positive; likewise, when a decrease in one factor is associated a decrease in the other, the correlation is negative. Lack of any kind of correlation would result in 0. Thereafter, we ran regression analysis for those that showed a moderate or stronger correlation ($r \geq 0.4$; $r \leq -0.4$).

Since CHI is a rapid (vs. intensive) assessment, one of the concerns was whether the ground flora metrics adequately captured the floristic quality of the sites. This question was addressed in two ways. First, the Hadle and Thomas (2019a) FQA plots that fell within CHI sampling units were re-sampled by NatureCITE in early September 2022. These and other FQA plot data that occurred within CHI sampling units (at nearby Chilton Creek) were analyzed for correlation and tested against the CHI ground flora subscore. The total sample size was 43 sampling units that contained one or more FQA plots. In cases where multiple FQA plots occurred within a CHI unit, we used the average Total Mean C across the FQA plots falling within a sampling unit. Second, in 2022 we randomly selected a subset of three sampling sampling units which included low, medium, and high scoring sites, respectively. Within these sampling units, we centered a five-acre polygon around the associated FQA plot array. We then subsampled the CHI ground flora component within the five-acre FQA "footprint" plot array.

Overall, 59 sampling units totaling 2,457 acres were included for the purpose of the analyses sans the FQA plot correlation analyses above (**Figure 3**). Sampling units were primarily from MTNF but also included sites from two MDC properties (Rocky Creek and Peck Ranch Conservation Areas) and the Randolph Tract of L-A-D Foundation/Pioneer Forest.

We would like to note that data were collected during a three-year field-testing sequence between 2020 and 2022. The final version of the CHI protocol for this community type is referenced in this document. Legacy field data from 2020 and 2021 field seasons were retrofitted to the final CHI version for analysis purposes. The CHI survey protocol includes a wildlife score that is optional, and may be additive to the CHI score, but this portion was not utilized for this report.

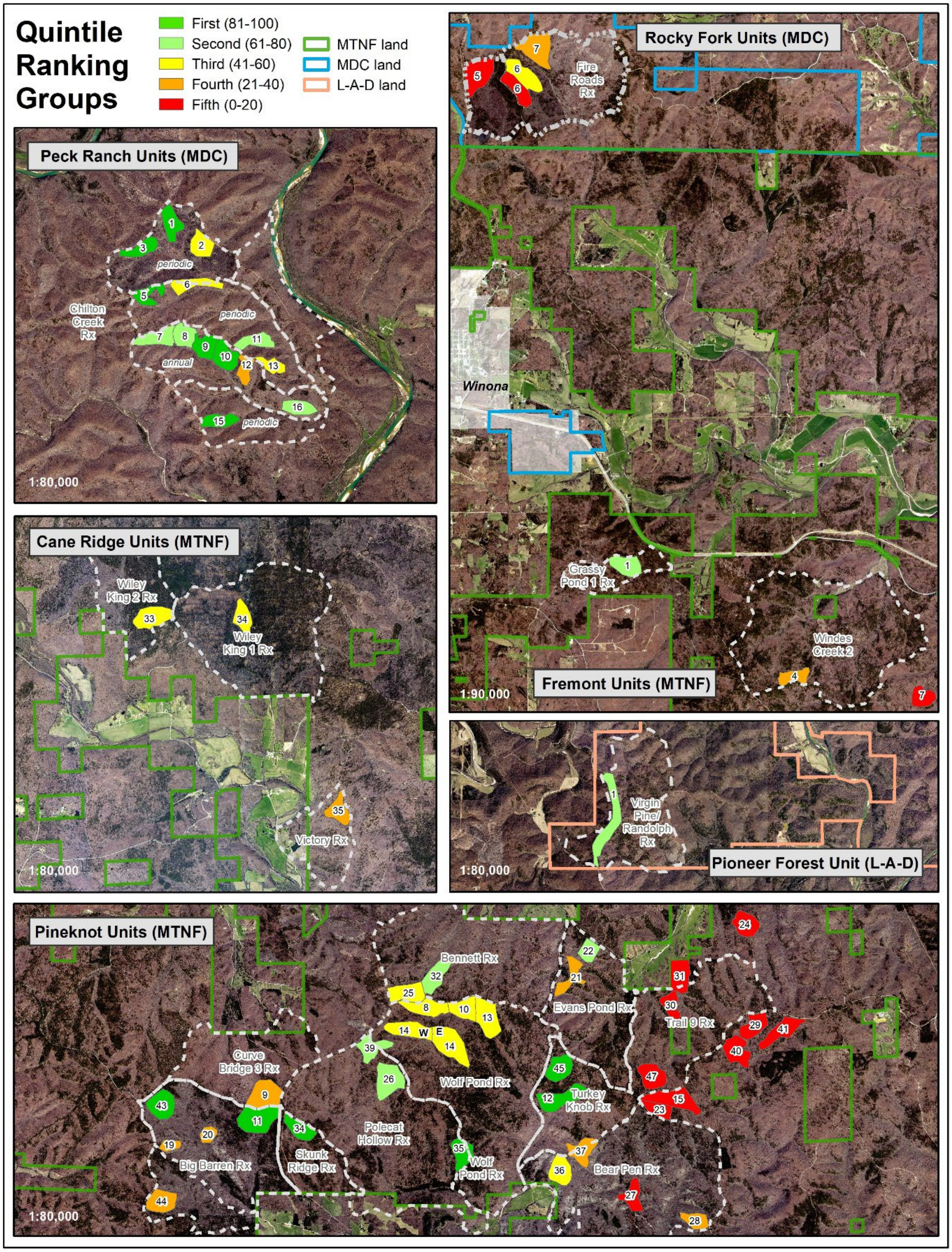

Figure 3. Locations of the 59 CHI sampling units used for this report, labeled by sample unit number and colored by CHI score quintile (refer to Appendix A for a summary of results by sample unit). MTNF = Mark Twain National Forest sites; L-A-D = L-A-D Foundation/Pioneer Forest; MDC = Missouri Department of Conservation.

RESULTS and DISCUSSION

Community Health Index validation

The Total Mean C values for the FQA plots were significantly and strongly positively correlated to CHI ground flora subscores ($r = 0.70$, $p < 0.001$; **Figure 4**). This result is interesting considering the sample size and differences in scale between the two methods.

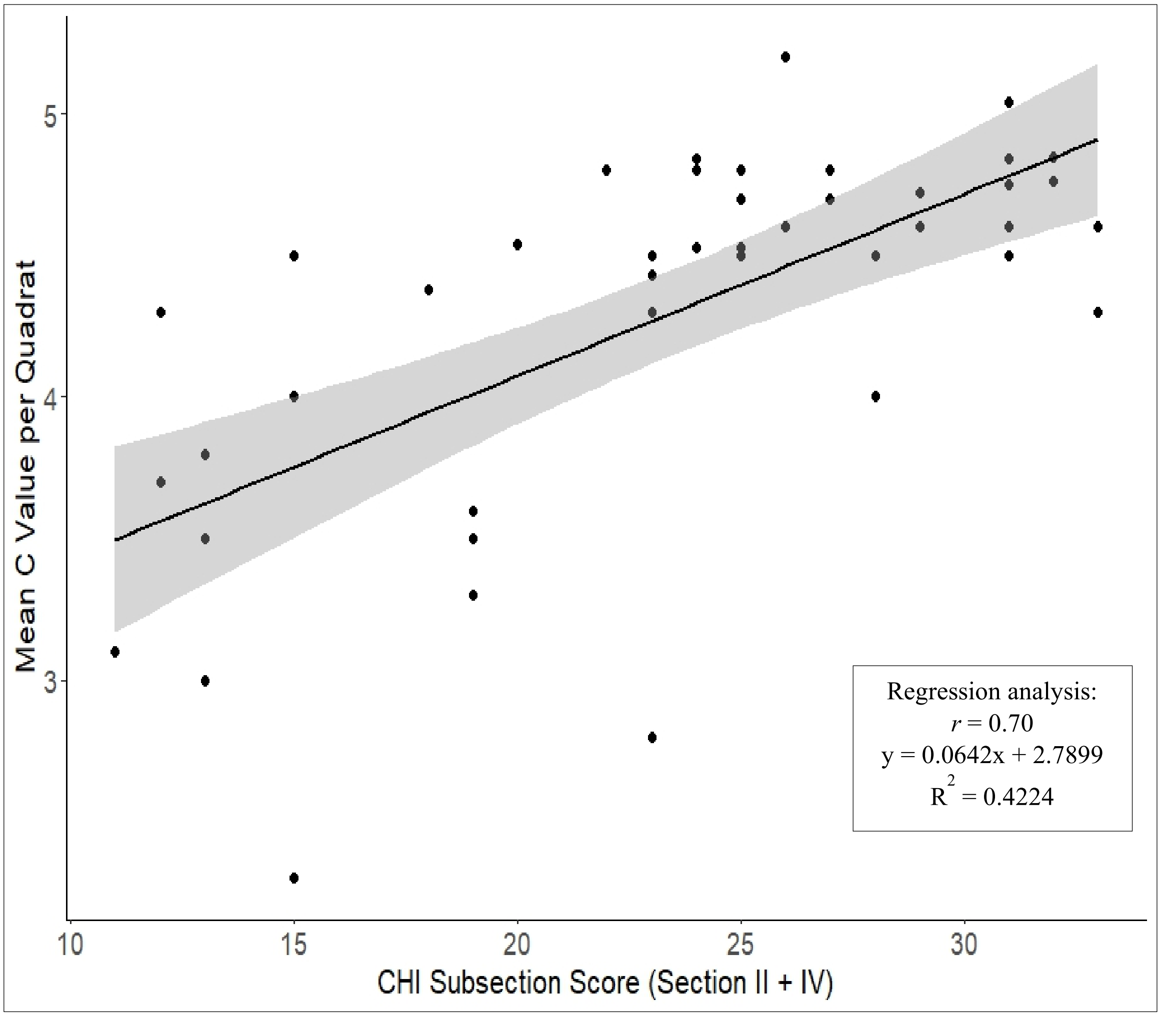

Figure 4. Scatterplot and linear regression showing the relationship of high intensity plot data (i.e., FQA) with moderate intensity CHI data, specifically showing the total mean C value of FQA quadrats related to indicator ground flora species metrics in the CHI (Section 2 and the NNIS section 4 of protocol; $r = 0.70$, moderate positive correlation); grey area indicates confidence interval.

Meanwhile, the small CHI subsamples focused within FQA plot arrays were less surprising since the data were collected in the same physical locale, but still provides helpful validation. While this was only three data points (and therefore only exploratory), the *r* value was 0.92. Although more sampling is needed to provide a complete picture, these data indicate that the ground flora composition component, which has always been a priority factor in CHI surveys, is tracking positively with high intensity floristic quality plot data. This is encouraging and suggests that reasonable estimates of floristic quality can be made using the CHI methodology. However, we do not suggest that CHI or any other rapid assessment is a replacement for high intensity plot data, but rather an opportunity to establish a baseline picture of current conditions and general change over time with lower intensity sampling efforts.

Community Health Index results

Overall trends

CHI scores were tested for normality and met the criteria for being normally distributed. Normality is a requirement for many statistical assumptions and important because it shows a set of data has a finite variance and predictable pattern or distribution. For a rapid assessment that is meant to be only semi-quantitative, this is an important result that facilitates and justifies further data analysis.

We found a positive relationship with the number of indicator matrix ground flora species, conservative ground flora species, and priority bird species in association with total CHI score. The upper 20 % quintile of units sampled had a very different profile than the bottom 20 % (**Tables 3 and 4**). Compared to the lowermost quintile sites, the uppermost quintile sites had 10 times more native grass and sedge cover, 7 times more forb cover, 3 times less sapling cover, 1.9 times more seedling cover, 2.5 times more conservative species present, 1.5 times lower stocking, and 1.3 times less canopy cover. This indicates the CHI protocol is effectively tracking key parameters related to natural community structure and composition.

Table 3. Summary of select CHI results categorized by quintile (0-20, 20-40, 40-60, 60-80, 80-100). The larger the quintile the higher the CHI score (green is high scoring and red is low scoring).

Quintile	Average graminoid cover	Average forb cover	Average # matrix species (C-value between 4-6)	Average # matrix species (C-value between > 6)	Number priority bird species seen/heard
80-100	15.9 ± 7.3	43.8 ± 10.8	64.0	19.0	7.0
60-80	11.9 ± 9.6	34.2 ± 16.2	53.1	14.5	7.5
40-60	6.8 ± 5.8	32.3 ± 17.0	54.1	14.0	6.7
20-40	8.2 ± 6.2	17.8 ± 10.2	36.5	9.9	6.5
0-20	1.8 ± 1.3	5.8 ± 5.4	36.3	6.0	5.8

Table 4. Correlation table showing the relationship of select CHI submetrics related to one another and colorized by their correlation strength (with greens showing positive correlation and reds showing negative correlations).

FACTOR	SCORE	BURN	G-M	F-M	SAP-M	SEED-M	RUB-M	GROUND	TOTAL	MEAN	CLOSE	STOCK
SCORE	1.00											
BURN	0.54	1.00										
G- M	0.55	0.27	1.00									
F - M	0.70	0.49	0.51	1.00								
SAP-M	-0.67	-0.44	-0.30	-0.43	1.00							
SEED-M	0.30	0.07	0.29	0.33	-0.28	1.00						
RUB-M	-0.22	-0.07	0.35	0.06	0.16	0.22	1.00					
GROUND	0.84	0.63	0.61	0.70	-0.37	0.56	0.21	1.00				
TOTAL	0.71	0.39	0.55	0.57	-0.27	0.41	0.19	0.86	1.00			
MEAN	0.53	0.27	0.55	0.47	-0.28	0.26	0.32	0.80	0.59	1.00		
CLOSE	-0.22	-0.22	-0.44	-0.43	0.41	-0.11	-0.32	-0.17	-0.09	-0.23	1.00	
STOCK	-0.24	-0.24	-0.46	-0.37	0.20	-0.25	-0.41	-0.35	-0.30	-0.33	0.63	1.00

SCORE: Total CHI score, BURN: Burns within the last 20 years, G - M: Graminoid cover, F - M: Forb cover, SAP-M: Sapling cover, SEED-M: seedling cover, RUB-M: Rubus and Rhus cover, GROUND: Ground flora (section II) score, TOTAL: Total species seen during three timed meanders, MEAN: Mean C of all species found during three timed meanders, CLOSE: Average canopy closure of unit, STOCK: Percent stand stocking of unit.

$1 > r \geq 0.8$	Strong positive correlation	$0 > r \geq -0.4$	Weak negative correlation
$0.8 > r \geq 0.4$	Moderate positive correlation	$-0.4 > r \geq -0.8$	Moderate negative correlation
$0.4 > r > 0$	Weak positive correlation	$-0.8 > r > -1$	Strong negative correlation

There was a moderate positive correlation and statistically significant relationship ($r = 0.5$, p value < 0.001) between total CHI score and the number of fires within the last 20 years (including both prescribed and wildfire; **Figure 5**). This result highlights the importance of fire as an ecological process in shortleaf pine-oak woodland sites. However, there are other factors to consider, particularly in relation to site management histories. It is important to remember that all sites have their own individual land use history, resulting in variable biological legacies Present which can lead to different management outcomes among sites. Many of the sites having the longest burn history were already known to be high quality remnant natural communities. Because they were already high-quality areas, they were given more priority for early and continuous management. Conversely, many of the sites having fewer burns were not historically considered high quality (i.e., were more degraded) and didn't receive priority restoration treatments until more recently. While fire is a key process in restoring these woodlands, these results do not necessarily indicate cause-and-effect, nor should it be interpreted that doing more of the same will lead to continued increases in ecological functionality. Lacking a true replicated experimental design, it is difficult to say what combination of treatments is ideal and further research is needed on this topic. Clearly fire is necessary and supports strong natural community response, but questions remain as to the best combination of frequency, timing, and intensity.

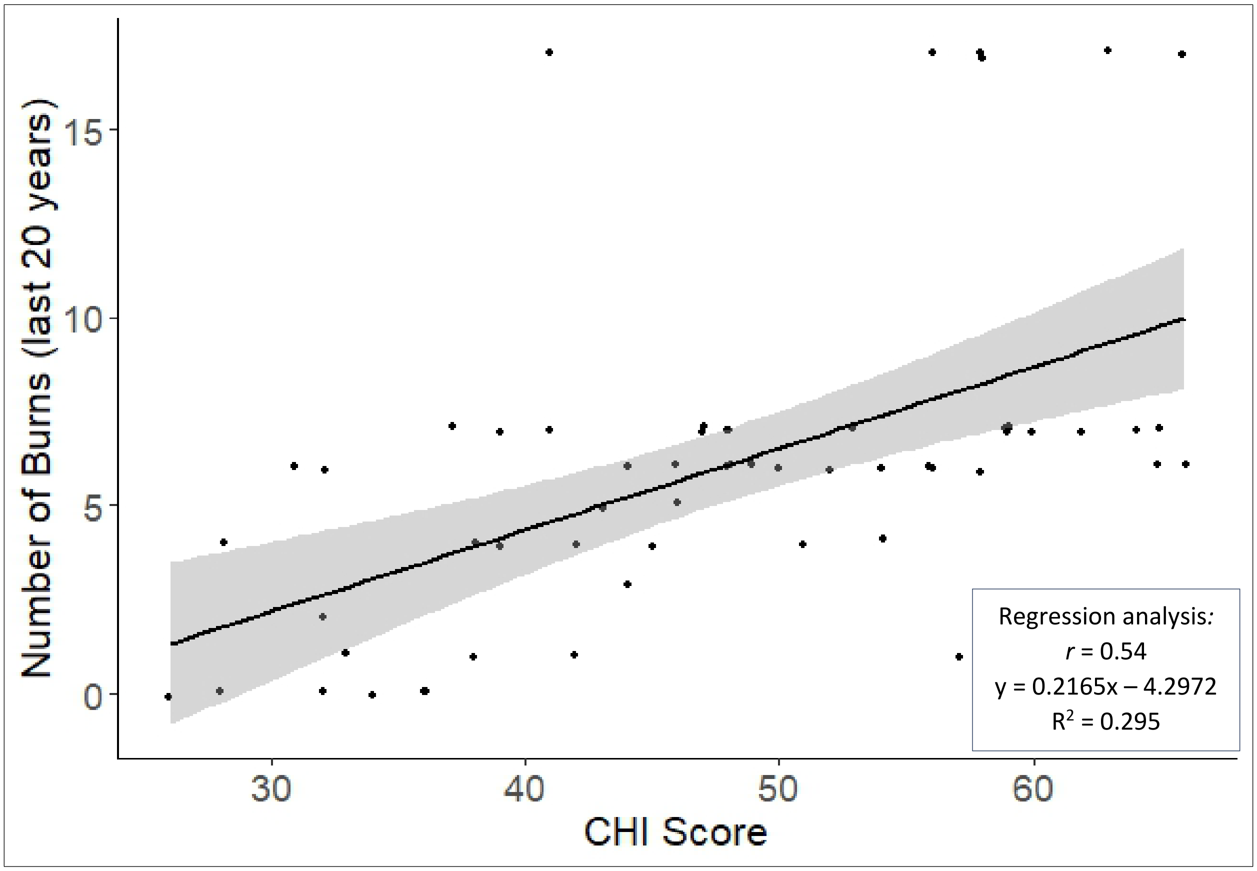

Figure 5. Scatterplot and linear regression of the number of prescribed fires related to total CHI score during the previous 20-year period (*r* = 0.5, moderate positive correlation); grey area indicates confidence interval.

Ground flora trends

When we examined the ground flora results, some interesting patterns were revealed. Decreasing midstory cover clearly positively impacted native ground flora cover and showed a strong relationship with total CHI score (**Figure 6**). Conservative ground flora species specifically appeared to increase with lower midstory cover. This is likely related to the fact that many Ozark woodland ground flora species require at least moderate levels of midstory sunlight to thrive, and many require high levels of sunlight. Conversely, increasing woody understory (i.e., seedling/shrub size) cover tracked with increasing native ground flora cover. This indicates that increased sunlight results in conditions conducive to both seedling/shrub development as well as native ground flora expansion. In many cases, promotion of both native ground flora and tree seedlings/shrubs becomes a management challenge. As open canopies and repeated fire release seedlings and increase sprouting, this can eventually produce a super-canopy shrub layer that can outcompete the ground flora and result in ineffective woodland structure. The impact of a super-canopy of hardwood sprouts prevents many ground flora species from having access to sunlight, and prescribed fire only temporary improves this situation (**Figure 7**).

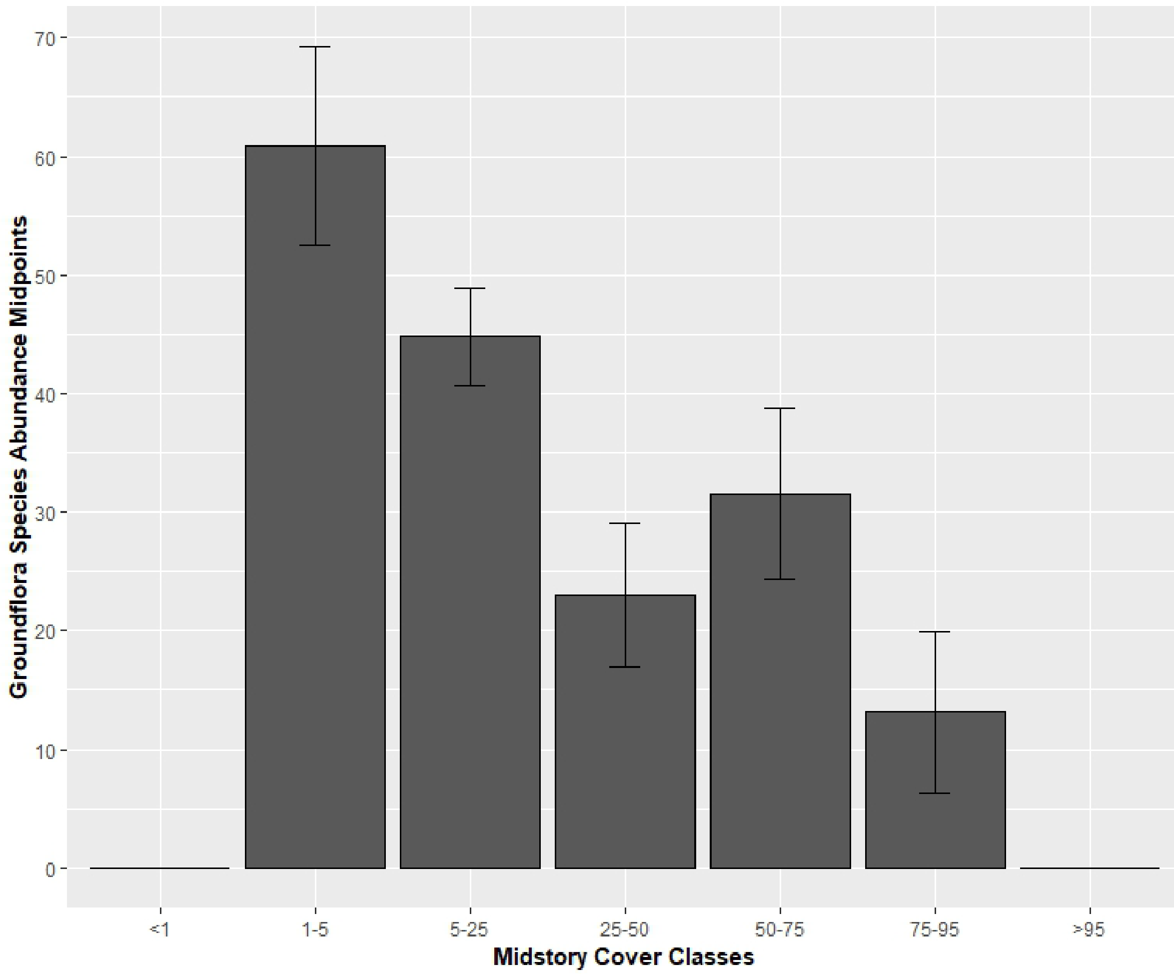

Figure 6. Abundance of all ground flora species related to midstory cover showing strong relationship with higher midstory cover impacting the ability for ground flora to proliferate; grey area indicates confidence interval.

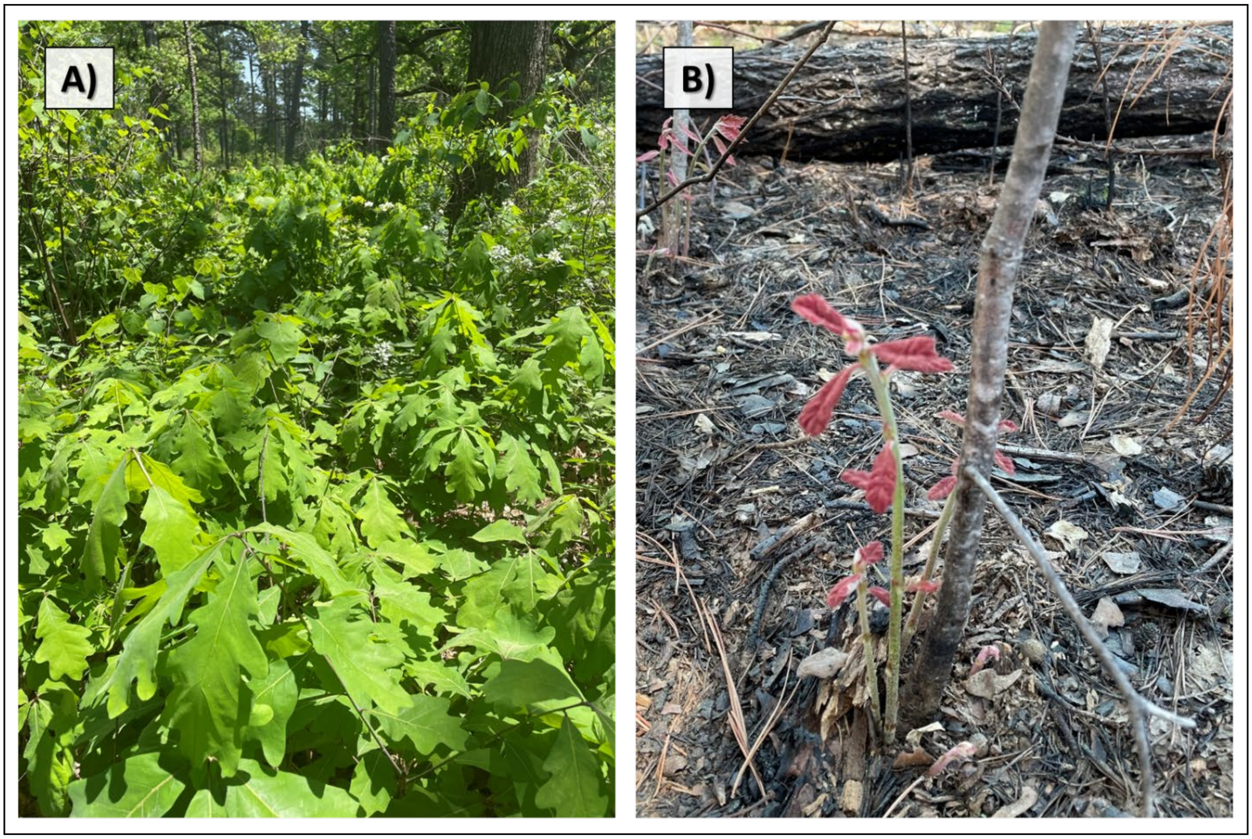

Figure 7. A) Super-canopy of white oak (*Quercus alba*) sprouts in sampling unit 26 in the Pineknot project area, and B) an example of resprouting potential of black oak (*Q. velutina*) two weeks after a mid-March prescribed burn on Cane Ridge Project area (photos by Kyle Steele).

The Ozark Pine-Oak Woodland and other Ozark CHI protocols prioritize tracking sumac and blackberry species cover, as these species can become problematic on some sites. Our results show an inverse relationship with percent stocking and sumac and blackberry cover (r = -0.4, *p-value* < 0.001; **Figure 8**). Sumac and blackberry species can negatively impact woodland structure, cause tree regeneration issues, outcompete native ground flora, and once established, are difficult to manage (**Figure 9**; Hadle and Thomas 2019a). While sumac and blackberry provide habitat and food for many species of wildlife, many ecologists equate large populations of these species with poor natural community health. Sumac and blackberry are indicators of disturbance, both natural and anthropogenic. While they are a natural component of our ecosystems, they should generally occur in low numbers. When abundant, their presence may indicate degrading conditions. Sumac and blackberry can accumulate as "scab" plants - inhabiting areas with more severe disturbance or stressors in the ecosystem. Such disturbance can result from a variety of sources – tracked equipment, soil disturbance, opening canopies too quickly, or high intensity fire – the latter of which may be associated with timing/seasonality of burning (a topic which requires more extensive research in this region). Surprisingly, the cover of sumac and blackberry was similar between the upper and lower quintiles. It seems logical that high sumac and blackberry cover in low scoring sampling units indicates degraded natural communities which likely saw more rigorous historical land use. We were surprised, however, to see similar sumac and blackberry cover results in the upper quintiles. This may in part relate to the management going on in these stands. In addition to having invasive potential, like many early-successional species, sumac and blackberry are also shade intolerant. Thus, opening the canopy using both mechanical methods and prescribed fire increases the potential for spread. More work is needed to determine acceptable amounts of sumac and blackberry within restoration units.

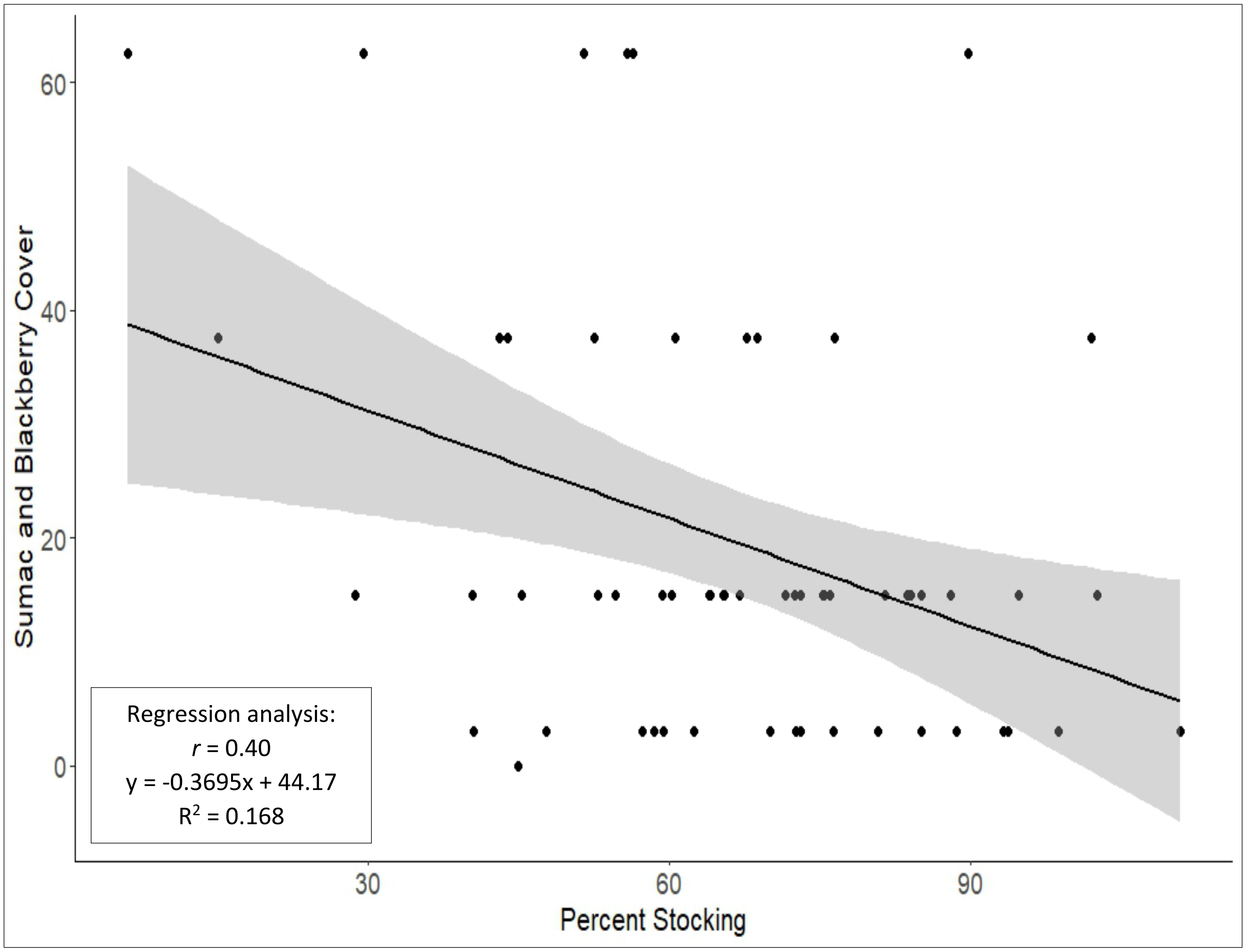

Figure 8. Scatterplot and linear regression showing invasive sumac and blackberry cover related to overstory stocking percent. The more open the stand the more potential for native and invasive species to spread into management units (*r* = -0.4, moderate negative correlation); grey area indicates confidence interval.

When sumac and blackberry cover was below 75 % there was not a clear trend related to the abundance of matrix and conservative ground flora species. However, when sumac and blackberry cover was over 75 % the abundance of matrix and conservative species decreased. For all native ground flora cover (including lower C-value species) there was a positive relationship with sumac and blackberry cover up to the 75 % threshold, after which it declined. It is important to note that this last metric includes all native ground flora and not necessarily only the desirable matrix or conservative species. An example of a lower C-value native present in these sites is old-field goldenrod *(Solidago nemoralis*).

Figure 9. An otherwise high-quality site with concerning and expanding cover of winged sumac (*Rhus copallinum*); Pineknot project area, sampling unit 14 (photo by Kyle Steele).

Similar to the correlation of total CHI score to the number of fires within the last 20 years, the composite ground flora scores versus number of burns in an area showed a moderate positive correlation and statistically significant relationship (r = 0.51, *p-value* < 0.001; **Figure 10**). Again, this is not surprising as fire is a key process in restoring woodlands in Missouri and across the Midwest and Southeast (McCarty et al 1998; Sparks et al. 1998; Dey and Kabrick 2015; Maginel et al. 2019). However, more information is needed as it is unclear whether current prescribed fire regimes are aligning with historical frequency, intensity, and timing in a way that will drive sites toward higher ecological integrity. Such integrity would presumably comprise a more intact ground flora component, and lower invasive woody understory coverage, such as sumac and blackberry. Continued monitoring will be necessary to track these and related questions.

The majority of existing fire history work using dendrochronology methods in the MOPWR landscape comes from the Oak-Pine Woodland/Forest Hills and Oak Forest Breaks LTAs (**Figure 2**; Guyette and Dey 2000). However, the majority of restoration treatments are located in the Pine-Oak Dissected Plains LTAs, which may have had different historical fire regimes.

Currently, MTNF and the University of Missouri Center for Tree-Ring Science are reconstructing historical fire regime characteristics of this landscape. Early results are showing samples dating back to the 1500s and repeated frequent fire. We believe this study will shed more light on the fire frequency, seasonality, severity, and sizes allowing us to better understand how fire in dissected plains landscape may have differed from other areas.

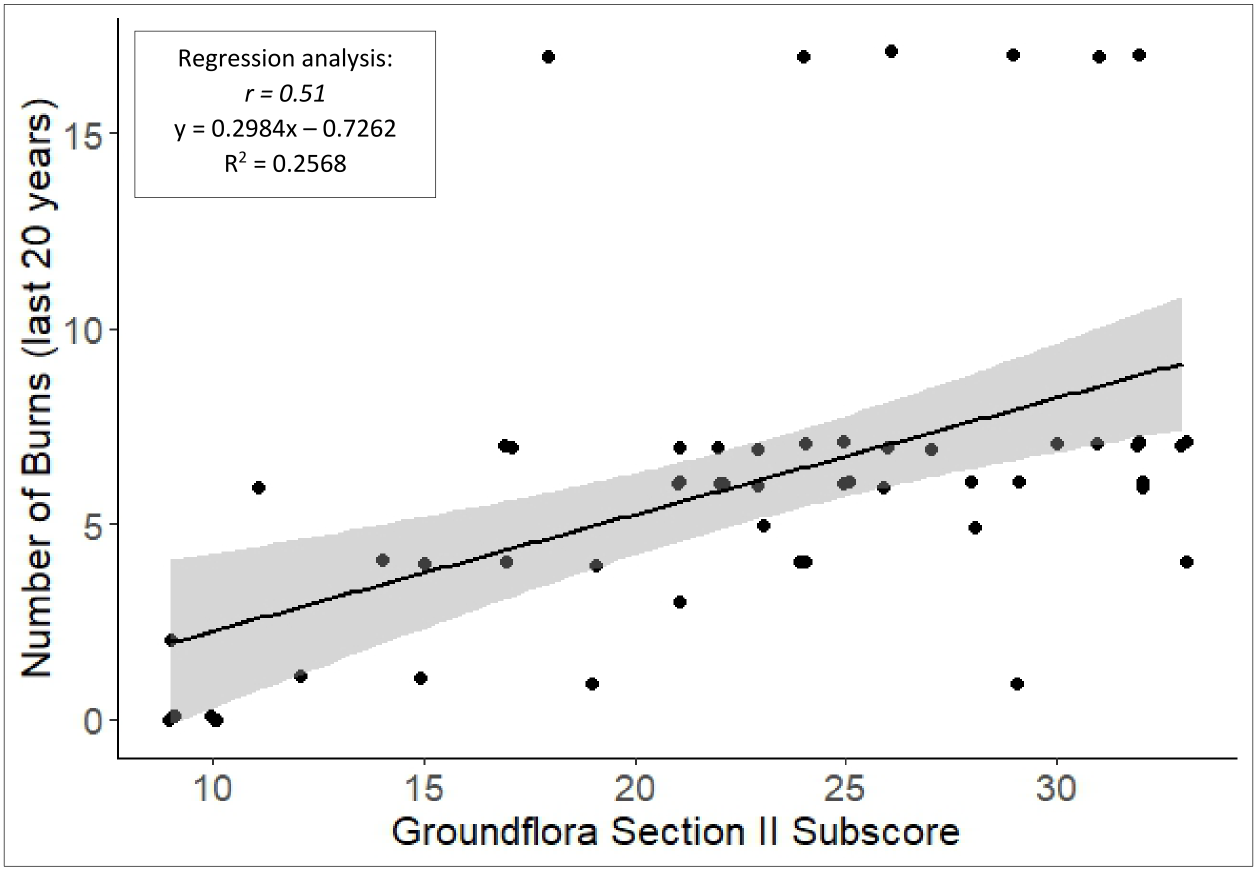

Figure 10. Scatterplot and linear regression of ground flora (matrix and conservative species) score versus number of burns within the last 20 years. These results further highlight the need for continuous utilization of prescribed fires within pine-oak landscapes (r = 0.51, moderate positive correlation); grey area indicates confidence interval.

Litter and duff trends

Consideration of litter (defined as recent leaf litter + Oi/fibric soil horizon) and duff (defined as the Oe/hemic and Oa/sapric soil horizons), and soils in general, is an often-overlooked natural community component. Thick accumulations of litter result in a physical impediment for plant growth and regeneration, while thin layers of duff provide protection of the soil and habitat for micro and macroinvertebrates. Ideally, within a prescribed burn unit fires would consume most of the litter while retaining most of the duff. In areas where litter and duff are completely consumed (to bare mineral soil), the site can become susceptible to soil displacement, runoff, and erosion. In areas of complete litter *and* duff removal, decomposers, bacteria, fungi, water infiltration, and some kinds of mycorrhizae will be impacted or completely removed (Tallamy 2021).

Not surprisingly, our data showed that prescribed burning effectively removes the litter cover that inhibits plant growth, supporting a proliferation of native ground flora. In addition, an estimated 92 % of CHI units sampled in 2022 have retained most of their duff. This is important as having an intact duff layer helps protect against excessive soil movement as well as providing other ecological benefits (increased refugia for soil fauna, soil biological health, nutrient infiltration, etc).

It is important to note that the duff layer is generally very thin to non-existent in this region (often only 0.25 inches or even less), and does not typically inhibit plant growth or regeneration of oak and shortleaf pine. Thus, producing a bare mineral soil environment may not be needed for regenerating these species, and every effort should be made to retain duff.

Overstory forest density, composition, and structure

Average stocking and canopy cover for the top quintile sites was 60 and 65 %, respectively. Conversely, the average stocking and canopy cover for the lowest quintile sites was 81 % for both measures. While there is a trend showing decreasing stocking percent with increasing ground flora score, surprisingly it was only a weak trend. This lack of correlation highlights the importance and apparent direct relationship of the midstory being a key structural element providing effective sunlight to the forest floor.

When looking at different sites and management areas, it's important to recognize land use history and resulting differing overstory conditions, which may impact the potential for seedling/sapling regeneration and recruitment into various woodland canopy strata. Most of the sites used for this report were selected because they had fully- or partially-stocked stands of shortleaf pine. The one outlier was Peck Ranch Conservation Area (Chilton Creek units). While most of the sampling units here scored high in CHI and various ground flora metrics, Chilton Creek has a low density of both shortleaf pine and white oak species. While this site was historically a mixed pine-oak forest type, beyond the use of prescribed fire, which generally promotes pine regeneration, there have been no natural or manmade attempts at regenerating shortleaf pine or white oak on these sites. Thus, the overstory is in a second growth condition and is heavily dominated by shorter-lived black oak (*Quercus velutina*) and related species. None of the top-scoring sampling units at Chilton Creek obtained top scores for either shortleaf pine or white oak basal area. Overstory conditions like this are common across the Ozark pine-oak woodland geography. In the case of Chilton Creek, from a ground flora and structural perspective, it is one of the most impressive woodland restoration areas in the region (**Appendix B**). Sites like this, however, are at risk of state change unless an effort is made to regenerate longer-lived overstory species. Further, concomitant with "red oak decline" is the fact that red oak species are more susceptible to fire damage in comparison to species such as shortleaf pine, post oak, and white oak. Because of this, these sites are predisposed to even faster overstory decline (Johnson et al. 2019). Sites with overstory composition in this condition are of concern and may not be well highlighted with the current CHI scoring metric – an issue that will be considered for future protocol revisions.

Overstory regeneration and recruitment

Of the 40 units sampled in 2022, only 5 % of them recorded shortleaf seedlings (individuals < 4.5 ft tall) as being abundant and none of the units recorded shortleaf pine saplings (individuals > 4.5 ft tall to < 5 in DBH) as being abundant. However, 62 % of the units recorded white oak group seedlings as being abundant and 42 % of the units recorded white oak saplings as being abundant. It appears that white oak group regeneration and recruitment is adequate, but eventually pine regeneration and recruitment will need to be addressed. Due to their long-lived nature (over 300 years; Lawson 1990), the lack of shortleaf pine regeneration is not of immediate concern on sites with existing pine in the overstory. Through continued prescribed fire and the creation of canopy gaps through natural processes and varied fire effects, shortleaf pine regeneration may eventually occur. While shortleaf pine seedlings usually sprout after being top-killed by fire, is it unknown how many times this event can occur before damaging the individual.

Non-native invasive species

No sampling units had greater than 5 % cover of NNIS and instead typically showed less than 1 %. Generally, sericea lespedeza (*Lespedeza cuneata*) occurred along roadside edges and landings along with beefstake plant (*Perilla frutescens*) and sometimes stiltgrass (*Microstegium vimineum*). But presently, these NNIS have not expanded far into the units. Spot patches of tree of heaven (*Ailanthus altissima*), princess tree (*Paulownia tomentosa*), multiflora rose (*Rosa multiflora*) and Japanese honeysuckle (*Lonicera japonica*) were found within a number of units. Occasionally, mimosa (*Albizia julibrissin*) and spotted knapweed (*Centaurea stoebe* ssp. *micranthos*) were encountered, but mainly near roadsides.

We believe continued tracking of NNIS using CHI monitoring will prove an important management tool, particularly as more species expand into the interior portions of large public land blocks. Typically, concerted inventories and general knowledge of where NNIS infestations occur are limited to areas of infrastructure, such as roads and log landings. Rarely do surveys include the interior of large, prescribed fire units or other treatment blocks. Across the 59 sampling units, we found and reported several new NNIS populations, allowing managers to prioritize early eradication efforts.

Preliminary pollinator results

Richness and abundance of pollinators is an often-overlooked element of natural community management and can indicate broader ecological function and trophic level responses in an ecosystem. Many of these species have deep ecological connections with our woodland ecosystems. Preliminary pollinator (bee) inventories were conducted by the University of Massachusetts-Amherst through co-production with another project happening in the MOPWR area (Fassler unpublished). This work was limited to units within the Pineknot project area on MTNF. Fassler and her crew sampled bees in five sampling units that spanned a range of scores, including those from the first (units 11 and 12), fourth (units 9 and 20) and fifth quintiles (unit 15). Utilizing bee bowl techniques for sampling they captured a total of 482 bees (Droege et al. 2016). The average bee abundance was highest in sampling unit 20 which scored in the second lowest (fourth) quintile for CHI (**Figure 11**). This site was a large accidental opening created by prescribed fire, with less than 10 % stocking, 50 % woody ground cover, and 40 % native forb cover with abundant blooms. Given the cover, habitat structure, and copious blooming of the native forbs, it's not surprising this unit had the greatest bee abundance. Sampling units 11 and 12 were included from the top (first) quintile had intermediate bee abundance, and were characterized by 53 and 76 % stocking, 37 and 63 % woody ground cover, and 37 and 63 % native forb cover, respectively. Units 9 and 15 had low bee abundance. Unit 9 is unmanaged and had 82 % stocking, 37 % woody ground cover and 15 % native forb cover. Unit 15 was unmanaged as well, and obtained the lowest CHI score out of all 59 sites and had 111 % stocking, 62 % woody ground cover, and only 3 % native forb cover.

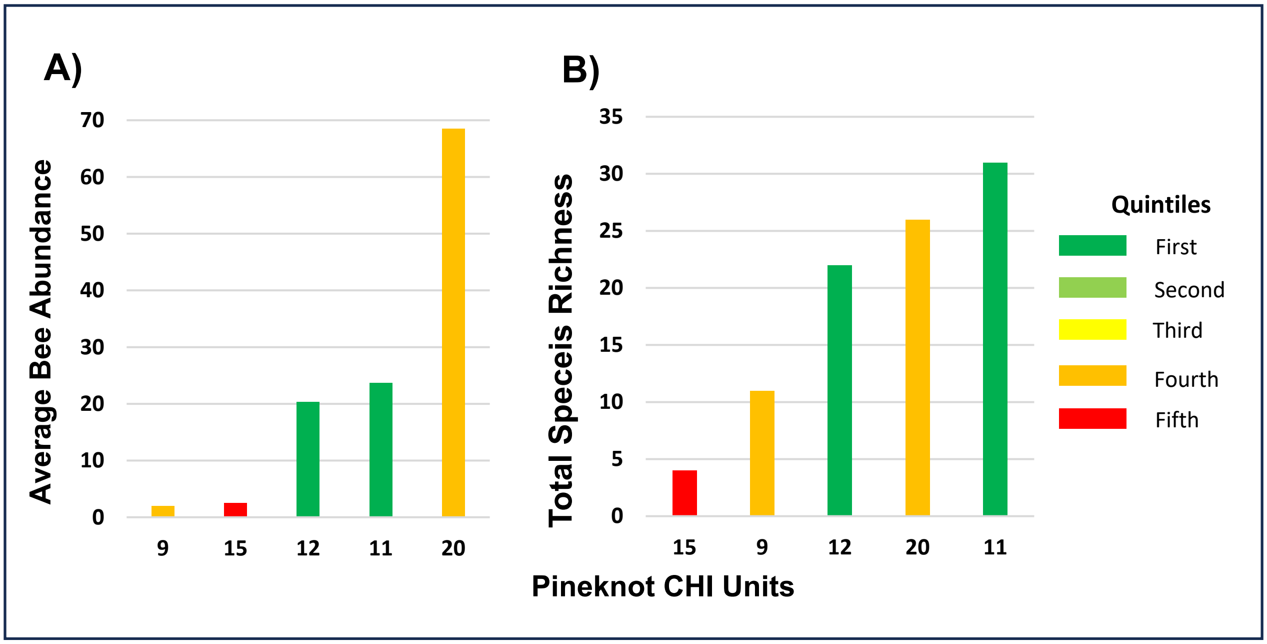

Figure 11. **A)** Average bee abundance and **B)** species richness across five sampling units in the Pineknot project area on MTNF. A range of site conditions were included with CHI scores in the top, fourth, and fifth quintiles. Sampling Unit 15 was the lowest scoring site in the dataset, while sampling unit 12 was tied for the highest scoring.

Higher scoring CHI units showed the highest bee species riches, and six times that of the lower scoring units. Twenty-two individuals of the native bee species called *Lasioglossum raleighense* (no common name) were found across CHI units 11, 12 and 20. This species was previously known from only one record in Missouri. In the southeast, it has been identified as a possible indicator species of mature open pine woodlands (Hanula et al. 2015). Several other habitat specialist bee species were also collected in these units. Additional bee sampling is currently in progress.

While preliminary, these results show that a key factor in pollinator abundance is effective flowering potential, which requires management for elevated understory light conditions. Although not typically part of silvicultural prescriptions, the mechanical creation of openings may be considered for future protocol.

CONCLUSIONS

A total of 2,457 acres across 59 sampling units were sampled within the MOPWR footprint. Based on vegetation structure and composition, number of fires, soil conditions, and the scoring profile of sampling units in the top two quintiles, it can be reasonably stated that restoration treatments in those areas have been successfully moved from FRCC 3 to FRCC 2 (LANDFIRE 2023). Sampling units from the lower two quintiles are still in FRCC 3, and these areas have received no or little restoration treatments. Sampling units from the middle quintile are units that are currently transitioning from FRCC 3 to FRCC 2.

Figure 12. Top-scoring quintile sampling unit in Pineknot project area showing nice complement of indicator matrix ground flora species: small-leaved tick trefoil (*Desmodium marilandicum*, C value 5), Bosc's panic grass (*Dichanthelium boscii*, C value 5), spreading aster (*Symphiotrichum patens*, C value 5), bristly sunflower (*Helianthus hirsutus*, C value 4), and yellow crownbeard (*Verbesina helianthoides*, C value 5); and one conservative species: rattlesnake master (*Eryngium yuccifolium*, C value 8) (photo by Mike Leahy).

These samples represent a modern-day reference point and provide a side-by-side comparison of the range of site conditions we believe is currently achievable (**Figure 12**). Whether this subsample of acreage within MOPWR is indicative of conditions on other project areas, including those of the MTNF, MDC, and Pioneer Forest, is unclear. A goal of future work will be to determine the appropriate CHI sample size to adequately characterize restoration effort at project and MOPWR scales.

It is important to verify whether these management-based changes can be considered restoration of reference condition in Ozark pine-oak woodlands, and if such reference conditions are even attainable. U.S. Forest Service distinguishes ecological restoration from functional restoration as described below (USFS 2012, 2016):

> *"**Ecological restoration** typically focuses on recreating the ecosystem conditions that were present prior to European influences. However, some ecosystems may have been altered to such an extent that reestablishing pre-European conditions may be ecologically or economically infeasible. In such circumstances, management goals and activities should create functioning ecosystems in the context of changing conditions through the process called **functional restoration.**"* (USFS 2016)
>
> *"**Functional restoration** focuses on the underlying processes that may be degraded, regardless of the structural condition of the ecosystem. Functionally restored ecosystems may have a different structure and composition than the historical reference condition. As contrasted with **ecological restoration** that tends to seek historical reference condition, the functional restoration focuses on the dynamic processes that drive structural and compositional patterns."* (USFS 2012)

It is evident that restoration treatments conducted by the MTNF, MDC, and Pioneer Forest in the MOPWR landscape are helping to restore a functional ecosystem. Focal bird and bee species are responding positively to the treatments. Ground cover of native plants and key indicator groups have increased. The remaining overstory stocks of shortleaf pine and white oak species have been released to grow with less competition, which should increase drought resiliency based on both lower stocking and better adapted species remaining in the stands. This will assist with climate change resilience. Treated stands with high CHI scores are less likely to burn as severely during wildfires compared to dense, overstocked stands. The treated stands may burn more readily (i.e., contain more fine fuels), but will have lower intensity overall, versus stands that are overstocked and drought-stressed, leaving them susceptible to overstory mortality. The restored stands should also experience less soil sterilization, as fuel loads are abated. In addition, the treated stands will be less susceptible to southern pine beetle (*Dendroctonus frontalis*), a potentially emerging threat to Ozark shortleaf pine-oak sites (USFS 2022).

Nevertheless, based on field experiences and discussions with resource managers and other ecologists, the authors wonder if ecological restoration (as defined) is achievable in the MOPWR landscape in terms of returning stands back to FRRC 1 reference conditions. Within sampling units, only small patches (typically three acres or less) had mature pine-oak canopies, ideal midstory and understory structure, and requisite cover of matrix and conservative ground flora; described in **Table 1** and Nelson (2010). It is currently an open question whether present management regimes in MOPWR can achieve true reference conditions across large landscapes. Various historic land uses occurred between 1880 and 1930 - exploitative logging, intense slash fires, cultivation attempts, and open range grazing resulted in many areas of this region being heavily impacted and altered (Cunningham 2007). This land use history precludes the attainment of reference conditions throughout much of the MOPWR area. However, restoration treatments can and continue to improve the functionality of this ecosystem, while providing goods and services with biologic, economic, and social benefits.

Further discussions are needed on the next steps in restoration treatments. Questions remain as to how to combat the problems associated with super-canopies of oak/hickory sprouts and overgrowth of sumac and blackberry, all of which may inhibit return to reference conditions. NNIS have gained limited ground within these treatment units, and in comparison to surrounding regions, the Ozarks in general (The Nature Conservancy 2003). Continued effort will be needed to maintain this status, and it should be fully expected that NNIS will continue to become problematic as climatic changes and additional land development occur.

Lastly, the authors believe that in addition to providing a valuable interpretation of the ecological "pulse" of an area, CHIs are useful to resource managers as a teaching and diagnostic tool. When combined with effective TEUI mapping, for resource managers early in their career or someone new to an area, CHI provides a set of defined vegetation metrics and targets that help define and categorize natural communities by their ecological integrity. By reviewing overall CHI score and subscores for specific units, managers may be able to determine which components of the system are driving their score up or down. This allows for effective implementation of adaptive management principles. Ongoing and future work will improve the development and deployment of CHIs across a variety of landscapes.

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APPENDIX A. Matrix, conservative, and non-native invasive plant species supported by the Shortleaf Pine-Oak Woodland CHI.

Scientific Name	Common Name	Family	Life Form	C-value
Amorpha canescens	Lead Plant	Fabaceae	shrub	8
Andropogon gerardii	Big Bluestem	Poaceae	grass	5
Angelica venosa	Wood Angelica	Apiaceae	forb	8
Asclepias purpurascens	Purple Milkweed	Asclepiadaceae	forb	6
Asclepias quadrifolia	Four-leaved Milkweed	Asclepiadaceae	forb	6
Asclepias tuberosa	Butterfly Milkweed	Asclepiadaceae	forb	5
Aureolaria flava	Smooth False Foxglove	Orobanchaceae	forb	8
Aureolaria grandiflora	Yellow False Foxglove	Orobanchaceae	forb	6
Baptisia bracteata	Cream Wild Indigo	Fabaceae	legume	7
Ceanothus americanus	New Jersey Tea	Rhamnaceae	shrub	7
Cirsium carolinianum	Carolina Thistle	Asteraceae	forb	8
Clitoria mariana	Butterfly Pea	Fabaceae	legume	7
Comandra umbellata	False Toadflax	Santalaceae	forb	7
Coreopsis palmata	Prairie Coreopsis	Asteraceae	forb	7
Cunila origanoides	Dittany	Lamiaceae	forb	6
Desmodium laevigatum	Smooth Tick Trefoil	Fabaceae	legume	7
Desmodium marilandicum	Small-Leaved Tick Trefoil	Fabaceae	legume	5
Desmodium rotundifolium	Round-Leaved Tick Trefoil	Fabaceae	legume	6
Dichanthelium boscii	Bosc's Panic Grass	Poaceae	grass	5
Dichanthelium	Slender-Leaved Panic	Poaceae	grass	5
Echinacea pallida	Pale Purple Coneflower	Asteraceae	forb	7
Erianthus alopecuroides	Silver Plume Grass	Poaceae	grass	8
Eryngium yuccifolium	Rattlesnake Master	Apiaceae	forb	8
Galactia regularis	Downy Milk-Pea	Fabaceae	legume	6
Galium arkansanum	Arkansas Bedstraw	Rubiaceae	forb	6
Galium pilosum	Hairy Bedstraw	Rubiaceae	forb	6
Gillenia stipulata	American Ipecac	Rosaceae	forb	5
Helianthus hirsutus	Bristly Sunflower	Asteraceae	forb	4
Hieracium gronovii	Hairy Hawkweed	Asteraceae	forb	4
Ionactis linariifolius	Flax-Leaved Aster	Asteraceae	forb	9
Krigia biflora	Orange False Dandelion	Asteraceae	forb	5
Lespedeza frutescens	Violet Bush Clover	Fabaceae	legume	5
Lespedeza hirta	Hairy Bush Clover	Fabaceae	legume	7
Lespedeza procumbens	Trailing Bush Clover	Fabaceae	legume	4
Lespedeza repens	Creeping Bush Clover	Fabaceae	legume	4
Lespedeza virginica	Slender Bush Clover	Fabaceae	legume	5
Liatris aspera	Rough Blazing Star	Asteraceae	forb	6
Liatris squarrosa	Scaly Blazing Star	Asteraceae	forb	6
Liatris squarrulosa	Scabrous Blazing Star	Asteraceae	forb	8
Malaxis unifolia	Adder's Mouth Orchid	Orchidaceae	forb	9
Mimosa quadrivalvis	Sensitive Briar	Fabaceae	legume	6

APPENDIX A. *Continued*

Scientific Name	Common Name	Family	Life Form	C-value
Monarda bradburiana	Bradbury Bee Balm	Lamiaceae	forb	5
Orbexilum pedunculatum	Sampson's Snakeroot	Fabaceae	legume	6
Oxalis violacea	Violet Wood Sorrel	Oxalidaceae	forb	5
Parthenium integrifolium	Wild Quinine	Asteraceae	forb	6
Phlox pilosa	Prairie Phlox	Polemoniaceae	forb	6
Potentilla canadensis	Running Cinquefoil	Rosaceae	forb	8
Pycnanthemum	White Mountain Mint	Lamiaceae	forb	7
Pycnanthemum pilosum	Hairy Mountain Mint	Lamiaceae	forb	5
Schizachyrium scoparium	Little Bluestem	Poaceae	grass	5
Silene virginica	Fire Pink	Caryophyllaceae	forb	7
Silphium asteriscus	Starry Rosinweed	Asteraceae	forb	7
Silphium integrifolium	Rosinweed	Asteraceae	forb	4
Solidago arguta	Atlantic Goldenrod	Asteraceae	forb	7
Solidago buckleyi	Buckley's Goldenrod	Asteraceae	forb	8
Solidago hispida	White Goldenrod	Asteraceae	forb	6
Solidago odora	Anise-scented Goldenrod	Asteraceae	forb	8
Solidago radula	Rough Goldenrod	Asteraceae	forb	6
Solidago ulmifolia	Elm-leaved Goldenrod	Asteraceae	forb	4
Stylosanthes biflora	Pencil Flower	Fabaceae	legume	5
Symphyotrichum	Blue Aster	Asteraceae	forb	6
Symphyotrichum patens	Spreading Aster	Asteraceae	forb	5
Symphyotrichum	Prairie Aster	Asteraceae	forb	6
Tephrosia virginiana	Goat's Rue	Fabaceae	legume	5
Tradescantia longipes	Wild Crocus	Commelinaceae	forb	8
Vaccinium arboreum	Farkleberry	Ericaceae	shrub	6
Vaccinium pallidum	Late Low Blueberry	Ericaceae	shrub	4
Vaccinium stamineum	Deerberry	Ericaceae	shrub	6
Verbesina helianthoides	Yellow Crownbeard	Asteraceae	forb	5
Viola palmata	Three-Leaved Violet	Violaceae	forb	5
Viola pedata	Bird's Foot Violet	Violaceae	forb	5
		Non-native Invasive Species		
Albiza julibrissin	Mimosa	Fabaceae	tree	x
Alliaria petiolata	Garlic Mustard	Brassicaceae	forb	x
Celastrus orbiculatus	Asiatic Bittersweet	Celastraceae	woody	x
Centaurea stoebe	Spotted Knapweed	Asteraceae	forb	x
Elaeagnus umbellata	Autumn Olive	Elaeagnaceae	shrub	x
Lespedeza cuneata	Sericea	Fabaceae	legume	x
Lonicera japonica	Japanese honeysuckle	Caprifoliaceae	woody	x
Lonicera maackii	Bush Honeysuckle	Caprifoliaceae	shrub	x
Microstegium vimineum	Stiltgrass	Poaceae	grass	x
Rosa multiflora	Multiflora Rose	Rosaceae	shrub	x

APPENDIX B. Comparison select submetric results of the 59 sampling units used for this analysis.

QUINTILE	SAMPLING UNIT		BURN	THIN	SCORE	RANK	MAT-SPP	CONS-SPP	G-M	F-M	GROUND	SAP-M	SEED-M	RUB-M	% BA PINE	% BA WO	CLOSE	STOCK
1st	Chilton Creek	10	17	N	66	1	72	23	5-25	25-50	32	5-25	5-25*	1-5*	26-50	> 75	55*	48*
	Pineknot	12	6	Y	66	1	30	14	25-50*	25-50	32	5-25	25-50	25-50	51-75*	51-75*	76	76
	Chilton Creek	1	7	N	65	3	70	24	5-25	25-50	31	1-5*	25-50	5-25	11-25	11-25	72*	55*
	Pineknot	45	6	Y	65	3	70	19	5-25	25-50	32	5-25	25-50	1-5*	51-75*	51-75*	67*	57*
	Chilton Creek	3	7	N	64	5	72	22	5-25	50-75*	31	5-25	25-50	5-25	11-25	11-25	58*	40*
	Chilton Creek	9	17	N	63	6	71	19	5-25	25-50	29	5-25	5-25*	1-5*	11-25	26-50*	71*	40*
	Pineknot	34	7	Y	62	7	64	18	5-25	50-75*	29	1-5*	50-75	5-25	> 75	26-50*	57*	60*
	Pineknot	11	7	Y	60	8	68	22	5-25	50-75*	33	5-25	50-75	5-25	> 75	26-50*	50*	53*
	Chilton Creek	5	7	N	59	9	63	16	1-5	25-50	25	5-25	25-50	1-5*	11-25	11-25	64*	73*
	Pineknot	43	7	Y	59	9	61	13	5-25	25-50	31	5-25	5-25*	5-25	11-25	> 76	73*	45*
	Pineknot	35	7	Y	59	9	62	22	5-25	25-50	27	5-25	50-75	5-25	51-75*	26-50*	72*	64*
	Chilton Creek	15	7	N	59	9	65	20	5-25	50-75*	32	25-50	25-50	5-25	11-25	11-25	64*	103
2nd	Chilton Creek	7	17	N	58	13	57	15	5-25	25-50	25	5-25	25-50	1-5*	0-10	26-50*	77	62*
	Pineknot	26	6	Y	58	13	62	14	1-5	5-25	26	5-25	25-50	1-5*	26-50	51-75*	80	59*
	Chilton Creek	16	17	N	58	13	61	17	1-5	50-75*	31	5-25	1-5	5-25	11-25	26-50*	78	84
	Fremont	1	1	N	57	16	66	20	5-25	25-50	31	50-75	5-25*	1-5*	> 75	11-25	87	85
	Pineknot	39	6	Y	56	17	56	13	1-5	5-25	23	5-25	25-50	1-5*	51-75*	51-75*	76	59*
	Chilton Creek	8	17	N	56	17	53	15	5-25	25-50	25	5-25	25-50	5-25	26-50	11-25	62*	64*
	Pineknot	32	6	Y	56	17	63	16	5-25	25-50	24	1-5*	25-50	5-25	11-25	51-75*	73*	72*
	Pioneer Forest	-	4	N	54	20	34	17	5-25	5-25	34	25-50	25-50	50-75	51-75*	> 76	87	56*
	Pineknot	22	6	Y	54	20	68	16	1-5	5-25	28	25-50	5-25*	1-5*	26-50	> 76	78	94
	Chilton Creek	11	7	N	53	22	55	12	1-5	25-50	26	5-25	25-50	1-5*	11-25	26-50*	67*	81
	Pineknot	10	6	N	52	23	29	10	25-50*	50-75*	26	5-25	25-50	50-75	> 75	> 76	29	29
	Pineknot	8	6	N	52	23	33	9	5-25	25-50	26	5-25	25-50	-	> 75	> 76	60*	45*
3rd	Pineknot	36	4	Y	51	25	54	14	1-5	5-25	24	5-25	5-25*	1-5*	0-10	26-50*	75*	99
	Pineknot	14W	6	Y	50	26	67	18	1-5	25-50	25	5-25	25-50	5-25	51-75*	51-75*	82	73*
	Pineknot	25	6	Y	49	27	54	12	1-5	5-25	21	5-25	5-25*	1-5*	0-10	51-75*	77	76
	Chilton Creek	2	7	N	48	28	59	14	1-5	25-50	29	5-25	25-50	25-50	0-10	11-25	45*	61*
	Pineknot	13	6	N	48	28	61	20	5-25	75-95	26	25-50	25-50	25-50	> 75	0-10	50*	43*
	Pineknot	14E	6	Y	48	28	63	13	5-25	5-25	24	5-25	50-75	25-50	26-50	11-25	78	69*
	Chilton Creek	6	7	N	48	28	50	9	1-5	25-50	23	50-75	25-50	1-5*	0-10	26-50*	75*	73*
	Cane Ridge	34	7	Y	47	32	59	22	5-25	25-50	30	50-75	25-50	5-25	> 75	0-10	73*	29
	Chilton Creek	13	7	N	47	32	56	8	1-5	25-50	21	5-25	25-50	5-25	0-10	26-50*	75*	81
	Rocky Creek	6a	6	Y	46	34	26	8	5-25	5-25	22	50-75	25-50	25-50	26-50	51-75*	-	68*
	Cane Ridge	33	5	Y	46	34	58	16	< 1	50-75*	29	50-75	25-50	25-50	> 75	11-25	83	53*
	Pineknot	28	4	N	45	36	42	12	1-5	5-25	20	25-50	5-25*	5-25	26-50	> 76	68*	67*

APPENDIX B. *Continued*

QUINTILE	SAMPLING UNIT		BURN	THIN	SCORE	RANK	MAT-SPP	CONS-SPP	G-M	F-M	GROUND	SAP-M	SEED-M	RUB-M	% BA PINE	% BA WO	CLOSE	STOCK
4th	**Pineknot**	**21**	6	Y	44	37	32	12	1-5	< 1	22	5-25	25-50	5-25	26-50	**51-75***	**67***	**66***
	Cane Ridge	**35**	3	Y	44	37	50	15	5-25	5-25	21	5-25	25-50	5-25	26-50	**51-75***	**68***	84
	Rocky Creek	**7**	5	Y	43	39	29	9	5-25	5-25	24	5-25	**5-25***	50-75	**51-75***	**51-75***	87	**56***
	Pineknot	**44**	4	N	42	40	42	13	1-5	5-25	19	25-50	25-50	5-25	26-50	**26-50***	**75***	**75***
	Fremont	**4**	1	N	42	40	48	6	1-5	5-25	19	50-75	**5-25***	**1-5***	> 75	0-10	86	89
	Pineknot	**20**	7	N	41	42	23	10	5-25	25-50	23	25-50	**5-25***	50-75	> 75	0-10	6	6
	Chilton Creek	**12**	17	N	41	42	45	10	1-5	5-25	18	25-50	25-50	5-25	0-10	**51-75***	81	76
	Pineknot	**37**	4	Y	39	44	63	11	1-5	5-25	18	5-25	50-75	25-50	0-10	**26-50***	15	15
	Pineknot	**19**	7	Y	39	44	15	7	5-25	25-50	24	5-25	**5-25***	50-75	> 75	0-10	77	90
	Pineknot	**9**	1	Y	38	46	23	8	< 1	5-25	19	25-50	25-50	-	26-50	**26-50***	82	82
	Rocky Creek	**5**	4	Y	38	46	31	8	5-25	5-25	23	75-95	25-50	25-50	> 75	**51-75***	-	**44***
5th	**Pineknot**	**31**	7	N	37	48	40	8	1-5	5-25	18	-	**5-25***	5-25	-	**26-50***	**75***	85
	Pineknot	**40**	0	Y	36	49	36	4	<1	1-5	14	25-50	**5-25***	5-25	> 75	**51-75***	81	**72***
	Pineknot	**29**	0	Y	36	49	39	4	<1	1-5	12	25-50	**5-25***	**1-5***	26-50	**26-50***	78	**70***
	Pineknot	**24**	0	Y	34	51	30	7	1-5	1-5	15	25-50	**5-25***	5-25	> 75	**26-50***	80	88
	Fremont	**7**	1	N	33	52	41	6	1-5	1-5	15	50-75	**5-25***	5-25	11-25	**26-50***	87	**75***
	Pineknot	**41**	0	Y	32	53	41	5	<1	1-5	13	25-50	25-50	5-25	0-10	0-10	77	**59***
	Pineknot	**47**	2	Y	32	53	40	4	< 1	1-5	13	50-75	**5-25***	**1-5***	> 75	**51-75***	78	93
	Rocky Creek	**6b**	6	Y	32	53	25	7	1-5	5-25	20	50-75	25-50	25-50	> 75	**51-75***	93	102
	Pineknot	**30**	6	Y	31	56	37	5	1-5	1-5	15	25-50	1-5	5-25	26-50	**51-75***	81	95
	Pineknot	**27**	4	N	28	57	49	10	1-5	5-25	21	75-95	25-50	50-75	**51-75***	**51-75***	91	**51***
	Pineknot	**23**	0	Y	28	57	32	4	< 1	< 1	13	75-95	**5-25***	5-25	> 75	11-25	79	**65***
	Pineknot	**15**	0	Y	26	59	25	5	< 1	1-5	13	75-95	75-95	**1-5***	> 75	11-25	**74***	111

SCORE: Total CHI score, BURN: Burns within the last 20 years, THIN: mechanically thinned or not, MAT-SPP: matrix species "hits" along transect meanders, CONS-SPP: conservative species "hits" along transect meanders, G - M: Graminoid cover, F - M: Forb cover, SAP-M: Sapling cover, SEED-M: seedling cover, RUB-M: Rubus and Rhus cover, GROUND: Ground flora (section II) score, % BA PINE: percent of total basal area in shortleaf pine, % BA WO: percent of total basal area in white or post oak, CLOSE: Average canopy closure of unit, STOCK: Percent stand stocking of unit.

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